Incipient Virtual Asset: Examining Trends in Marcellus Production Across Space and Time

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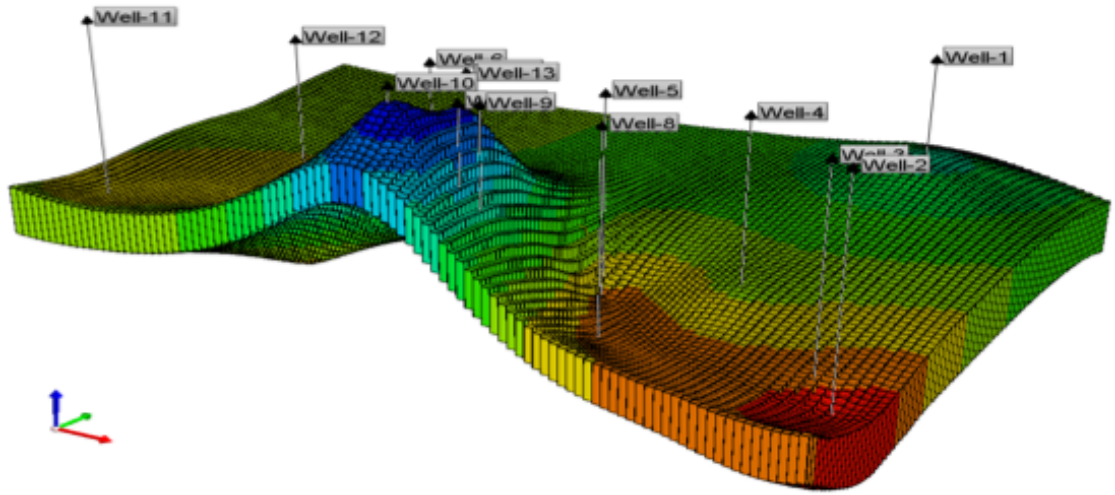
Estimating Reservoir Production

Common methods to estimate ultimate recovery from a well penetrating a reservoir:

- Volumetric Calculation
- Material Balance
- Reservoir Simulation
- Decline Curves



Decline Curves

Observation/Assumption

With all else being the same, well production will decrease as reservoir pressure decreases over time.

- Initially developed for conventional reservoirs
- Challenge to find one that works well for shale gas reservoirs (and unconventionals in general)
  - Hetergeneous porosity and permeability
  - Micro-permeability in shale matrix has different physics governing fluid flow
  - Higher degree of variability in operational practices among wells in same play

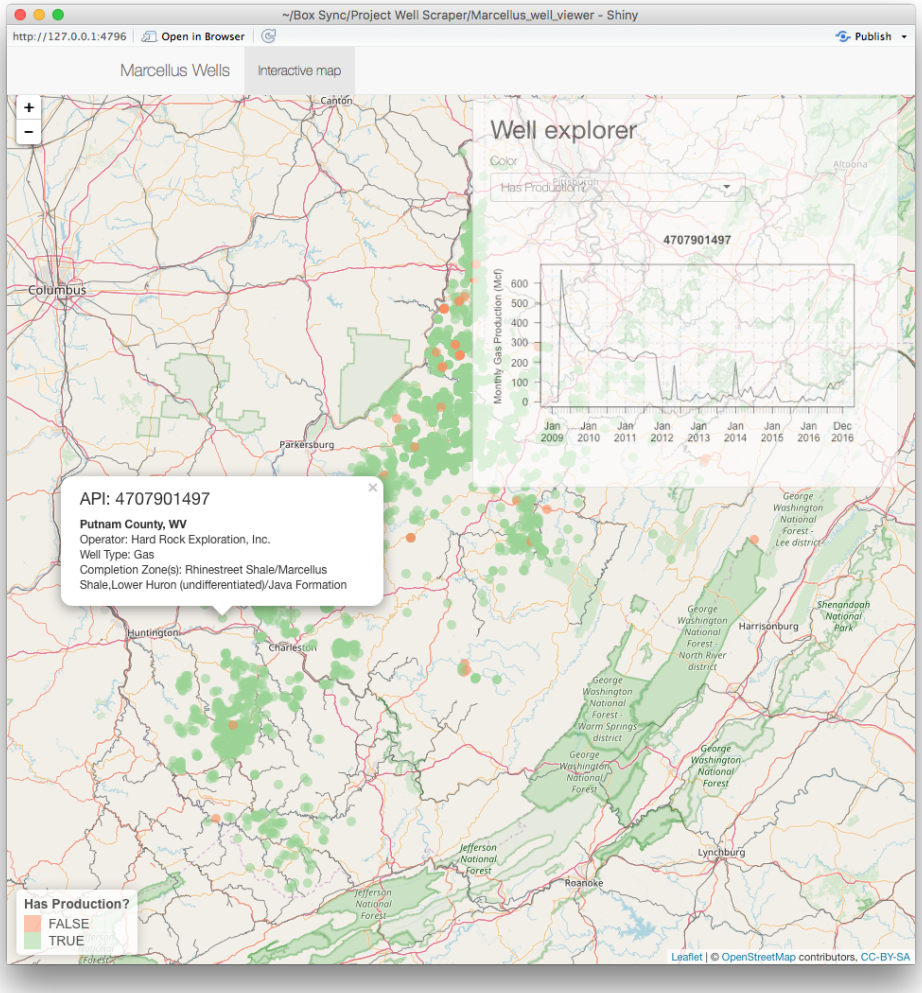
Decline Curve Models

Decline Curve Name	Functional Form	Prior Distributions for Parameters
Exponential	$q_t = q_i \exp(-D_i t)$	$q_i \sim \text{lognormal}(q_1, \log_{10}(\exp(q_1))$ $D_i \sim \text{lognormal}(\ln(-(q_2 - q_1)), 1)$
Hyperbolic/Harmonic	$q_t = q_i(1 + D_i bt)^{-1/b}$	q_i, D_i as above $b \sim \text{lognormal}(0, 2)$
Power Law Loss-ratio	$q_t = q_i \exp(-D_\infty t - D_i t^n)$	q_i, D_i as above $D_\infty \sim \text{lognormal}(\ln(1e^{-5}), 0.2)$ $n \sim \text{uniform}(0, 1)$
Stretched Exponential	$q_t = q_i \exp(-(t/\tau)^n)$	q_i, n as above $\tau \sim \text{lognormal}(2, 1)$
Logistic Growth	$q_t = Knt^{n-1}/(a + t^n)^2$	$K \sim \text{lognormal}(14, 3)$ $n \sim \text{lognormal}(\ln(0.9), 10)$ $a \sim \text{lognormal}(4, 2)$
Duong's Model	$q_t = q_i t^{-m} \exp((a/(1-m))(t^{1-m} - 1)) + q_\infty$	q_i as above $m \sim \text{normal}(1.5, 0.25)$ $a \sim \text{normal}(1.15, 0.1)$ $q_\infty \sim \text{exponential}(5/\min(q_t))$

What production rate behavior is captured in decline models? What is not?

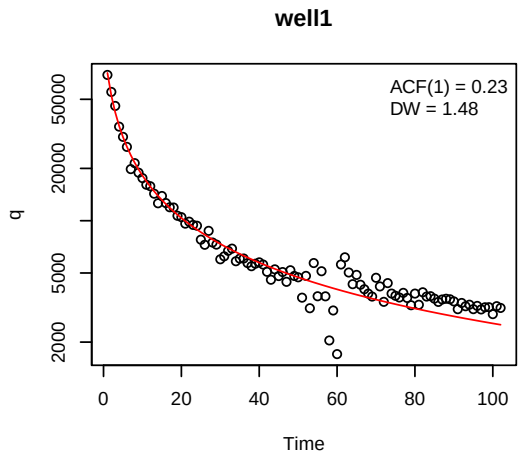
- What structure remains in model error?
- Well-to-well, are model coefficients independent?

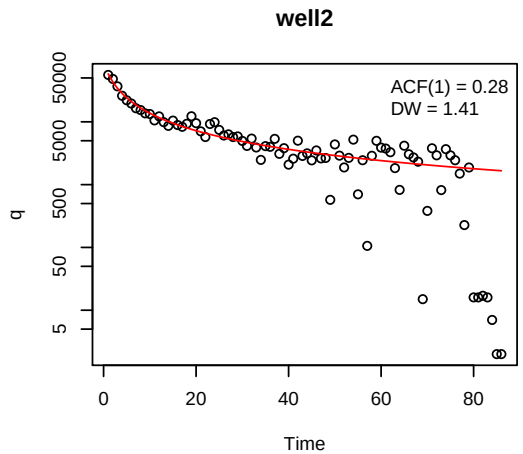
Virtual Asset: Data Exploration

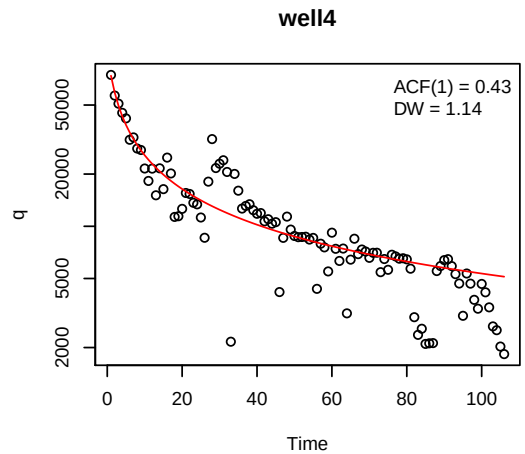


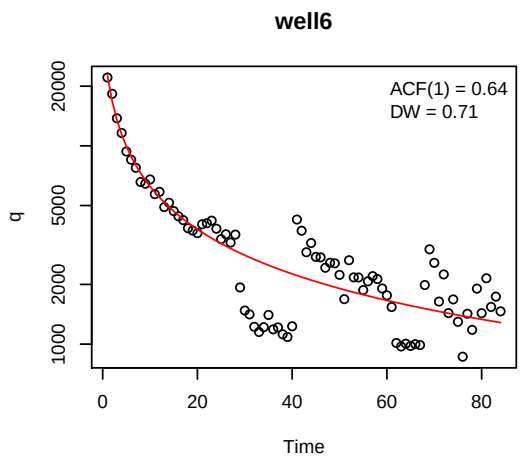
- Restrict search to WV
- Only wells completed in Marcellus
- 3,244 wells in all

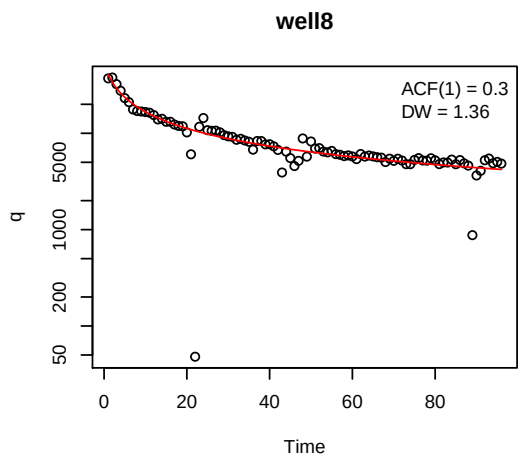
Autocorrelation in Decline Curve (Hyperbolic) Residuals

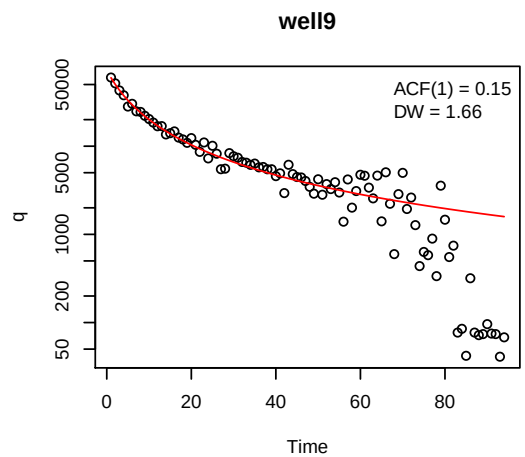




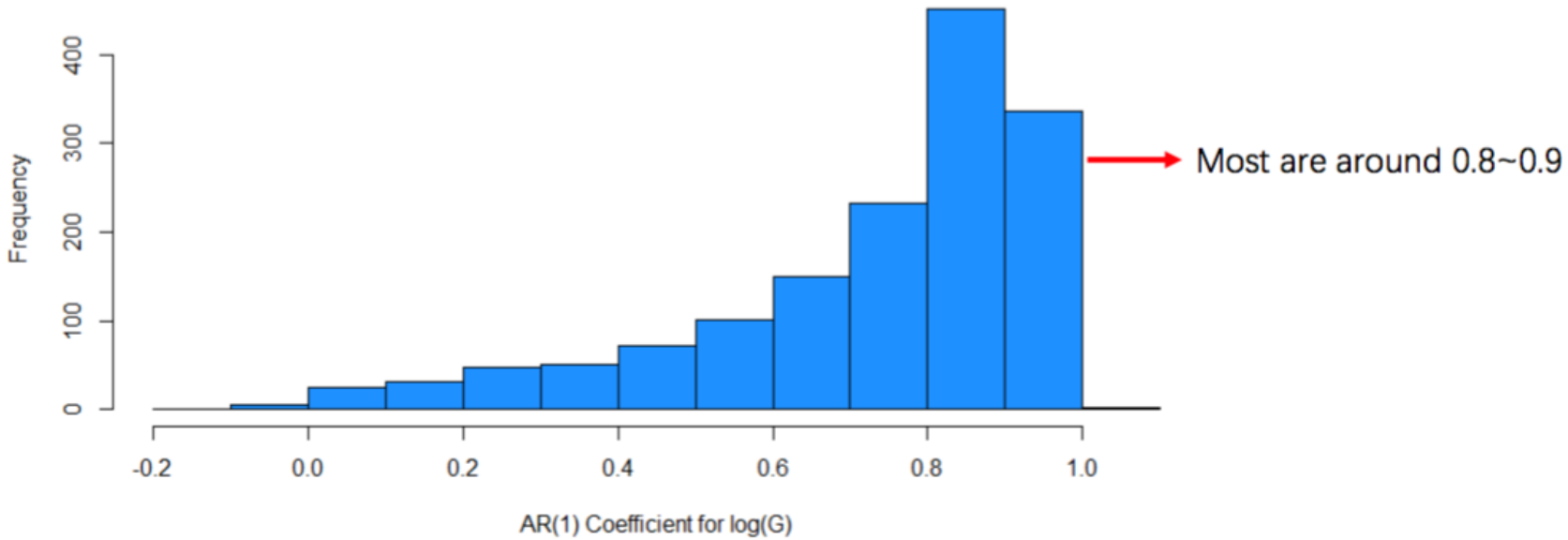








Large Autocorrelation Coefficients



Including AR(1) Only Gives Incremental Gains

One-sided paired t-tests:

- Means of differences:

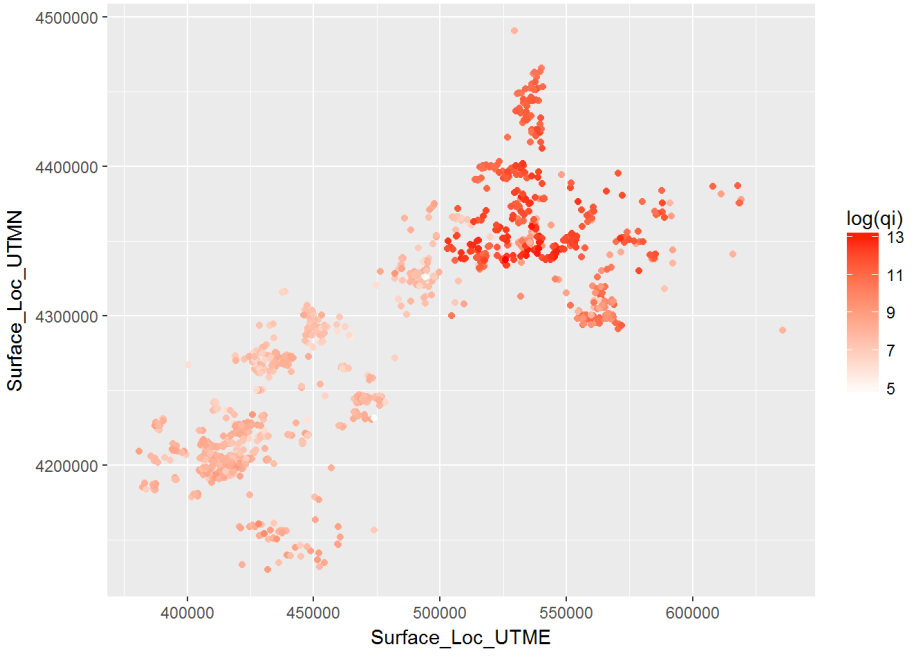
	Exp	Hyp	Pow	Str	Log
DIC w/ AR1 < DIC w/o AR1	-4.81	-3.02	-7.47	-6.20	-17.68
MAPE w/ AR1 < MAPE w/o AR1	-2.45	-1.99	-2.90	0.22	-1.76
|CR - 0.8|/0.8 w/ AR1 < |CR - 0.8|/0.8 w/o AR1	-0.01	-0.04	-0.11	-0.06	-0.14

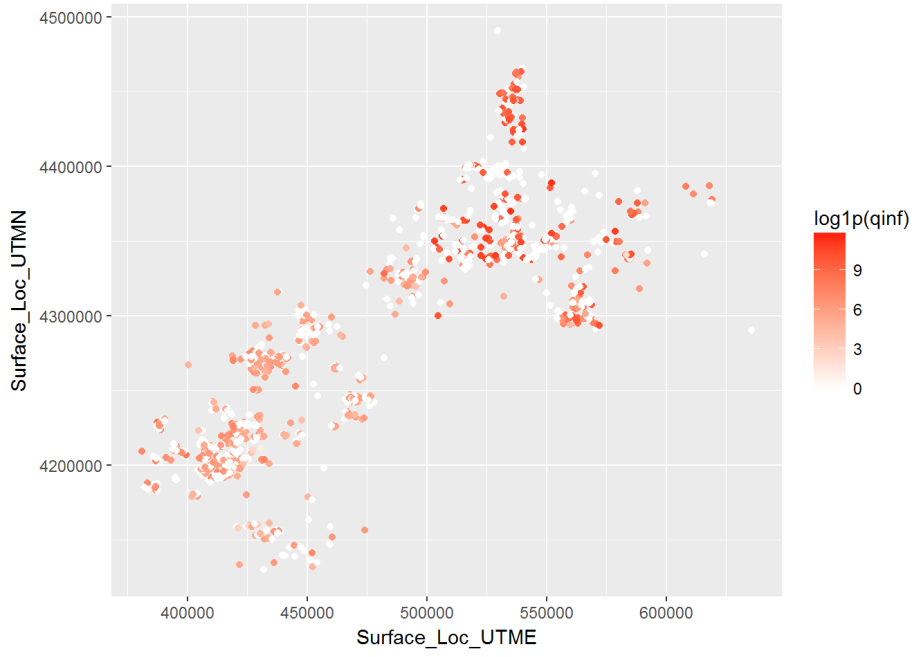
- p-values:

	Exp	Hyp	Pow	Str	Log
DIC w/ AR1 < DIC w/o AR1	3.6e-60	2.9e-21	1.1e-64	1.1e-61	6.4e-114
MAPE w/ AR1 < MAPE w/o AR1	1.9e-05	4.8e-05	0.0063	0.73	0.051
|CR - 0.8|/0.8 w/ AR1 < |CR - 0.8|/0.8 w/o AR1	0.00031	3.1e-20	3.4e-47	1.7e-28	2.6e-97

- Largest improvements gained from adding AR1 component:
  - DIC: Logistic Growth
  - MAPE: Power Law Loss-ratio
  - CR: Logistic Growth

Decline Curve Parameters are Spatially (Cross-) Correlated



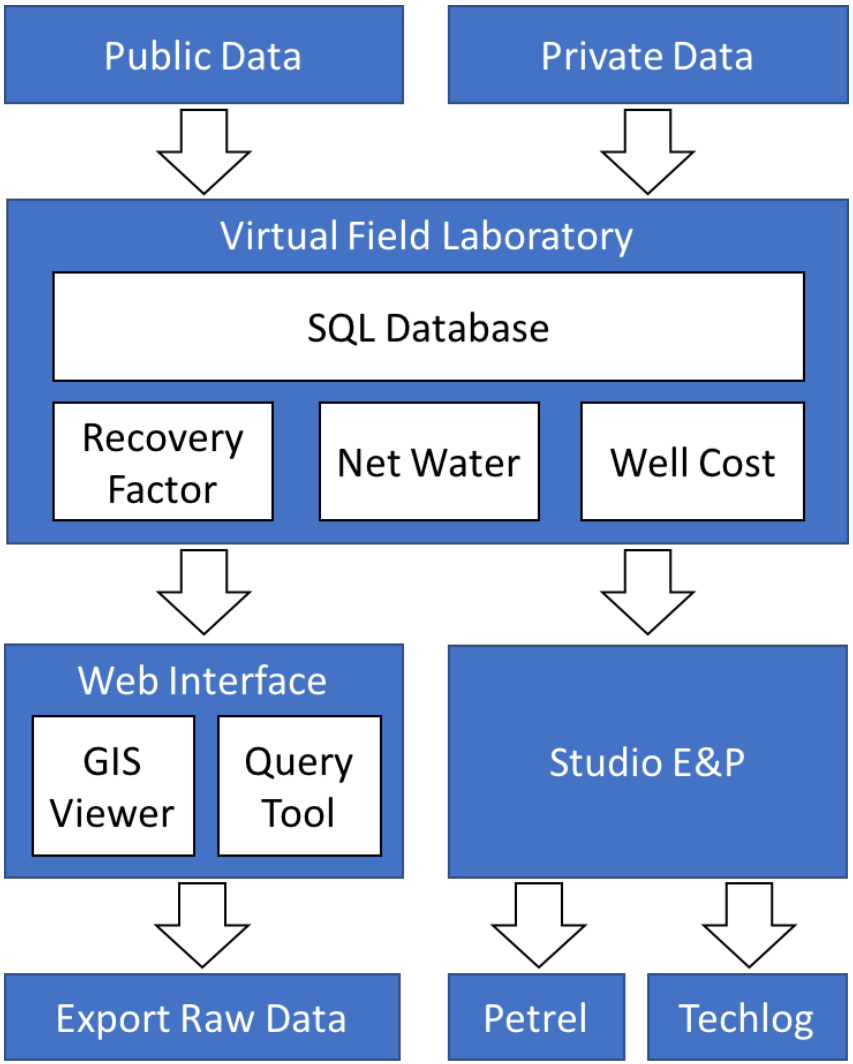


Show geostats in Virtual Asset!

Summary

- There often exists significant auto-correlation in the residuals of decline curve fits
- Decline curve parameters show spatial correlation
- Next:
  - What about spatial correlation in the residuals?
  - What about relationships with exogenous variables?

Virtual Asset: Bigger Picture



- More than just a database: opportunity to present research in interactive way
- Research objectives:
  - Decision support for operators
  - Enhanced predictive tools, especially at candidate well sites
  - Inference on treatments/procedures
- Educational tie-in:
  - Internships
  - Bring real, modern data (and data science methods) into classroom