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The Price Elasticity of US Shale Oil Reserves

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Research Objectives

- Estimate price elasticity of the volume of US shale oil reserves, by play.
- Estimate price elasticity of the number of viable shale oil drilling sites, by play.
- Estimate potential for infill drilling to augment the volume of reserves.
- Estimate the economic threshold for completing investment in DUCs.
- Estimate sensitivity of production from mature shale oil wells to low prices.

This Paper is not About the Breakeven Price of US Shale Oil

- 80% of potential U.S. tight oil capacity additions in 2015 remain resilient at price as low as $70/barrel.

  - *IHS Online, Nov. 20, 2014.*

- Breakeven price for "some" US shale oil is $30/bbl.

  - *Ali Naimi, PIW, Jan. 5, 2015.*

- US shale oil costs are around $50/barrel at present.

  - *Mike Winter, Societe Generale, PIW, Oct. 12, 2015*

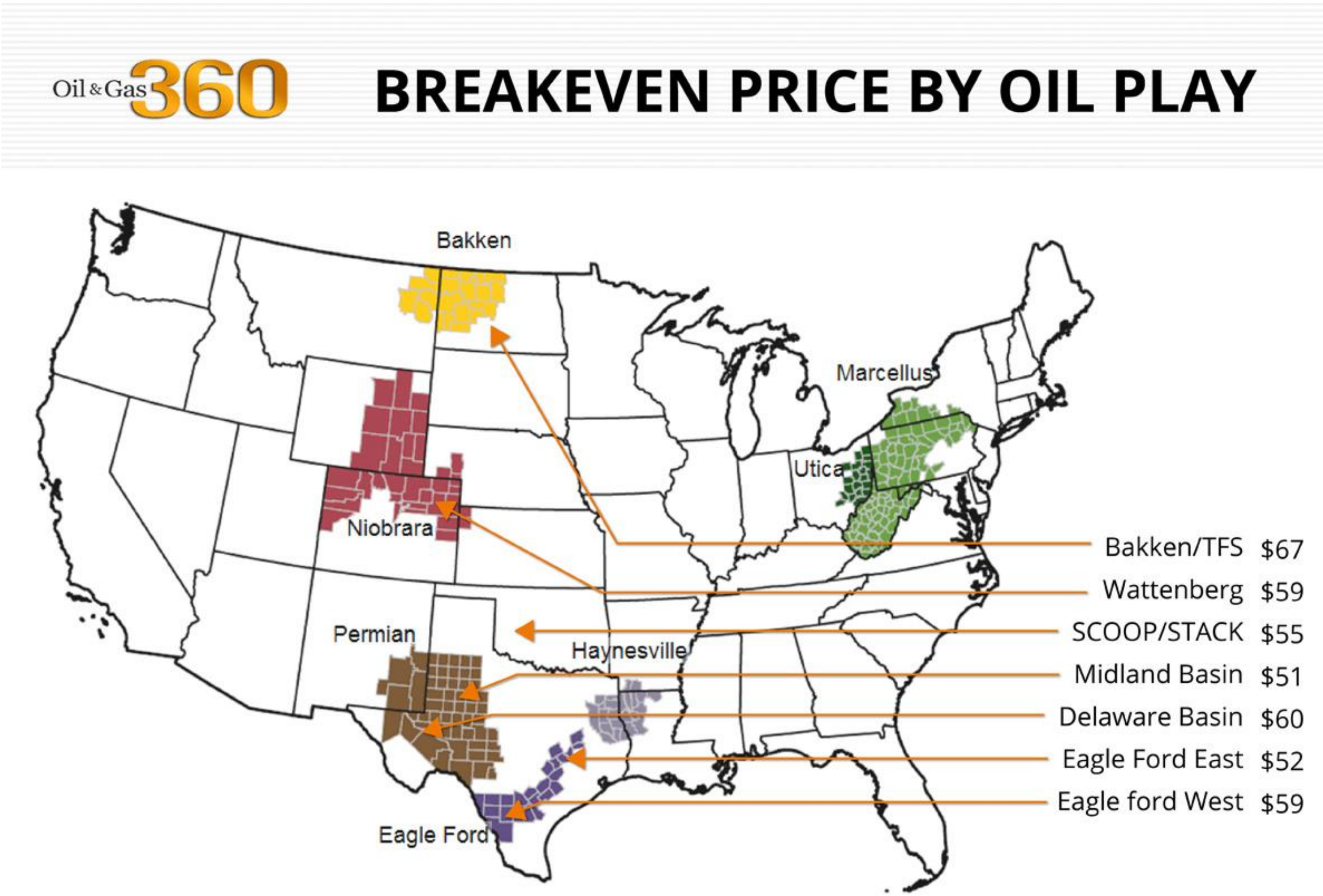
- Bone Spring, Wolfcamp, & Scoop: breakeven = $40/barrel,
  Eagle Ford: breakeven = $50/barrel

  - *WoodMackenzie, PIW, Aug. 8, 2016.*

- Breakeven cost now under $30 in Permian's Delaware and Midland basins.

  - *Wells Fargo, PIW, Sept. 19, 2016*

Breakeven Price Varies Across Shale Oil Plays



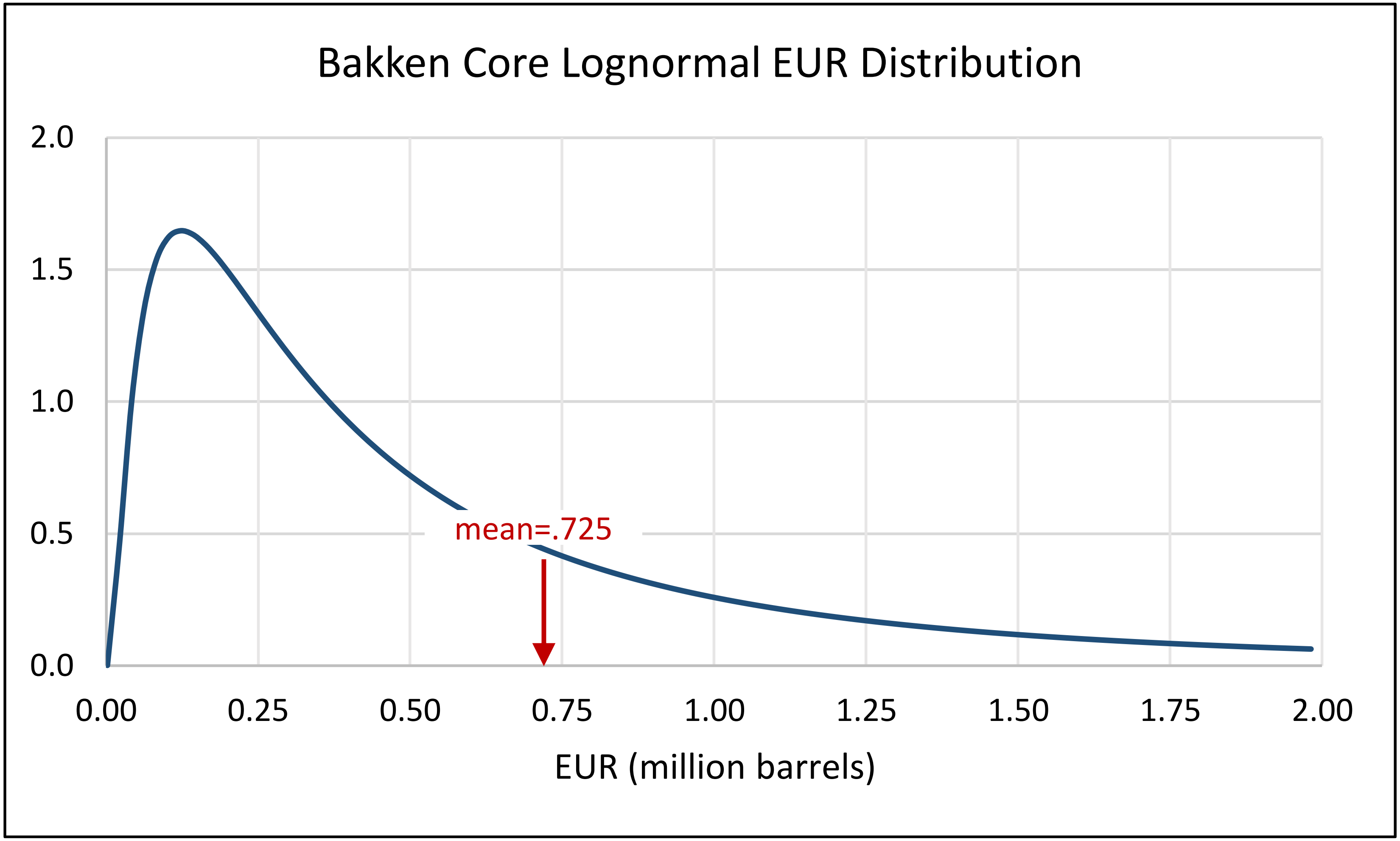
KLR Group, reported by Oil & Gas 360, May 23, 2016.

There is no Single Breakeven Price, Not Even Within a Single Play

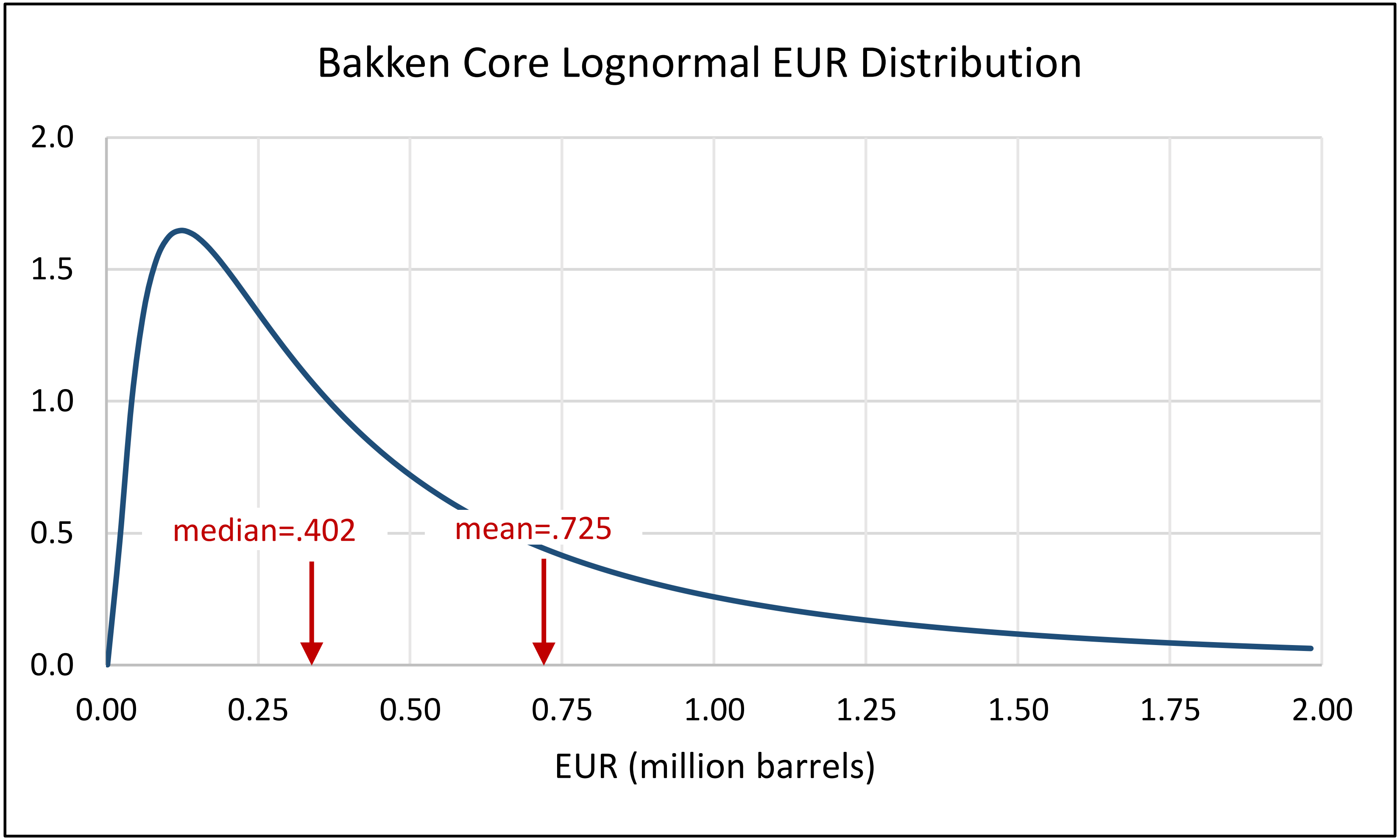
It is perhaps better to think of break-even as a bell-shaped curve, where some wells in a shale play can break even at $30, 50% break even at <$60/bbl (for example), but then some small fraction on the far side of the curve don't even break even when oil prices are at $100/bbl.

- Robert Rapier, Forbes/Energy, Feb. 29, 2016

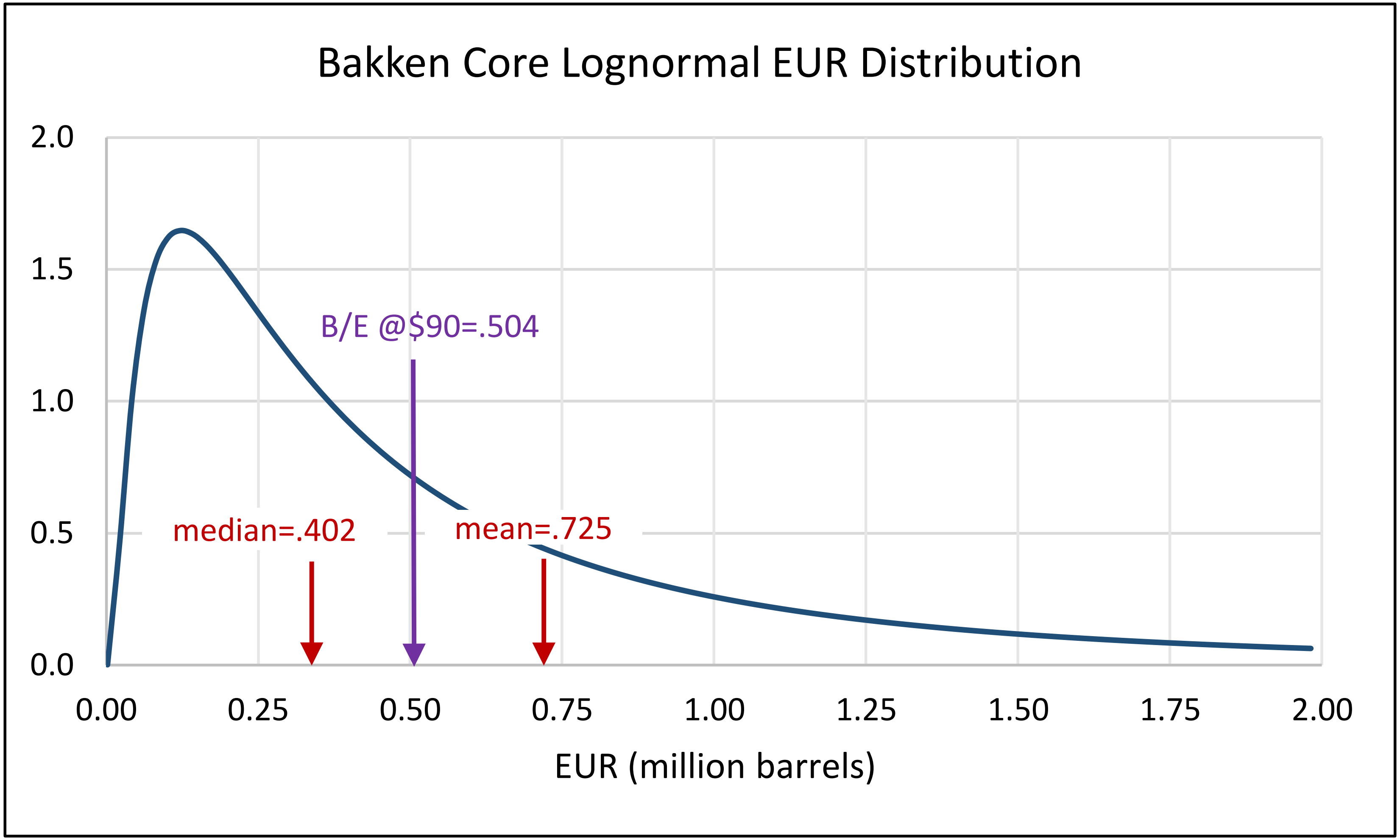
Heterogeneous Well Productivity Within a Play



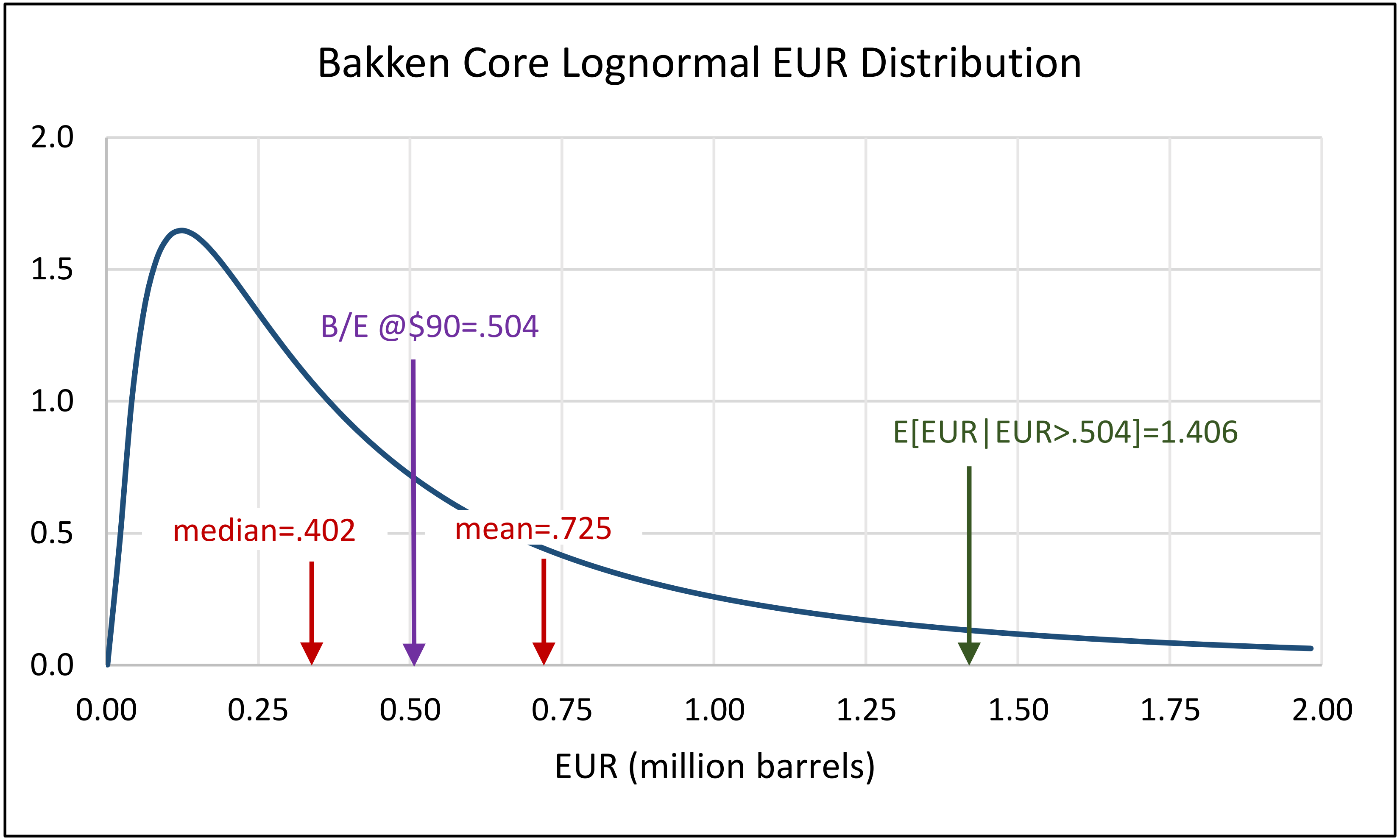
The “Average” Well is not “Typical”



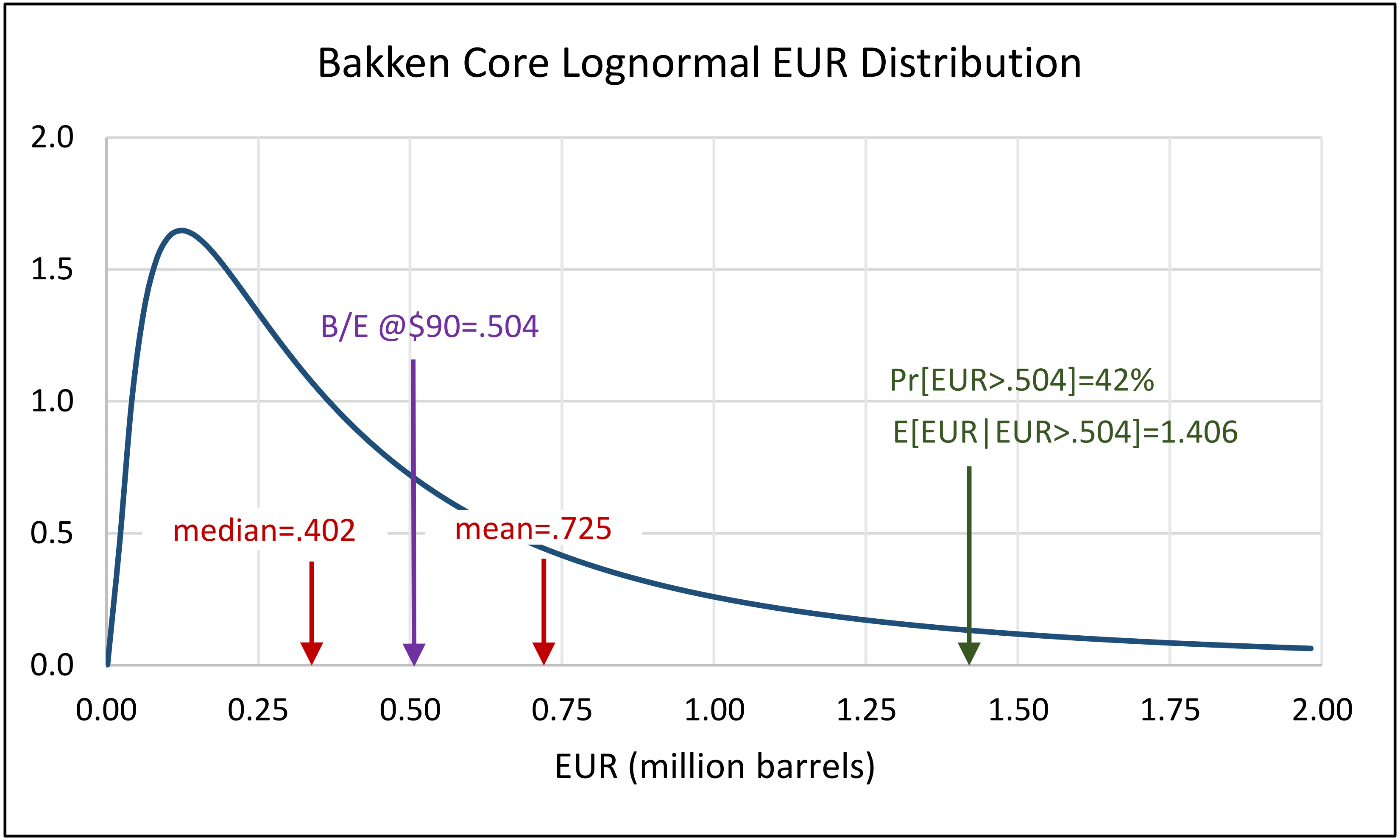
At $90, Any Well Above the B/E EUR is Viable



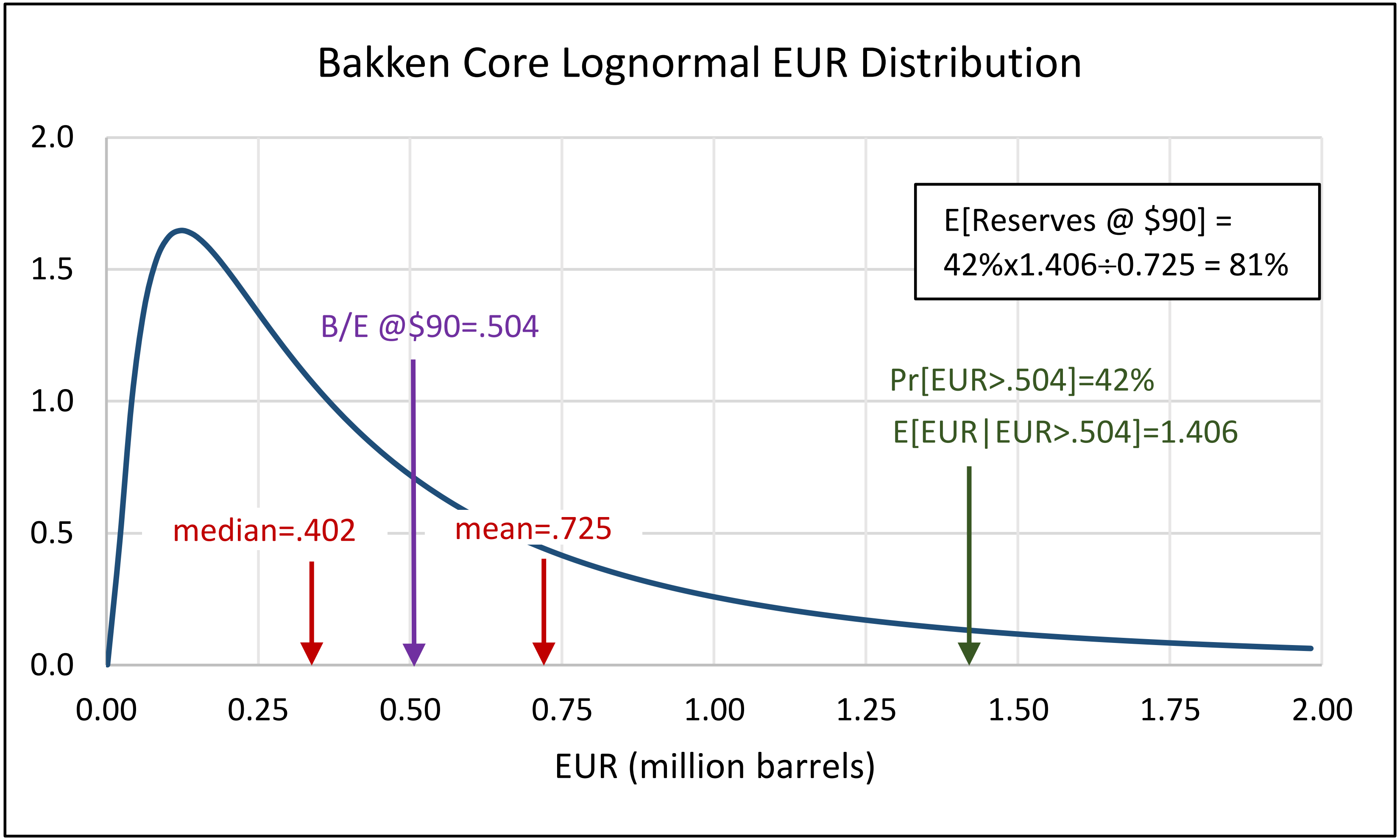
Average Size of Those Wells is 1.406 mmb



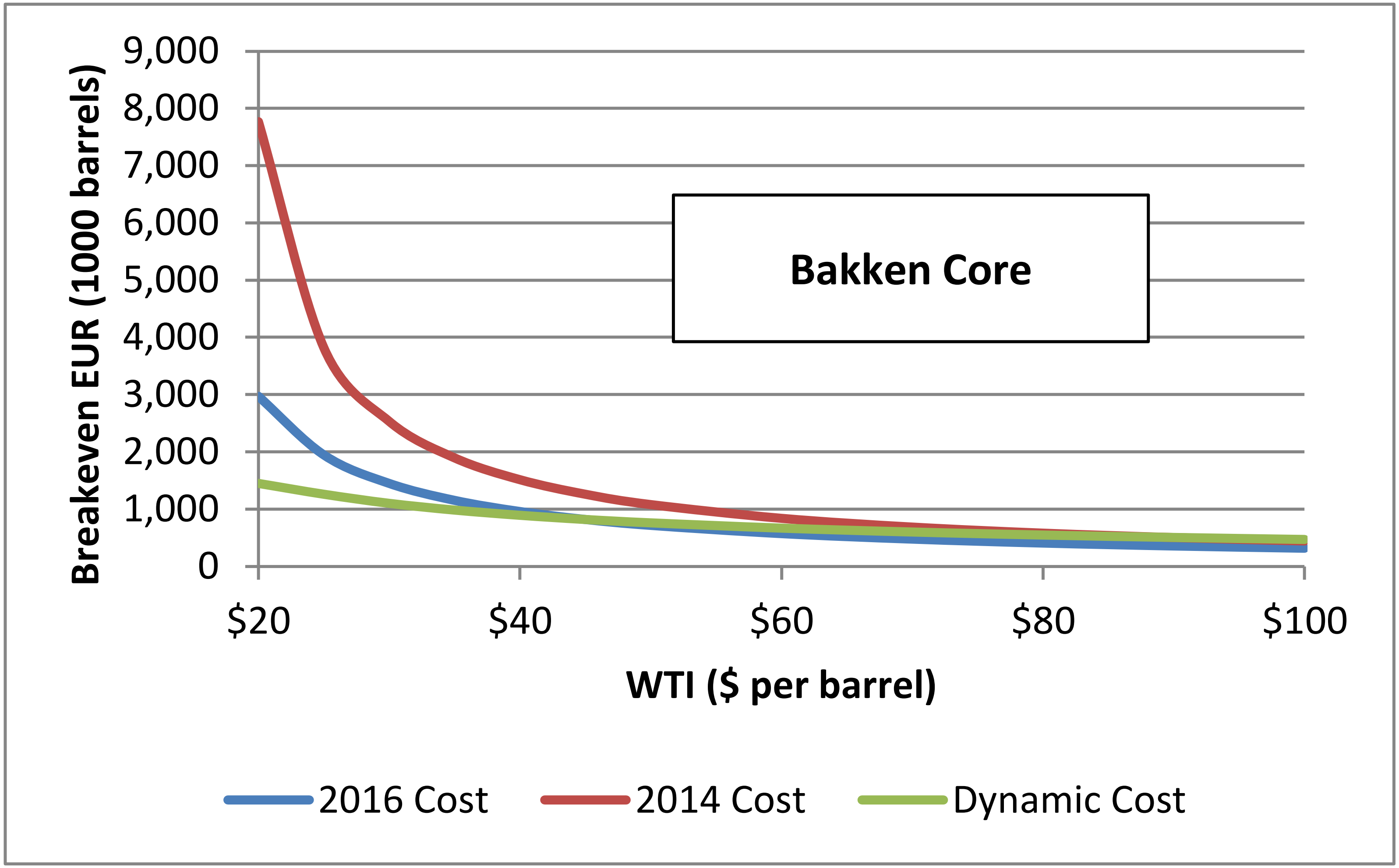
But Only 42% of Potential Drill Sites Meet the Criterion



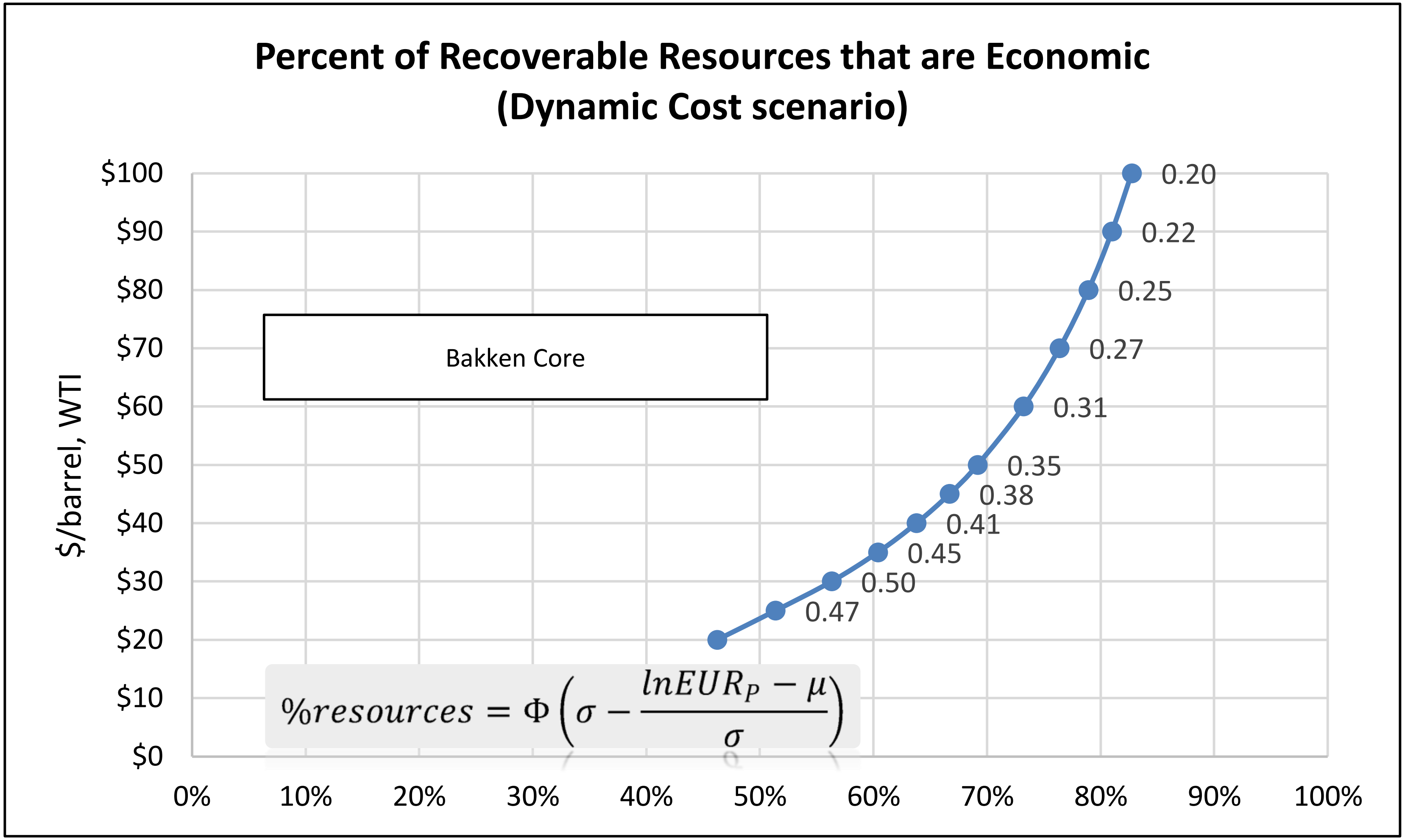
81% of Recoverable Resources are Viable at $90



Breakeven Well Productivity, EUR_P

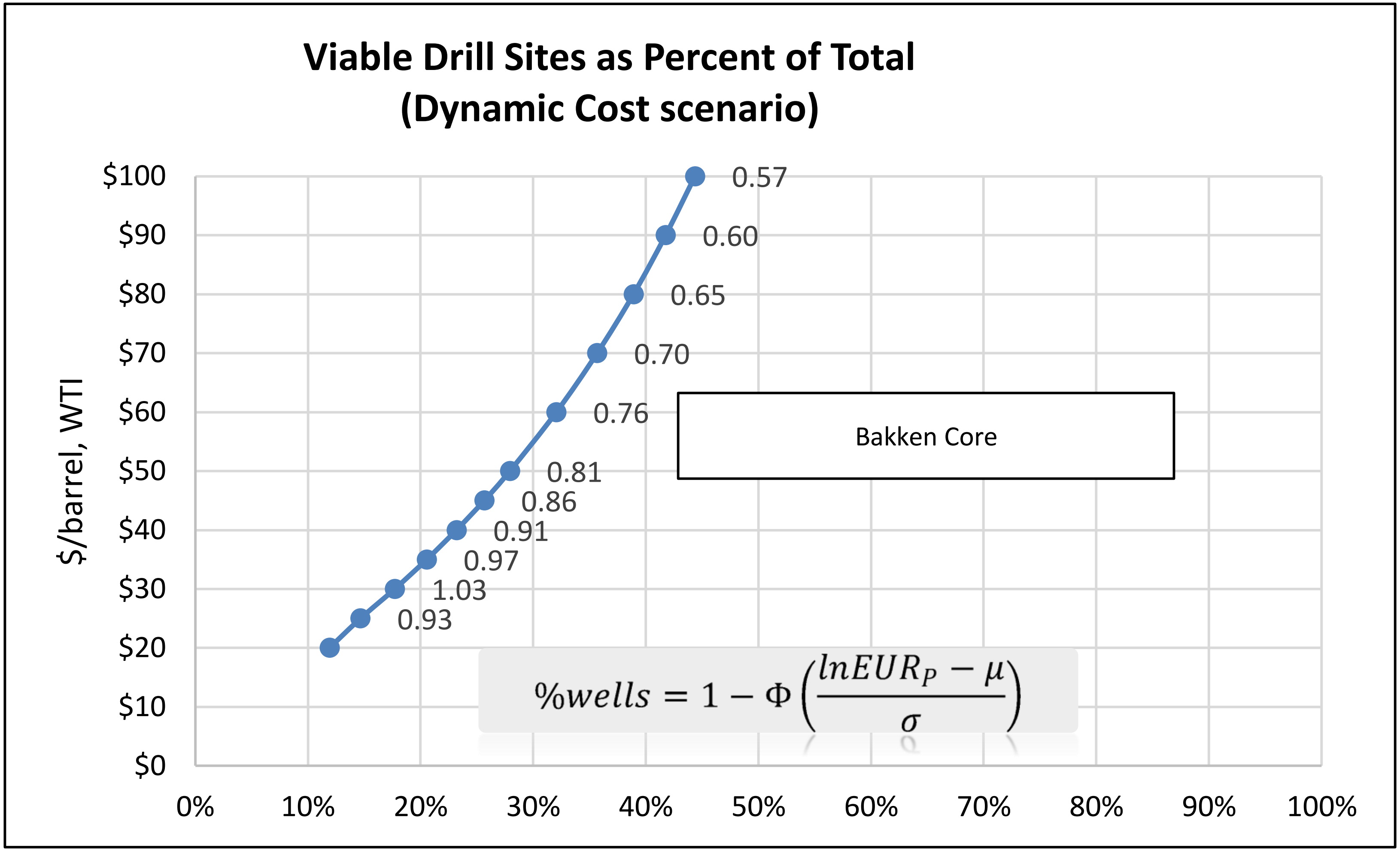


Goal #1: Chart Reserves as Function of Price



$$\%resources = \Phi\left(\sigma - \frac{lnEUR_P - \mu}{\sigma}\right)$$

Goal #2: Chart the Number of Viable Drill Sites



Related Studies of Shale Oil Supply

- Browning, et al., 2014-2016 (UT Bureau of Economic Geography)
  - Process-oriented model tied to specific geology of resource base and variation in productivity of wells.

- Newell, Prest, and Vissing, 2016 (NBER)
- Lasky, 2015 (CBO)
  - Econometric projections based on time-series trends. No geology, no depletion, no variation in productivity of wells. Steady-state "manufacturing" model.

- Kleinberg, et al., 2016 (MIT CEEPR)
  - No "model" but an explicit discussion of variation in productivity of wells.

Scope of the Analysis: Oil Plays

Table 1: Oil Plays										
		Uniform	Specific	Well Cost	EUR	IP Rate	Oil	Gas	NGL
Basin	Play	Coef Var	Coef Var	$mm	mboe	boe/d	%	%	%
Anadarko/MidCont	Springer	1.500	1.991	9.0	904	720	68%	16%	17%
Anadarko/MidCont	Mamaton	1.500	1.991	3.1	201	276	55%	25%	20%
Anadarko/MidCont	Tonkawa	1.500	1.991	3.7	249	340	56%	28%	17%
Bakken	Bakken Core	1.500	1.970	7.5	725	851	85%	13%	2%
Bakken	Bakken Non Core	1.500	1.970	6.5	558	655	88%	9%	3%
Denver/Julesburg	N Wattenberg	1.500	1.082	4.0	357	400	71%	20%	10%
Denver/Julesburg	N Wattenberg XL	1.500	1.082	6.6	727	722	67%	21%	13%
Denver/Julesburg	S Wattenberg	1.500	1.082	3.4	395	430	51%	33%	17%
Eagle Ford	Eagle Ford Oil	1.500	1.620	6.0	515	915	71%	15%	14%
Eagle Ford	Eagle Ford Condensate	1.500	1.620	8.0	801	1,367	63%	20%	17%
Other	San Juan Gallup	1.500	1.500	4.2	451	550	65%	18%	18%
Other	Tuscaloosa Marine Shale	1.500	1.500	11.0	683	1,048	92%	8%	0%
Permian	Midland Spraberry	1.500	0.805	6.5	753	825	76%	12%	12%
Permian	N Delaware Bone Spring	1.500	0.805	6.5	676	1,000	60%	20%	20%
Permian	S Delaware Wolfcamp	1.500	0.805	7.8	883	1,100	55%	25%	20%
Permian	Midland Wolfcamp	1.500	0.805	6.5	746	745	60%	19%	21%
Uinta	Greater Monument Butte	1.500	1.500	1.4	188	120	87%	9%	4%
Uinta	Wasatch SXL	1.500	1.500	14.0	1,000	1,444	75%	25%	0%
Uinta	Uteland Butte SXL	1.500	1.500	11.0	700	1,290	75%	25%	0%

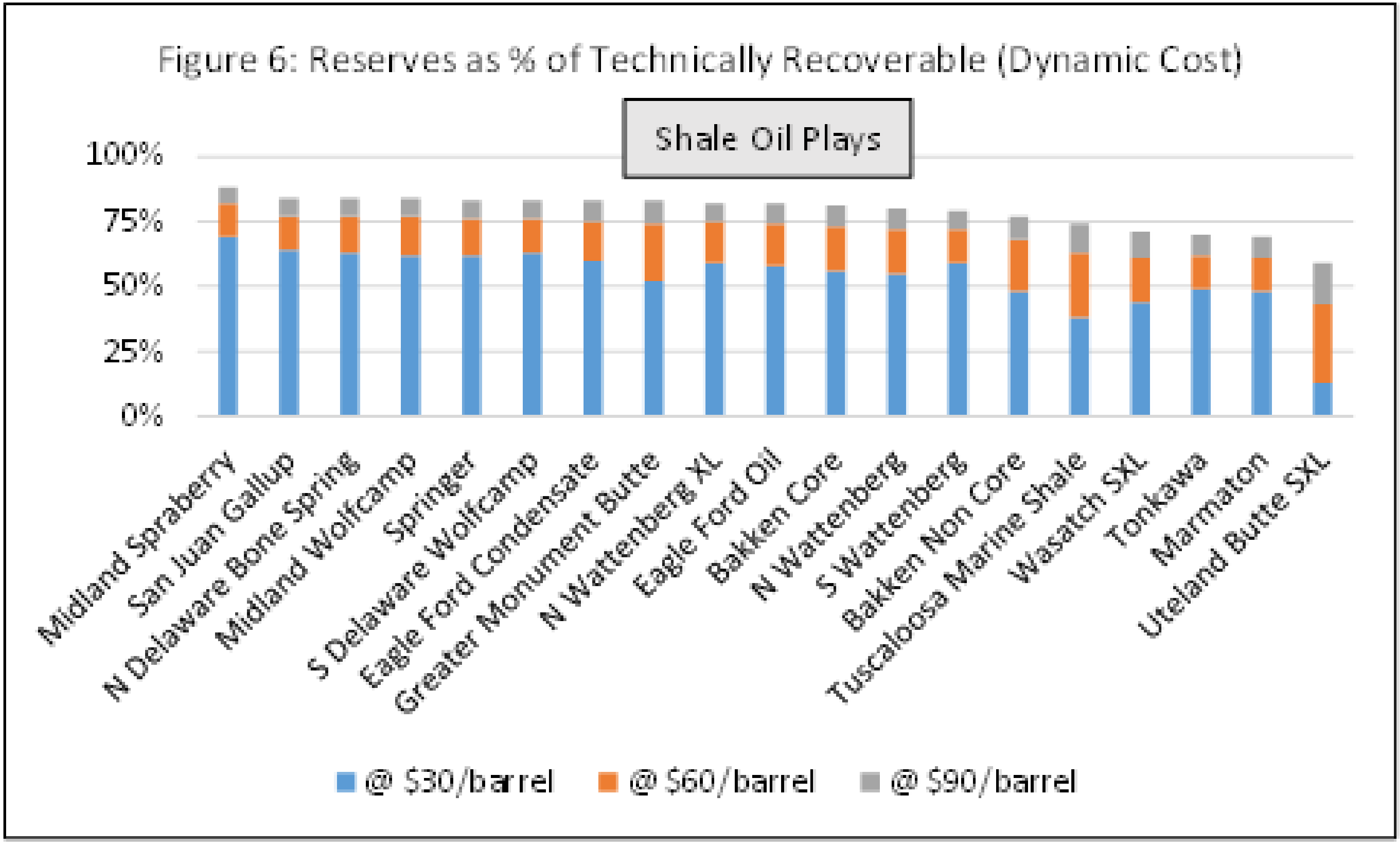
Scope of the Analysis: Combo Plays

Table 2: Combo Plays									
		Uniform	Specific	Well Cost	EUR	IP Rate	Oil	Gas	NGL
Basin	Play	Coef Var	Coef Var	$mm	mboe	boe/d	%	%	%
Anadarko/MidCont	Cana Woodford	1.500	1.991	7.0	1,826	1,606	5%	63%	32%
Anadarko/MidCont	SCOOP Oil	1.500	1.991	9.4	979	762	48%	23%	29%
Anadarko/MidCont	SCOOP Condensate	1.500	1.991	9.6	1,952	1,400	10%	50%	40%
Anadarko/MidCont	STACK	1.500	1.991	8.5	940	826	40%	30%	30%
Anadarko/MidCont	Meramec	1.500	1.991	7.6	1,338	1,425	22%	47%	31%
Anadarko/MidCont	Mississippian	1.500	1.991	2.8	410	409	34%	46%	20%
Anadarko/MidCont	Granite Wash	1.500	1.991	7.5	736	1,340	20%	50%	30%
Anadarko/MidCont	Cleveland	1.500	1.991	2.8	232	400	30%	45%	25%
Appalachia	SW PA Wet Gas	1.500	1.500	5.9	2,933	2485	0	49%	50%
Appalachia	SW PA Super Rich	1.500	1.500	5.9	2,150	1,536	8%	46%	46%
Appalachia	Utica Wet Gas	1.500	1.500	10.3	3,000	3,000	3%	67%	30%
Appalachia	Utica Condensate	1.500	1.500	9.4	1,186	1,186	28%	48%	24%
Eagle Ford	Eagle Ford Combo	1.500	1.620	5.5	898	1,085	21%	45%	34%
Permian	Culberson LL Wolfcamp	1.500	0.805	11.9	1,955	2,450	20%	50%	30%
Permian	S Midland Basin Wolfcamp	1.500	0.805	4.8	500	525	48%	27%	25%

Estimation of the Lognormal Parameters

- Coefficient of variation (mean/std.dev) is based on USGS lognormal estimates.
  - This immediately determines σ.
  - Hypothesis: σ has not changed despite technological progress.
- The mean EUR is based on expert industry judgment.
  - Given the σ from above, this determines μ.
  - Hypothesis: μ has increased due to technological progress.

The Impact of Low Prices on Reserves



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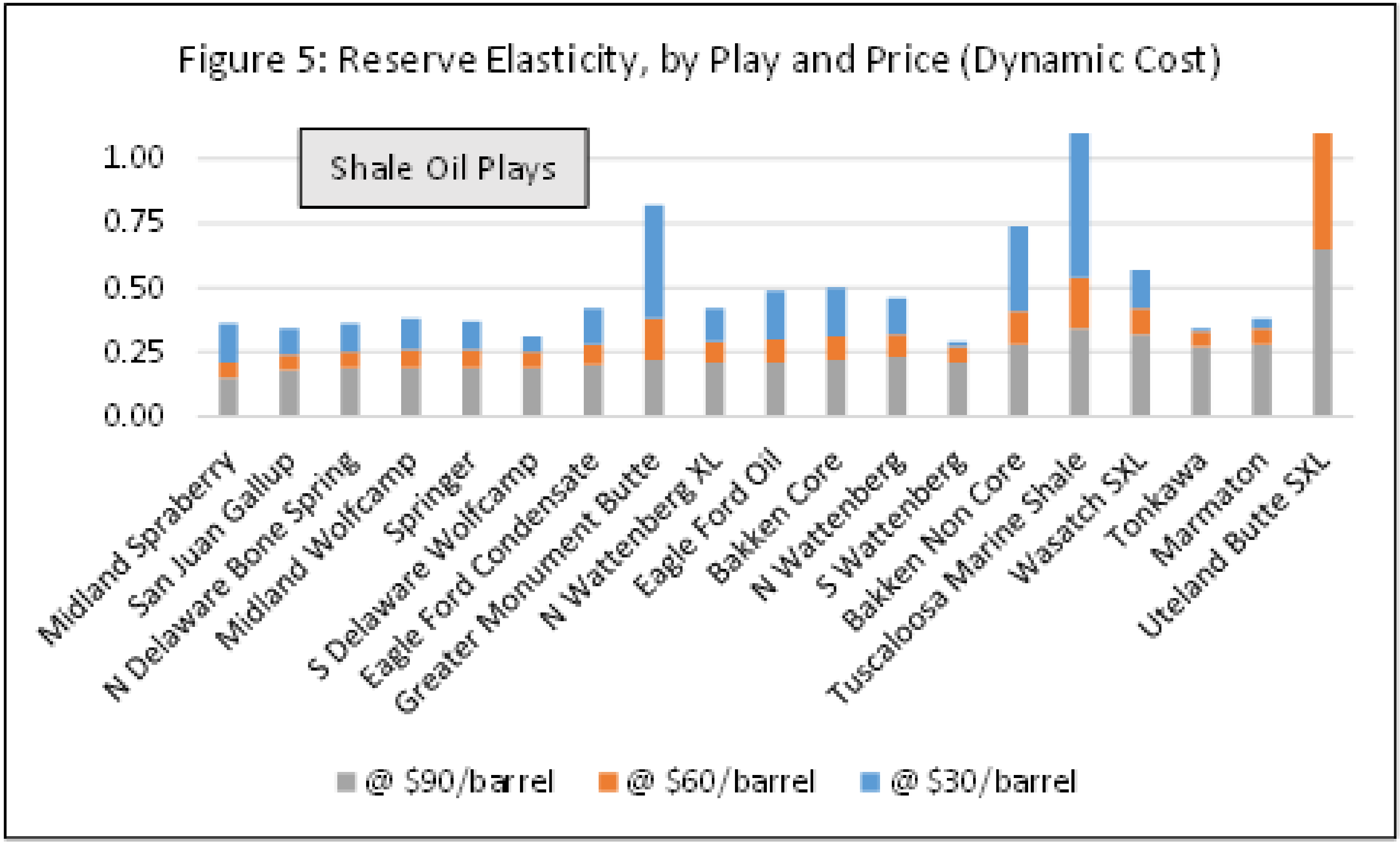
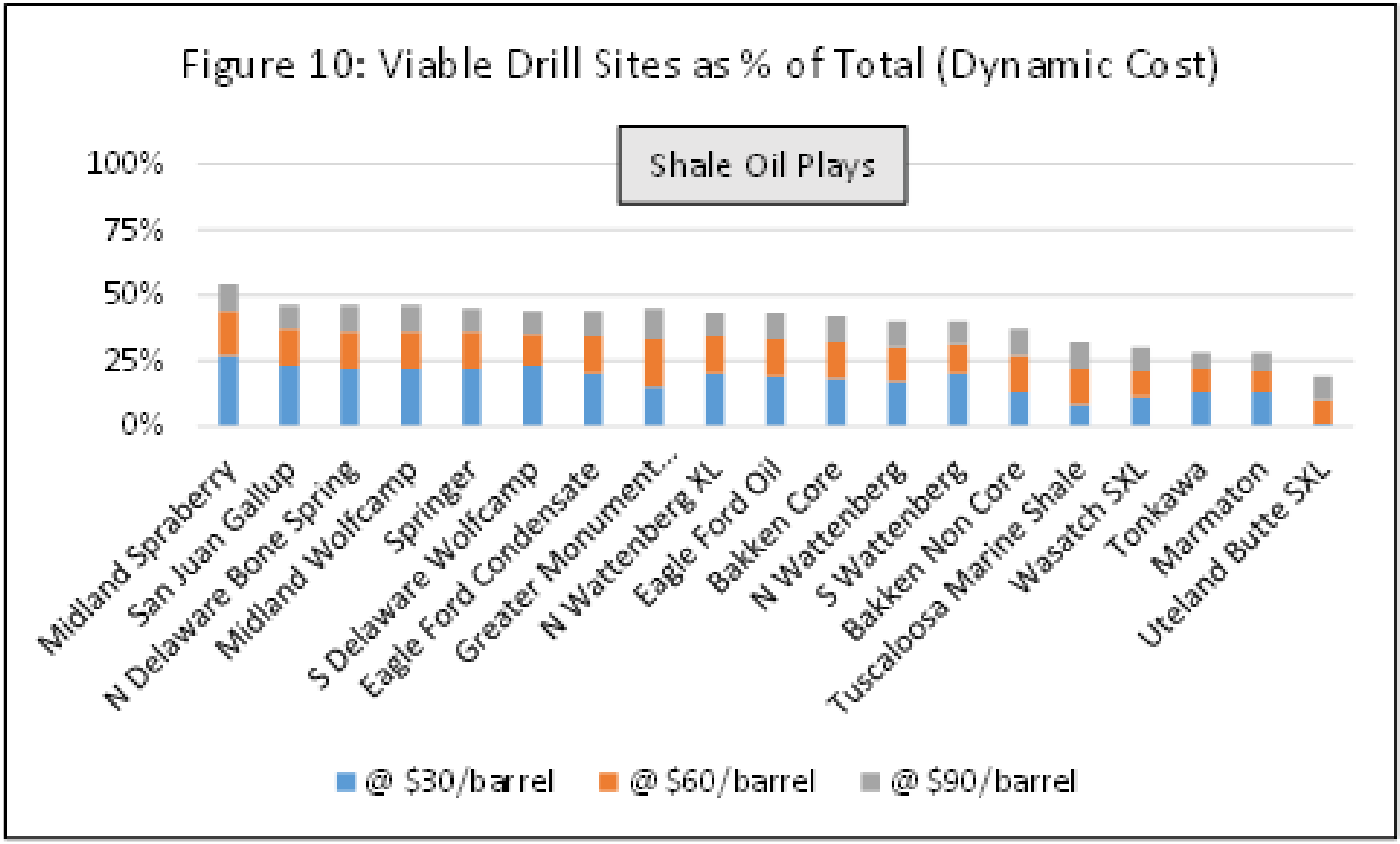
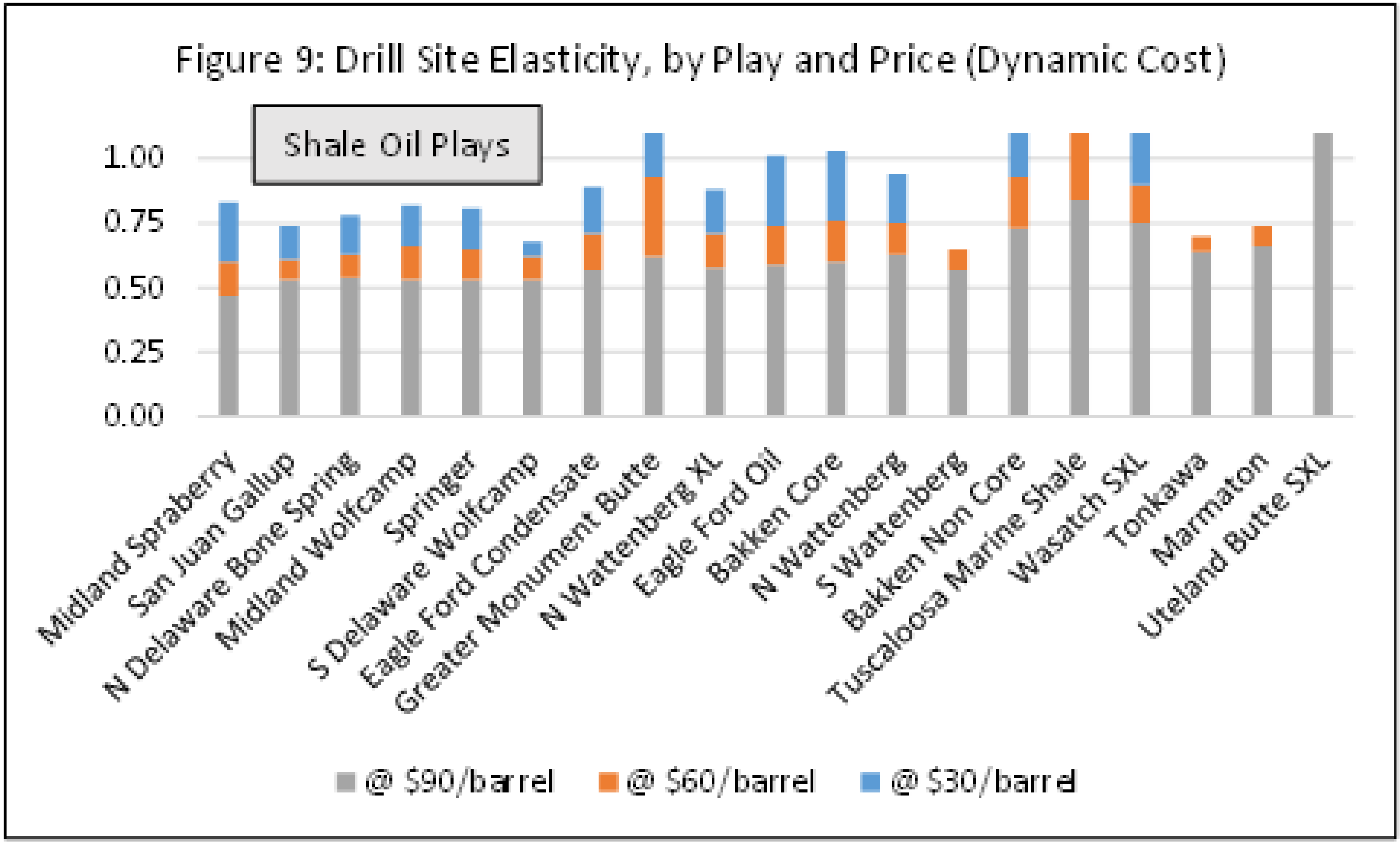
The Price Inelasticity of Shale Oil Reserves



The Impact of Price on Viable Drill Sites



The Price Elasticity of Viable Drill Sites



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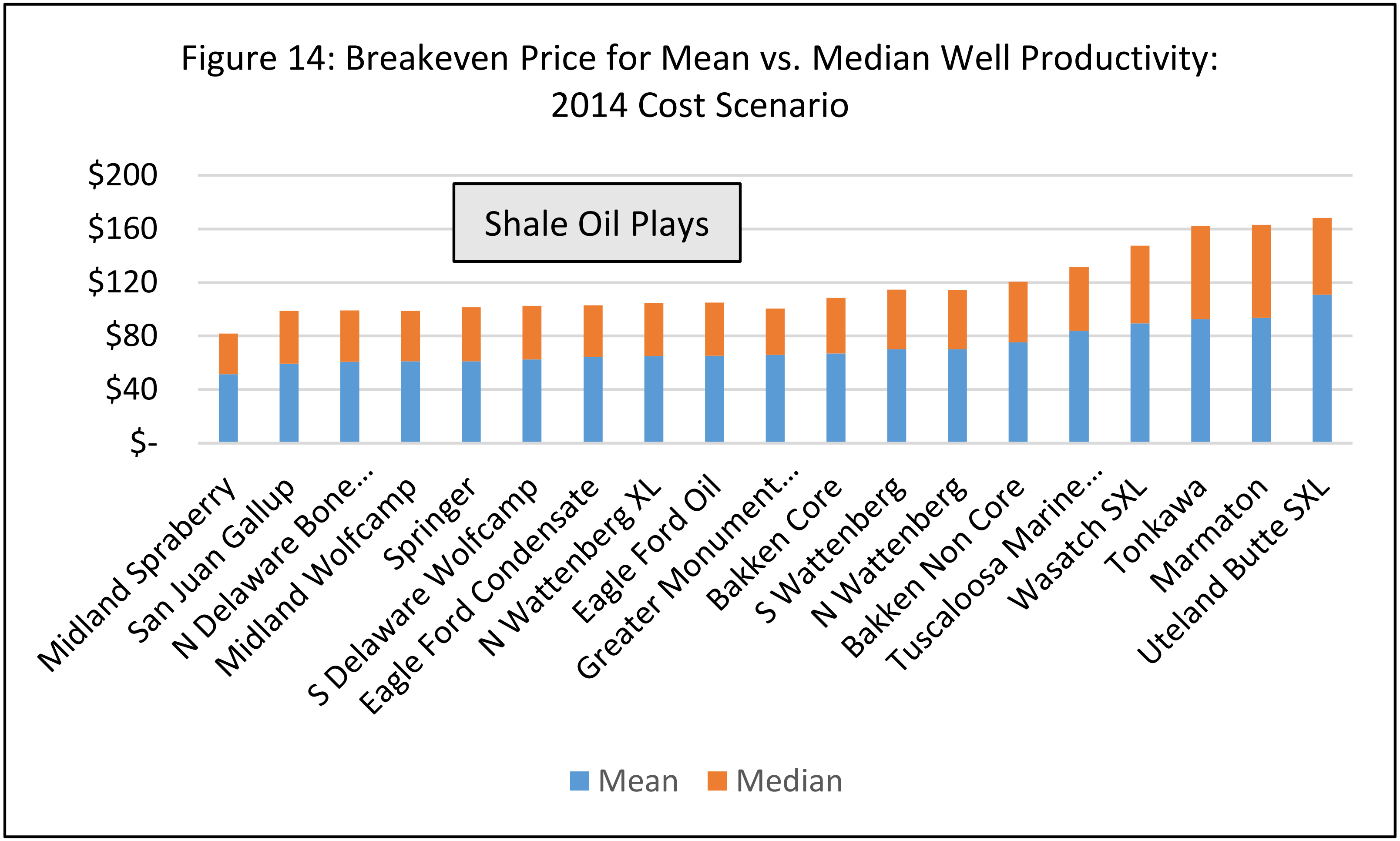
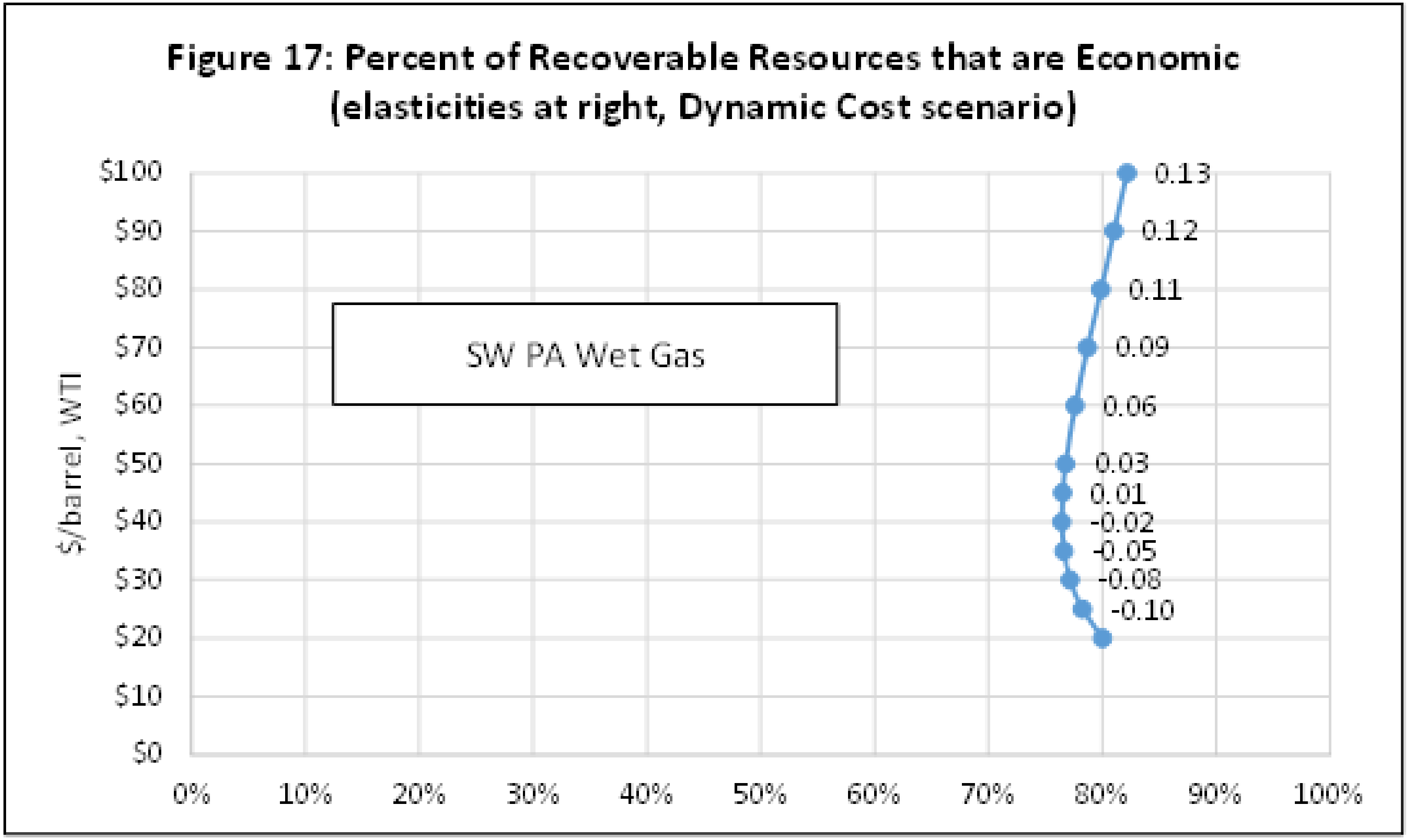
Breakeven Prices for Mean vs. Median Wells



Backward Bending Supply from Combo Plays



Infill Drilling Constitutes Play within a Play

Primary wells: $EUR \sim \Lambda(\mu, \sigma)$

Infill wells: $EUR_{infill} = \delta \times EUR$

Infill performance: $\delta \sim \Lambda\left(\mu_{infill}, \sigma_{infill}\right)$

Thus: $EUR_{infill} \sim \Lambda\left(\mu + \mu_{infill}, \sqrt{\sigma^2 + \sigma_{infill}^2}\right)$

To illustrate, assume: $mean_{\delta} = 0.4, stdev_{\sigma} = 0.2$

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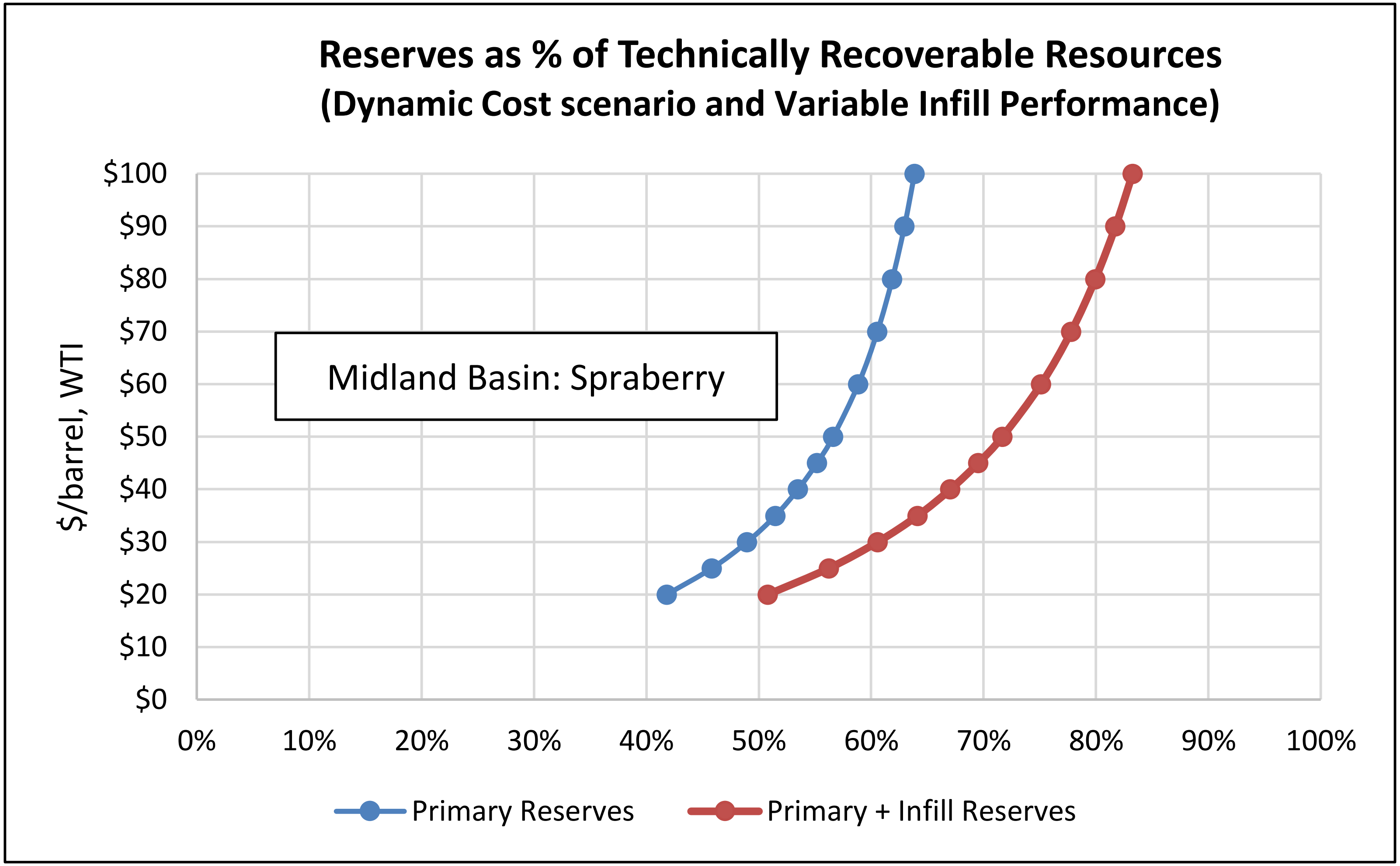
Potential Contribution of Infill Drilling



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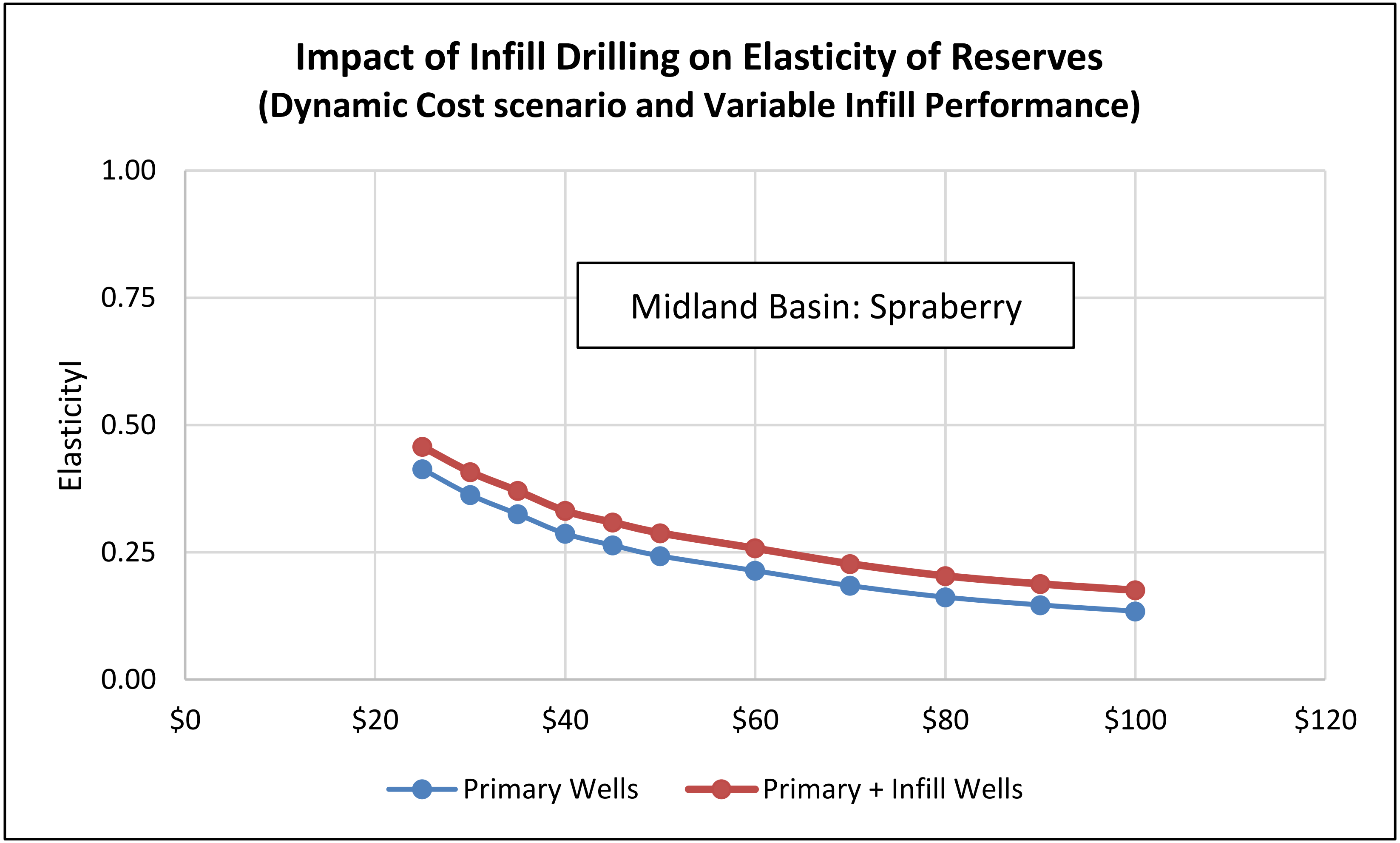
Infill Drilling Hardly Affects Elasticity



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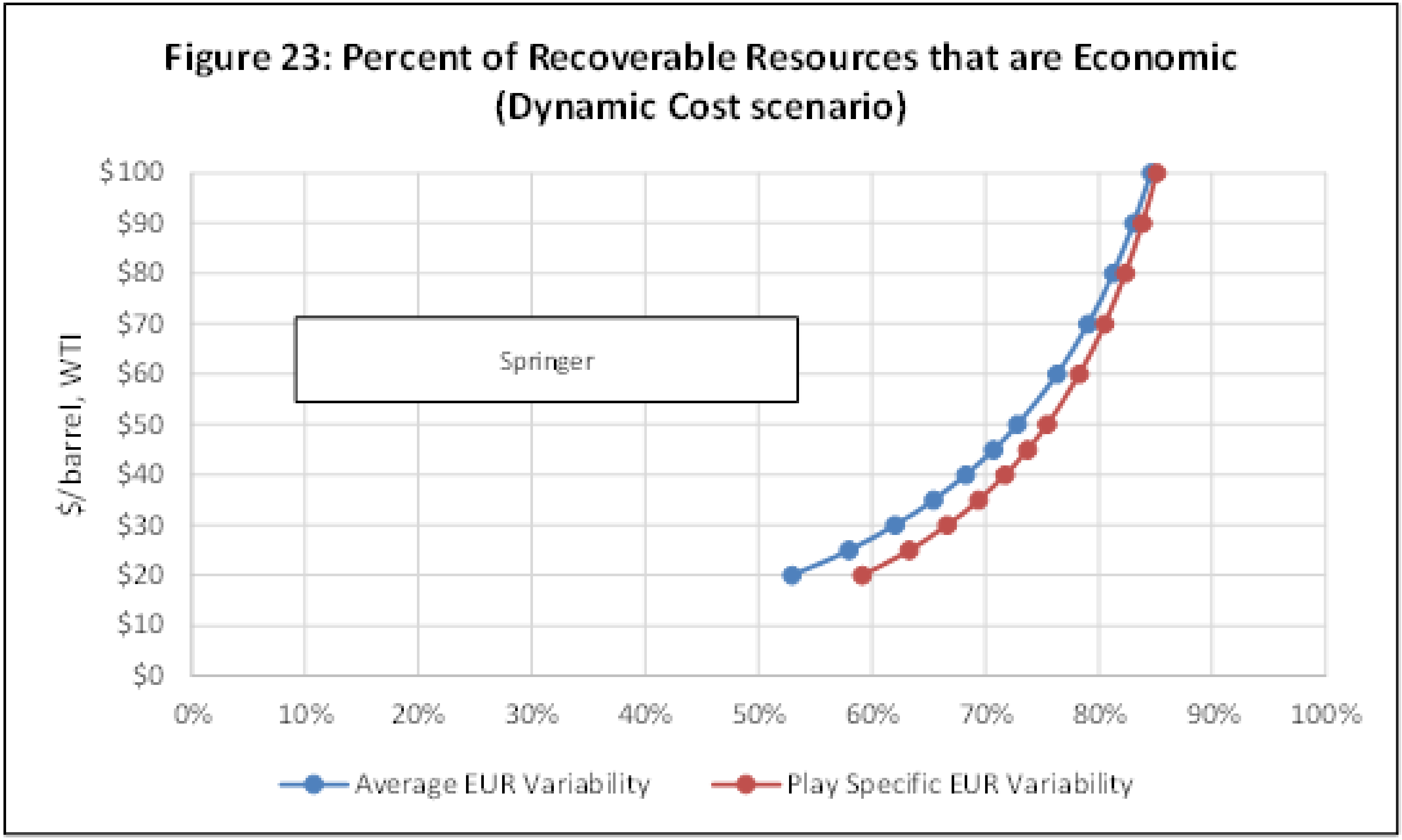
Thank You

Play-Specific Coefficients of Variation

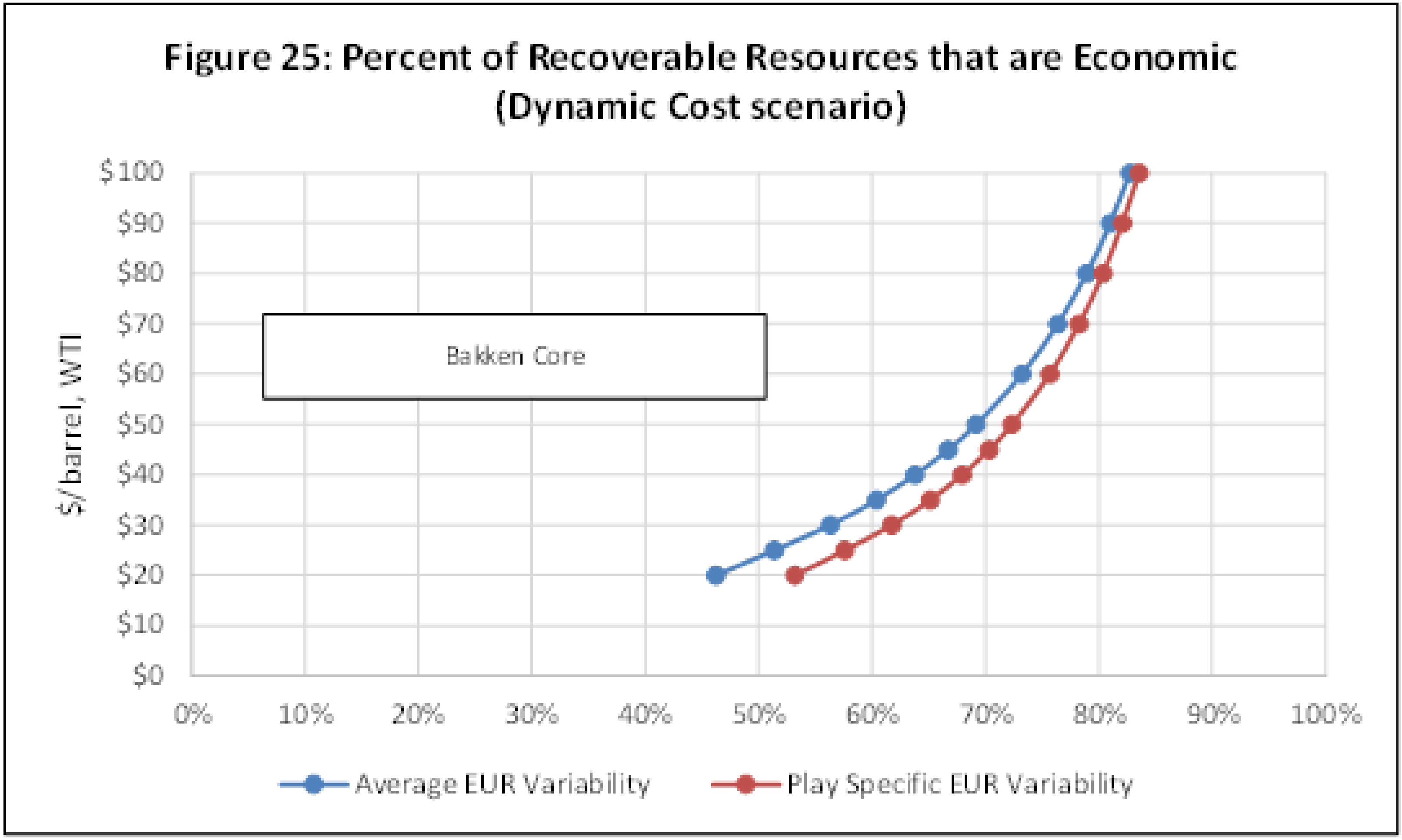
Table 6: Regional Coefficients of Variation

Petroleum Basin	Basin Average Coefficient of Variation
Anadarko/MidContinent	1.991
Bakken	1.970
Denver/Julesburg	1.082
Eagle Ford	1.620
Permian	0.805
Overall Average	1.500

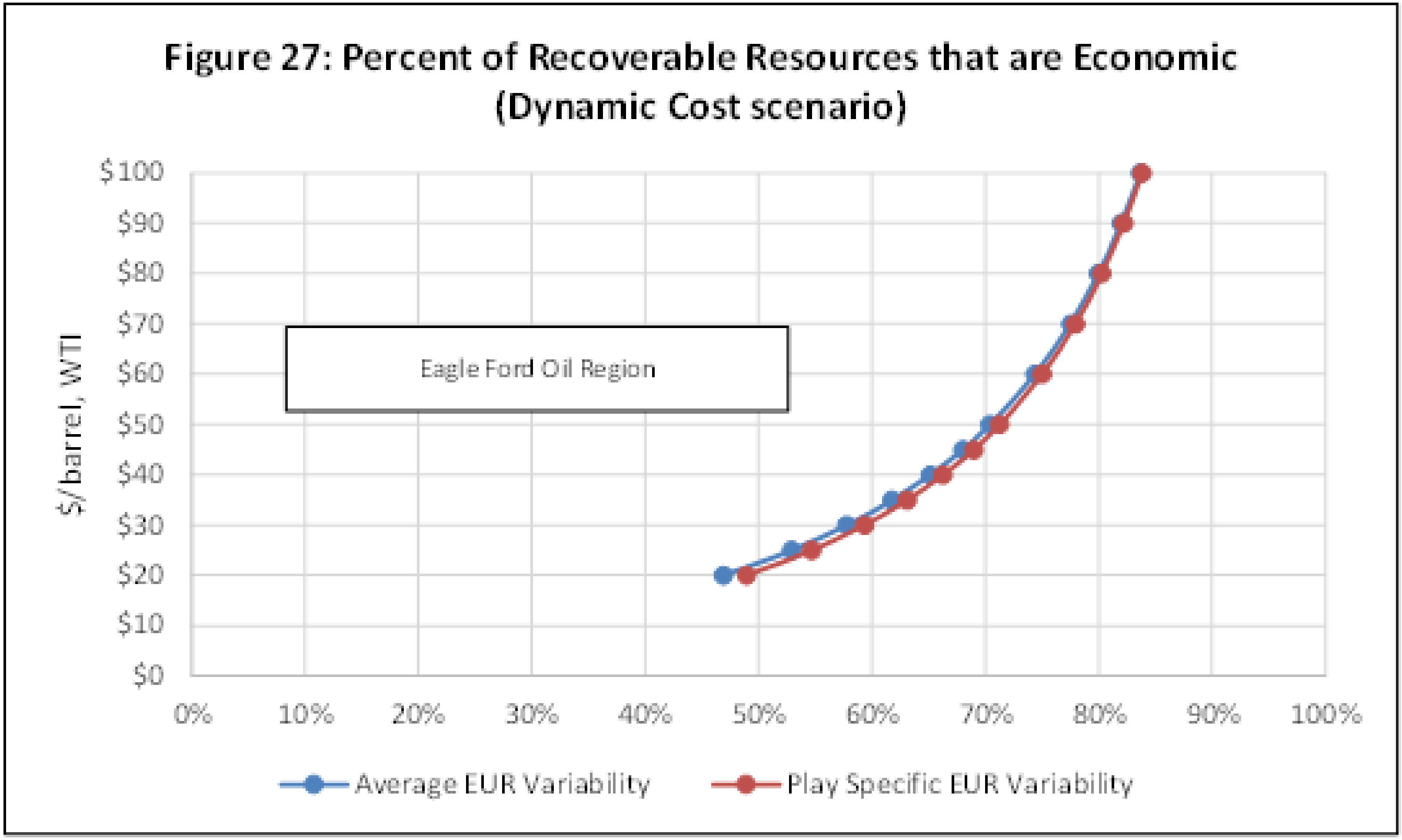
Impact of Coefficient of Variation: Springer



Impact of Coefficient of Variation: Bakken Core



Impact of Coefficient of Variation: Eagle Ford Oil



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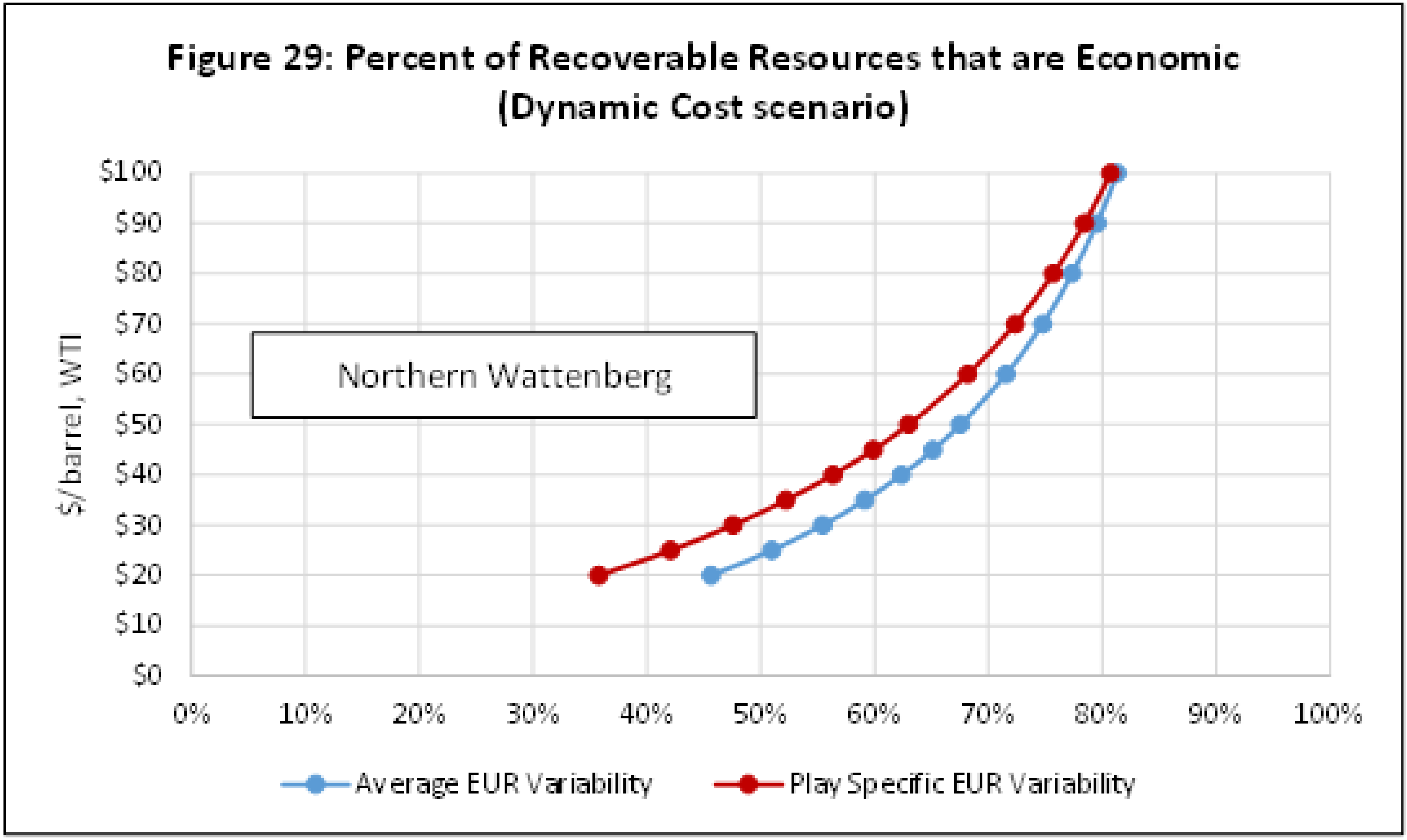
Impact of Coefficient of Variation: N. Wattenberg



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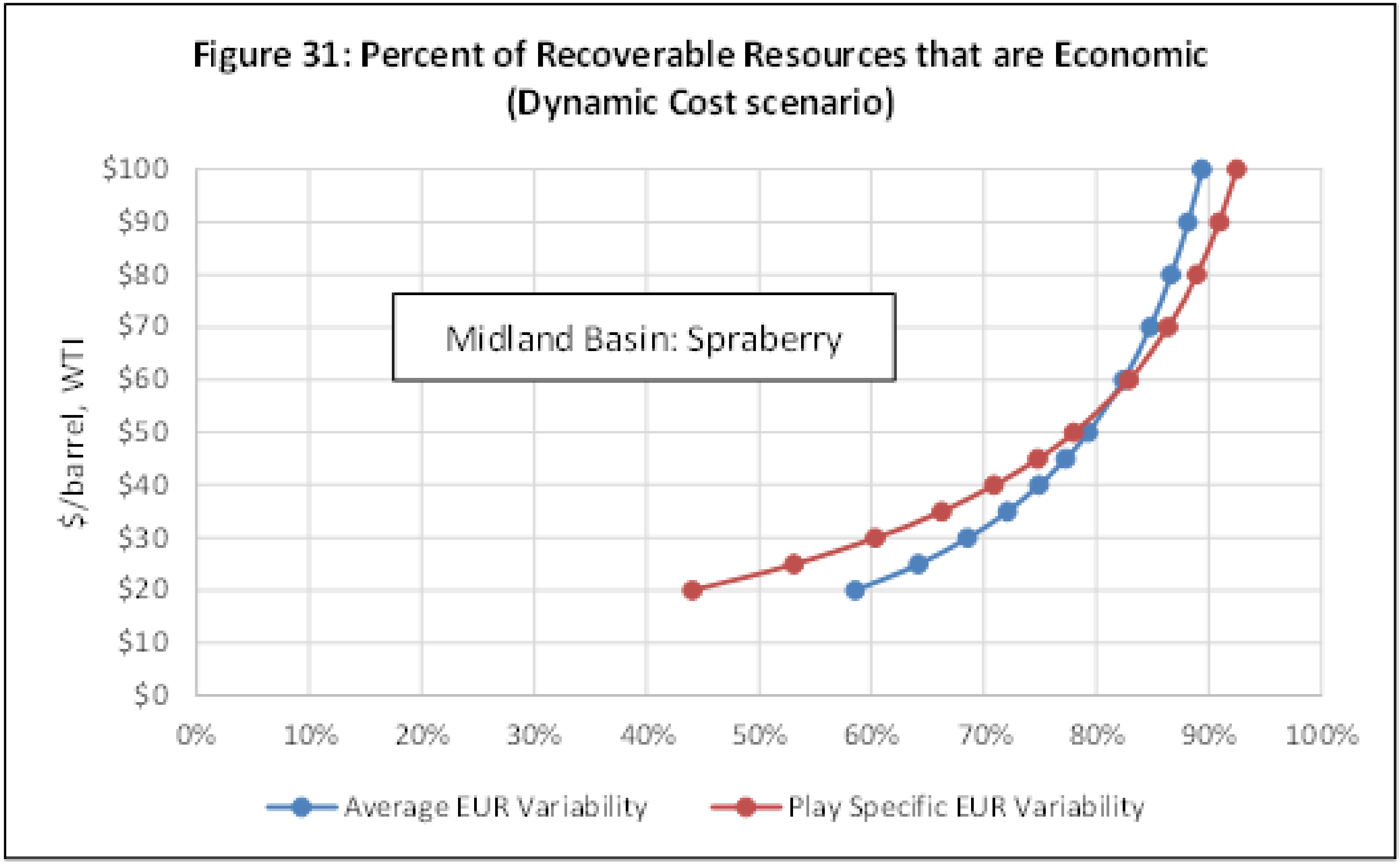
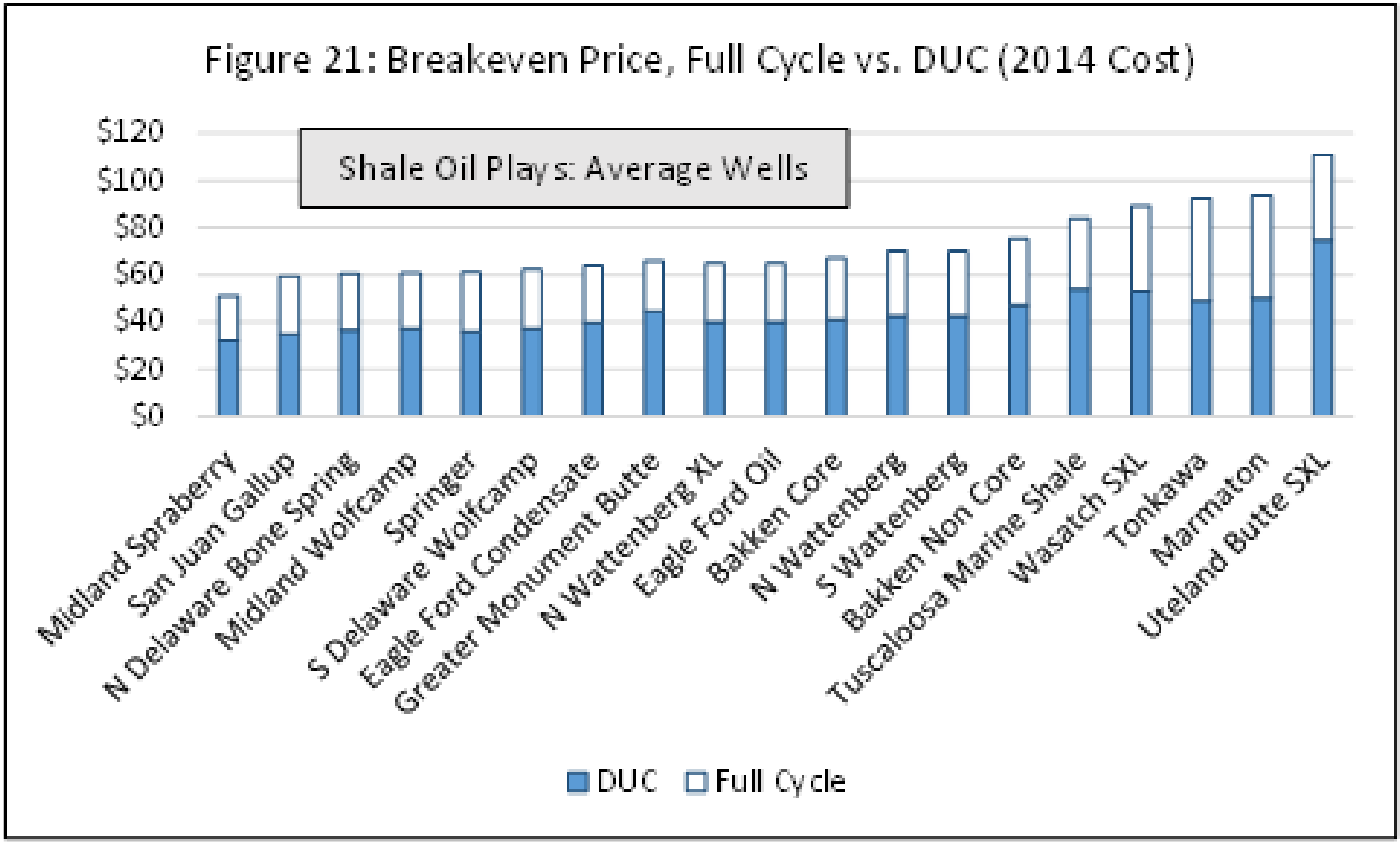
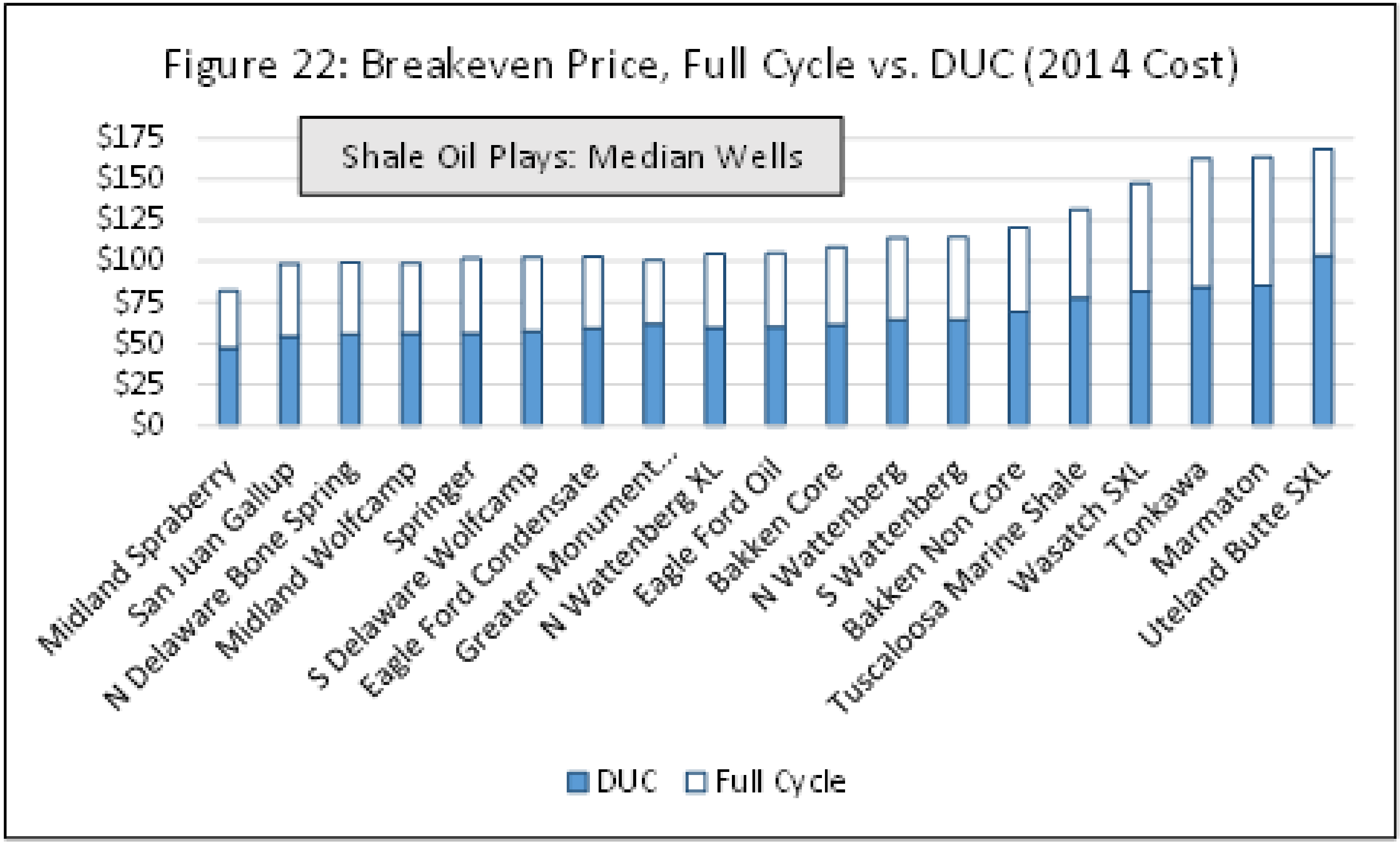
Impact of Coefficient of Variation: Spraberry



Resilience of DUCs vs. New Wells (mean EUR)



Resilience of DUCs vs. New Wells (median EUR)



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