Unconventional Resources in US: Potential & Lessons Learned

Looking at Barnett Shale from top of Barnett Pass, British Columbia, Photo by John McCall

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Summary of Conclusions


- The post-2008 (right-most) Hubbert curve is very steep and its area (cumulative gas produced) is small; not a good sign

- With over 14 thousand Barnett wells and up 6 years of production in some wells, there seems to be enough data to draw quantitative conclusions about current and future production of shale gas

- There is a problem, however, almost no one knows how to draw the conclusions; only rough sketching comes to mind
Multi-scale shales

Classical depositional models will not work: We are cursed with 6 orders of magnitude of grain sizes and irregular grain shapes

Source: André Kempe et al., PNAS, 99(14), 9117, 2002
Gas Rate from Barnett Shale

Source: Texas Railroad Commission. 1EJ $\approx$ 1Tcf.
A High Gas Rate Scenario

High Cum Gas from Barnett Shale

Source: Texas Railroad Commission. 1EJ ≈ 1Tcf.
Disclaimer...

- I have used a constant gas price of $4.00/Mcf
- Therefore my calculations should be used only for planning purposes and do not reflect the historical profits realized over the last 6-7 years from historical wells
- Work to do: Evaluate wells the average annual gas price starting from when a well was drilled
- Everything I will say, is equally applicable to condensate- and oil-producing shales
More Conclusions...

- Barnett shale is very heterogeneous areally and gas production is highly dependent on time.

- Cumulative gas production by well in a given county is approximately lognormally distributed for fixed production times (1, 2, or 3 years in this presentation).

- One can therefore calculate the expected values of cumulative gas production by well after 1, 2, or 3 years, the median values, and the most probable (mode) values.

- According to the results, no mean, median, or most probable well in the Barnett shale is profitable for three years, if its drilling cost is $3 million, and the gas price is close to $4/Mcf.
More Conclusions…

- The shale heterogeneity and different completion and production strategies result in the standard deviations from the expected production values (means) that are of the same order as the means.

- Therefore, it is difficult to predict a priori the probability of a desired level of production in a given geographic area.

- One can run Monte Carlo simulations and calculate the probabilities of exceeding a certain cumulative production after 1, 2, or 3 years (only the first-year results are shown here).

- The Monte Carlo simulations reveal that high-productivity wells are possible, but highly unlikely.
More Conclusions...

According to the Monte Carlo simulations, chances of drilling and completing a Barnett shale well that will pay for itself in 1 year are about:

- 1/8 in Tarrant county
- 1/10 in Johnson county
- 0 in all other Barnett shale counties

A novel and potentially ground-breaking approach to estimating gas shale production is sketched; it still needs further research and development.
Map of Barnett Shale in Texas

Source: HPDIP, from Dr. Peter Valko, Feb 13, 2011
Barnett wells in Tarrant county
First year gas cums in Tarrant county

Zoom on the highest well density
Barnett wells in Johnson county
First year gas cums in Johnson county

Zoom on the highest well density
Barnett wells in Denton county

Easting, $10^5$ ft

Northing, $10^5$ ft
First year gas cums in Denton county

Zoom on the highest well density
Barnett wells in Wise county
First year gas cums in Wise county

Zoom on the highest well density
The Lognormal Distribution

In a log-normal distribution of a random variable \( X > 0 \) that has outcomes \( \{x\} \), \( \mu \) is the mean and \( \sigma \) standard deviation, respectively, of \( \ln x \) (the variable’s logarithm is normally distributed). In cartesian coordinates, \( \mu \) and \( \sigma \) are the location and scale parameters, respectively.

\[
\text{pdf}(x; \mu, \sigma) = f(x; \mu, \sigma) = \frac{1}{x \sqrt{2\pi\sigma^2}} \exp \left[ -\frac{(\ln x - \mu)^2}{2\sigma^2} \right]
\]

where pdf = \( f \) is the probability density function.

The distribution mode (pdf’s peak value) is

\[
\text{Mode} = \exp(\mu - \sigma^2)
\]
The Lognormal Distribution, cntd.

Median is defined as

\[
\text{Median}(\mu, \sigma) = \int_0^{m^*} f(x; \mu, \sigma) \, dx = \int_{m^*}^{\infty} f(x; \mu, \sigma) \, dx = \frac{1}{2}
\]

The lognormal distribution’s median is equal to

\[
\text{Median}(\mu) = \exp(\mu)
\]

The most important mean or expected value of the lognormal distribution is

\[
\mathbb{E}(X) = m = \int_0^{\infty} x f(x; \mu, \sigma) \, dx = \exp \left[ \mu + \frac{\sigma^2}{2} \right]
\]
The Lognormal Distribution, cntd.

The variance of the lognormal distribution is

\[ V(X) = \int_{0}^{\infty} x^2 f(x; \mu, \sigma) \, dx = \left[ \exp(\sigma^2) - 1 \right] \exp(2\mu + \sigma^2) \]

The standard deviation is

\[ s = \sqrt{V} \]

Note that \( \mu \) and \( \sigma \) describe the normal distribution of \( \ln x \), while \( m \) and \( s \) the lognormal distribution of \( x \).
Generalized Extreme Value (GEV)

The novel GEV approach is based on the observation that gas production from a shale is an extreme event that corresponds to a certain level of changing the shale structure and connecting to it.

The GEV fits of county-wide Barnett shale data are almost perfect, much better than the lognormal fits (here I only show the nine largest counties after 1 – 3 years).

With better fits, I can obtain tighter bounds on the uncertainties of production volumes, i.e., narrower 95% confidence intervals.
GEV pdf: $\xi = 0.0657$, $\mu = 0.3177$, $\sigma = 0.2075$
MLE of GEV pdf in Tarrant county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
GEV cdf: $\xi = 0.0657$, $\mu = 0.3177$, $\sigma = 0.2075$
Tarrant county after 2.00 yrs

GEV pdf: $\xi = 0.0883$, $\mu = 0.4639$, $\sigma = 0.3035$
MLE of GEV pdf in Tarrant county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.00 yrs
Tarrant county after 2.00 yrs

GEV cdf: $\xi = 0.0883$, $\mu = 0.4639$, $\sigma = 0.3035$
Tarrant county after 3.00 yrs

GEV pdf: $\xi = 0.1793$, $\mu = 0.5148$, $\sigma = 0.3453$
MLE of GEV pdf in Tarrant county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Tarrant county after 3.00 yrs

GEV cdf: $\xi = 0.1793$, $\mu = 0.5148$, $\sigma = 0.3453$
Johnson county after 1.00 yrs

GEV pdf: $\xi = 0.0298$, $\mu = 0.3086$, $\sigma = 0.1834$
MLE of GEV pdf in Johnson county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
Johnson county after 1.00 yrs

GEV cdf: $\xi = 0.0298$, $\mu = 0.3086$, $\sigma = 0.1834$
Johnson county after 2.00 yrs

GEV pdf: $\xi = 0.0568, \mu = 0.4429, \sigma = 0.2599$
MLE of GEV pdf in Johnson county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.00 yrs
Johnson county after 2.00 yrs

GEV cdf: $\xi = 0.0568$, $\mu = 0.4429$, $\sigma = 0.2599$
GEV pdf: $\xi = 0.0821, \mu = 0.5449, \sigma = 0.3228$
MLE of GEV pdf in Johnson county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Johnson county after 3.00 yrs

GEV cdf: $\xi = 0.0821$, $\mu = 0.5449$, $\sigma = 0.3228$
Denton county after 1.00 yrs

GEV pdf: $\xi = 0.2427$, $\mu = 0.1429$, $\sigma = 0.0938$
MLE of GEV pdf in Denton county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
Denton county after 1.00 yrs

GEV cdf: $\xi = 0.2427, \mu = 0.1429, \sigma = 0.0938$
Denton county after 2.00 yrs

GEV pdf: $\xi = 0.2789$, $\mu = 0.2049$, $\sigma = 0.1327$
MLE of GEV pdf in Denton county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.00 yrs
Denton county after 2.00 yrs

GEV cdf: $\xi = 0.2789$, $\mu = 0.2049$, $\sigma = 0.1327$
Denton county after 3.00 yrs

GEV pdf: $\xi = 0.2758$, $\mu = 0.2427$, $\sigma = 0.1503$
MLE of GEV pdf in Denton county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Denton county after 3.00 yrs

GEV cdf: $\xi = 0.2758$, $\mu = 0.2427$, $\sigma = 0.1503$
Wise county after 1.00 yrs

GEV pdf: $\xi = 0.1310, \mu = 0.1480, \sigma = 0.1026$
MLE of GEV pdf in Wise county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
Wise county after 1.00 yrs

GEV cdf: $\xi = 0.1310$, $\mu = 0.1480$, $\sigma = 0.1026$
Wise county after 2.00 yrs

GEV pdf: $\xi = 0.1595$, $\mu = 0.2302$, $\sigma = 0.1561$
MLE = Maximum Likelihood Estimate, 95% CI for \( \mu \) and \( \sigma \) after 2.00 yrs
Wisconsin county after 2.00 yrs

GEV cdf: $\xi = 0.1595$, $\mu = 0.2302$, $\sigma = 0.1561$
Wise county after 3.00 yrs

GEV pdf: \(\xi = 0.1708, \mu = 0.2828, \sigma = 0.1866\)
MLE of GEV pdf in Wise county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Wise county after 3.00 yrs

GEV cdf: $\xi = 0.1708, \mu = 0.2828, \sigma = 0.1866$
Parker county after 1.00 yrs

GEV pdf: $\xi = 0.1278, \mu = 0.1337, \sigma = 0.1010$
MLE of GEV pdf in Parker county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
Parker county after 1.00 yrs

GEV cdf: \( \xi = 0.1278, \mu = 0.1337, \sigma = 0.1010 \)
Parker county after 2.00 yrs

GEV pdf: $\xi = 0.1154$, $\mu = 0.2154$, $\sigma = 0.1554$
MLE of GEV pdf in Parker county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.00 yrs
Parker county after 2.00 yrs

GEV cdf: $\xi = 0.1154$, $\mu = 0.2154$, $\sigma = 0.1554$
Parker county after 3.00 yrs

GEV pdf: $\xi = 0.1000$, $\mu = 0.2797$, $\sigma = 0.2007$
MLE of GEV pdf in Parker county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Parker county after 3.00 yrs

GEV cdf: $\xi =0.1000$, $\mu =0.2797$, $\sigma =0.2007$
Hood county after 0.97 yrs

GEV pdf: $\xi = -0.1225$, $\mu = 0.1599$, $\sigma = 0.0878$
MLE of GEV pdf in Hood county

MLE = Maximum Likelihood Estimate, 95% CI for \( \mu \) and \( \sigma \) after 0.97 yrs
Hood county after 0.97 yrs

GEV cdf: $\xi = -0.1225$, $\mu = 0.1599$, $\sigma = 0.0878$
Hood county after 1.94 yrs

GEV pdf: $\xi = -0.1795$, $\mu = 0.2605$, $\sigma = 0.1276$
MLE of GEV pdf in Hood county

MLE = Maximum Likelihood Estimate, 95% CI for \( \mu \) and \( \sigma \) after 1.94 yrs
Hood county after 1.94 yrs

GEV cdf: $\xi = -0.1795$, $\mu = 0.2605$, $\sigma = 0.1276$
Hood county after 2.92 yrs

GEV pdf: \( \xi = -0.2524, \mu = 0.3518, \sigma = 0.1544 \)
MLE of GEV pdf in Hood county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.92 yrs
Hood county after 2.92 yrs

GEV cdf: $\xi = -0.2524$, $\mu = 0.3518$, $\sigma = 0.1544$
Hill county after 0.83 yrs

GEV pdf: $\xi = 0.0048$, $\mu = 0.1625$, $\sigma = 0.0888$
MLE of GEV pdf in Hill county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 0.83 yrs
Hill county after 0.83 yrs

GEV cdf: $\xi = 0.0048$, $\mu = 0.1625$, $\sigma = 0.0888$
Hill county after 1.67 yrs

GEV pdf: $\xi = 0.0111$, $\mu = 0.2504$, $\sigma = 0.1292$
MLE of GEV pdf in Hill county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.67 yrs
Hill county after 1.67 yrs

GEV cdf: $\xi = 0.0111$, $\mu = 0.2504$, $\sigma = 0.1292$
GEV pdf: $\xi = 0.0202$, $\mu = 0.2925$, $\sigma = 0.1356$
MLE of GEV pdf in Hill county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.50 yrs
Hill county after 2.50 yrs

GEV cdf: $\xi = 0.0202$, $\mu = 0.2925$, $\sigma = 0.1356$
Erath county after 0.78 yrs

GEV pdf: $\xi = -0.0157$, $\mu = 0.0739$, $\sigma = 0.0481$
MLE of GEV pdf in Erath county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 0.78 yrs
Erath county after 0.78 yrs

GEV cdf: $\xi = -0.0157$, $\mu = 0.0739$, $\sigma = 0.0481$
Erath county after 1.56 yrs

GEV pdf: $\xi = -0.0523$, $\mu = 0.1192$, $\sigma = 0.0712$
MLE of GEV pdf in Erath county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.56 yrs
Erath county after 1.56 yrs

GEV cdf: $\xi = -0.0523$, $\mu = 0.1192$, $\sigma = 0.0712$
Erath county after 2.33 yrs

GEV pdf: $\xi = -0.0304$, $\mu = 0.1416$, $\sigma = 0.0860$
MLE of GEV pdf in Erath county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.33 yrs
Erath county after 2.33 yrs

Cumulative Probability

Block Extremum, Bcf/well-year

Fitted Generalized Extreme Value CDF
Empirical CDF
$R_{10}$ 95% CI

GEV cdf: $\xi = -0.0304$, $\mu = 0.1416$, $\sigma = 0.0860$
Jack county after 1.00 yrs

GEV pdf: $\xi =0.1490$, $\mu =0.0669$, $\sigma =0.0541$
MLE of GEV pdf in Jack county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 1.00 yrs
Jack county after 1.00 yrs

GEV cdf: $\xi = 0.1490$, $\mu = 0.0669$, $\sigma = 0.0541$
Jack county after 2.00 yrs

GEV pdf: $\xi = 0.1061$, $\mu = 0.1124$, $\sigma = 0.0834$
MLE of GEV pdf in Jack county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 2.00 yrs
Jack county after 2.00 yrs

GEV cdf: $\xi = 0.1061, \mu = 0.1124, \sigma = 0.0834$
GEV pdf: $\xi = 0.1197, \mu = 0.1483, \sigma = 0.1052$
MLE of GEV pdf in Jack county

MLE = Maximum Likelihood Estimate, 95% CI for $\mu$ and $\sigma$ after 3.00 yrs
Jack county after 3.00 yrs

GEV cdf: $\xi = 0.1197$, $\mu = 0.1483$, $\sigma = 0.1052$
Cumulative gas in Tarrant county

Rescaled time on production

Cumulative gas production, Bcf

GEV $\mu \pm \sigma$

Fit

- 2012
- 2010
- 2008
- 2006
- 2004
- 2002
- 2000
- 1998
- 1996
- 1994
- 1992
Cumulative gas in Johnson county

Cumulative gas production, Bcf

Rescaled time on production

\[ \text{GEV } \mu \pm \sigma \]

Fit

- 1992
- 1994
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012
Cumulative gas in Denton county

Cumulative gas production, Bcf

Rescaled time on production

GEV $\mu \pm \sigma$

Fit

- 1992
- 1994
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012
Cumulative gas in Wise county

- Cumulative gas production, Bcf

- GEV $\mu \pm \sigma$

- Fit

- Rescaled time on production
Cumulative gas in Parker county

![Cumulative gas production, Bcf vs. Rescaled time on production](chart.png)

- GEV $\mu \pm \sigma$
- Fit

- p.110/173
Cumulative gas in Hood county
Cumulative gas in Hill county

Cumulative gas production, Bcf

Rescaled time on production

GEV $\mu \pm \sigma$

Fit
Cumulative gas in Erath county

Cumulative gas production, Bcf

Rescaled time on production

GEV $\mu \pm \sigma$

Fit

- p.113/173
Cumulative gas in Jack county

- GEV $\mu \pm \sigma$
- Fit

Rescaled time on production

Cumulative gas production, Bcf
Revenue in Tarrant Co. after 1.00 yrs

\[ k = 0.0902, \mu = 1.2860, \sigma = 0.8050 \]
Revenue in Tarrant Co. after 1.00 yrs

\[ \text{Revenue, Million \$/well @$4.00/Mcf} \]

Cumulative Probability

Fitted CDF
Sample-based CDF

\[ k=0.0902, \mu =1.2860, \sigma =0.8050 \]

\[ - \text{p.116/173} \]
Revenue in Johnson Co. after 1.00 yrs

Revenue, Million $/well @$4.00/Mcf

k=0.0319, μ =1.2542, σ =0.7227
Revenue in Johnson Co. after 1.00 yrs

\[ k = 0.0319, \mu = 1.2542, \sigma = 0.7227 \]
Revenue in Denton Co. after 1.00 yrs

\[ k=0.2499, \mu =0.5680, \sigma =0.3705 \]
Revenue in Denton Co. after 1.00 yrs

\[ k = 0.2499, \mu = 0.5680, \sigma = 0.3705 \]
Revenue in Wise Co. after 1.00 yrs

Random sampling of pdf
Sample-based GEV pdf

$k=0.1573, \mu =0.5956, \sigma =0.3989$
Revenue in Wise Co. after 1.00 yrs

\[ k = 0.1573, \mu = 0.5956, \sigma = 0.3989 \]
Revenue in Parker Co. after 1.00 yrs

$\text{Revenue, Million \$/well @$4.00/\text{Mcf}$

$\text{Probability Density}$

Random sampling of pdf
Sample-based GEV pdf

$k=0.1771, \mu =0.5505, \sigma =0.3897$

$p.123/173$
Revenue in Parker Co. after 1.00 yrs

$$k = 0.1771, \mu = 0.5505, \sigma = 0.3897$$
Revenue in Hood Co. after 0.97 yrs

\[ k = -0.0994, \mu = 0.6375, \sigma = 0.3349 \]
Revenue in Hood Co. after 0.97 yrs

Cumulative Probability

Revenue, Million $/well @$4.00/Mcf

$Fitted CDF$

$Sample-based CDF$

$k = -0.0994, \mu = 0.6375, \sigma = 0.3349$
Revenue in Hill Co. after 0.83 yrs

\[ k = 0.0081, \mu = 0.6561, \sigma = 0.3517 \]
Revenue in Hill Co. after 0.83 yrs

Revenue, Million $/well @$4.00/Mcf

Cumulative Probability

Fitted CDF

Sample-based CDF

k=0.0081, \( \mu = 0.6561 \), \( \sigma = 0.3517 \)
Revenue in Erath Co. after 0.78 yrs

\[ k = 0.0220, \mu = 0.2991, \sigma = 0.1821 \]
Revenue in Erath Co. after 0.78 yrs

Cumulative Probability

Fitted CDF
Sample-based CDF

Revenue, Million $/well @$4.00/Mcf

k=0.0220, \( \mu = 0.2991 \), \( \sigma = 0.1821 \)
Revenue in Jack Co. after 1.00 yrs

\[ k=0.2048, \mu =0.2754, \sigma =0.2013 \]
Revenue in Jack Co. after 1.00 yrs

\[ k=0.2048, \mu =0.2754, \sigma =0.2013 \]
Revenue in Tarrant Co. after 2.00 yrs

Random sampling of pdf
Sample–based GEV pdf

\[ k = 0.1058, \quad \mu = 1.8553, \quad \sigma = 1.1774 \]
Revenue in Tarrant Co. after 2.00 yrs

Revenue, Million $/well @$4.00/Mcf

Cumulative Probability

Fitted CDF
Sample-based CDF

\[ k = 0.1058, \mu = 1.8553, \sigma = 1.1774 \]
Revenue in Johnson Co. after 2.00 yrs

\[ k = 0.0808, \mu = 1.7689, \sigma = 1.0200 \]
Revenue in Johnson Co. after 2.00 yrs

Cumulative Probability

Revenue, Million $/well @$4.00/Mcf

Fitted CDF
Sample-based CDF

\[ k = 0.0808, \mu = 1.7689, \sigma = 1.0200 \]
Revenue in Denton Co. after 2.00 yrs

k = 0.2784, \( \mu = 0.8155, \sigma = 0.5246 \)
Revenue in Denton Co. after 2.00 yrs

Cumulative Probability

Revenue, Million $/well @$4.00/Mcf

Fitted CDF
Sample-based CDF

k = 0.2784, $\mu = 0.8155, \sigma = 0.5246$
Revenue in Wise Co. after 2.00 yrs

\[ k = 0.1863, \mu = 0.9219, \sigma = 0.6057 \]
Revenue in Wise Co. after 2.00 yrs

Cumulative Probability vs. Revenue, Million $/well @$4.00/Mcf

Fitted CDF
Sample–based CDF

k=0.1863, \( \mu =0.9219 \), \( \sigma =0.6057 \)
Revenue in Parker Co. after 2.00 yrs

Random sampling of pdf
Sample-based GEV pdf

k=0.1427, \( \mu = 0.8711 \), \( \sigma = 0.5899 \)
Revenue in Parker Co. after 2.00 yrs

Fitted CDF
Sample-based CDF

Revenue, Million $/well @$4.00/Mcf

Cumulative Probability

k=0.1427, \( \mu =0.8711, \sigma =0.5899 \)
Revenue in Hood Co. after 1.94 yrs

\[ k = -0.1696, \mu = 1.0469, \sigma = 0.5003 \]
Revenue in Hood Co. after 1.94 yrs

Revenue, Million $/well @$4.00/Mcf

Cumulative Probability

Fitted CDF
Sample-based CDF

k = -0.1696, μ = 1.0469, σ = 0.5003
Revenue in Hill Co. after 1.67 yrs

\[ k = 0.0109, \mu = 1.0176, \sigma = 0.5115 \]
Revenue in Hill Co. after 1.67 yrs

\[ k=0.0109, \mu=1.0176, \sigma=0.5115 \]
Revenue in Erath Co. after 1.56 yrs

Probability Density

Random sampling of pdf
Sample-based GEV pdf

Revenue, Million $/well @$4.00/Mcf

k = -0.0195, \(\mu = 0.4791\), \(\sigma = 0.2718\)
Revenue in Erath Co. after 1.56 yrs

\[ k = -0.0195, \mu = 0.4791, \sigma = 0.2718 \]
Revenue in Jack Co. after 2.00 yrs

Random sampling of pdf
Sample-based GEV pdf

\[ k = 0.1546, \mu = 0.4512, \sigma = 0.3102 \]
Revenue in Jack Co. after 2.00 yrs

$k=0.1546, \mu =0.4512, \sigma =0.3102$
Revenue in Tarrant Co. after 3.00 yrs

Random sampling of pdf
Sample–based GEV pdf

k = 0.2049, \( \mu = 2.0260, \sigma = 1.3452 \)
Revenue in Tarrant Co. after 3.00 yrs

![Graph showing cumulative probability distribution of revenue in Tarrant Co. after 3 years.]

Cumulative Probability

Revenue, Million $/well @ $4.00/Mcf

Fitted CDF
Sample-based CDF

k = 0.2049, μ = 2.0260, σ = 1.3452
Revenue in Johnson Co. after 3.00 yrs

\[ k = 0.1133, \mu = 2.1835, \sigma = 1.2562 \]
Revenue in Johnson Co. after 3.00 yrs

k=0.1133, μ =2.1835, σ =1.2562
Revenue in Denton Co. after 3.00 yrs

- $k = 0.2826, \mu = 0.9674, \sigma = 0.5991$
Revenue in Denton Co. after 3.00 yrs

\[ k = 0.2826, \mu = 0.9674, \sigma = 0.5991 \]
Revenue in Wise Co. after 3.00 yrs

\[ k = 0.1971, \mu = 1.1221, \sigma = 0.7280 \]
Revenue in Wise Co. after 3.00 yrs

Cumulative Probability

Fitted CDF
Sample-based CDF

Revenue, Million $/well @ $4.00/Mcf

k = 0.1971, \mu = 1.1221, \sigma = 0.7280
Revenue in Parker Co. after 3.00 yrs

\[ k = 0.1326, \mu = 1.1376, \sigma = 0.7622 \]
Revenue in Parker Co. after 3.00 yrs

\[ k = 0.1326, \mu = 1.1376, \sigma = 0.7622 \]
Revenue in Hood Co. after 2.92 yrs

Random sampling of pdf
Sample-based GEV pdf

k = -0.2374, \( \mu = 1.4054, \sigma = 0.6087 \)
Revenue in Hood Co. after 2.92 yrs

![Graph showing cumulative probability distribution]

Cumulative Probability

Revenue, Million $/well @$4.00/Mcf

Fitted CDF
Sample-based CDF

\[ k = -0.2374, \mu = 1.4054, \sigma = 0.6087 \]
Revenue in Hill Co. after 2.50 yrs

Random sampling of pdf
Sample-based GEV pdf

Revenue, Million $/well @$4.00/Mcf

Probability Density

0 2 4 6 8 10

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

k=0.0052, \( \mu =1.1767, \sigma =0.5456 \)
Revenue in Hill Co. after 2.50 yrs

\[ k = 0.0052, \mu = 1.1767, \sigma = 0.5456 \]
Re revenue in Erath Co. after 2.33 yrs

\[ k=0.0002, \mu =0.5765, \sigma =0.3345 \]
Revenue in Erath Co. after 2.33 yrs

Cumulative Probability

Revenue, Million $/well @$4.00/Mcf

Fitted CDF
Sample-based CDF

k=0.0002, \( \mu = 0.5765 \), \( \sigma = 0.3345 \)
Revenue in Jack Co. after 3.00 yrs

Revenue, Million $/well @$4.00/Mcf

Random sampling of pdf
Sample–based GEV pdf

$k = 0.1630, \mu = 0.5887, \sigma = 0.3998$
Revenue in Jack Co. after 3.00 yrs

\[ k = 0.1630, \mu = 0.5887, \sigma = 0.3998 \]
GEV statistics of cum gas: Means

Source: HPDIP, from Dr. Peter Valko, Feb 13, 2011
GEV statistics of cum gas: SDs

Source: HPDIP, from Dr. Peter Valko, Feb 13, 2011
Remedial Technology

- Suppose that you had a technology that would allow you to stop drilling and completing a Barnett well if its 3-year production would be below 1 Bcf.
- You would spend only $1 million on that well.
- You would charge this sunk cost to the project and drill another, better well for $3 millions.
- Such strategy could limit your negative cash flow quite considerably at $4/Mcf.
Profit by county after 3 yrs

Discard unprofitable wells
Blind drilling

Johnson
Tarrant
Parker
Denton
Wise
Hill
Hood
Erath

Profit from drilling 100 wells @ $4.00/Mcf

Source: HPDIP, from Dr. Peter Valko, Feb 13, 2011
Conclusions

- Economic gas production from gas shales is difficult but **possible**, even at $4-5$ per 1000 standard cubic feet of gas.
- We still understand too **little** about the mechanisms of gas/condensate flow through shales, and fracture generation and connectivity.
- Significant fundamental and applied research is needed to predict and improve the **long-time** performance of hydrofractured horizontal wells in shales.
- Full water **reuse** and **recycling** will be necessary to allow for drilling unconventional gas wells in many parts of the U.S.