

Learning through Subcontractors in an Emerging Technology

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Introduction

Motivation: Understand the channels by which firms learn about production function in an emerging technology.

- Read papers by energy economists
- Buy fuel (coal or natural gas)
- Learn from others

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 - ▶ Informal exchanges
 - ▶ Published reports (e.g., regulatory filings)
 - ▶ Hire their contractors

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Research Questions:

- ▶ What explains heterogeneous patterns of contractor hiring behavior?
- ▶ Do firms learn about the production function via contractors?

Fracking Technology 102

Design objectives

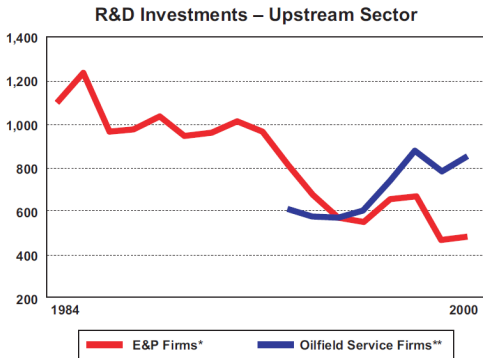
- ▶ Identify and exploit natural rock fractures
- ▶ Increase permeability of rock face
- ▶ Exert maximum pressure on formation
- ▶ Maximize fracture height and carry proppant deep into fracture
- ▶ Prevent fluid from leaking into target formation
- ▶ Break up fluid to facilitate gas recovery

Some recent developments

- ▶ Smaller perforation intervals (as small as 2-3 feet)
- ▶ Improved chemical combinations

Contractors play substantial role in fracture design

Contractors Perform Most R&D



*U.S. E&P firms and the U.S. R&D investments of international E&P firms, EIA, CERA analysis

**Traditional oil field service companies (Baker Hughes, Halliburton, Schlumberger, Smith, Weatherford) annual reports, CERA analysis

Source: Rao (2007)

Related Literature

- ▶ Kellogg (2011)
 - ▶ Learning occurs in joint relationships between firms and contractors
 - ▶ Costs (drilling time) are lower in longer-established relationships between operators and contractors
 - ▶ Relatively mature technology (Texas oil fields 1991-2005)
- ▶ Covert (2015)
 - ▶ Operator experimentation relatively unusual
 - ▶ Operators fail to take full advantage of social learning opportunities
 - ▶ Emerging technology in boom phase (ND shale oil 2005-2012)
- ▶ Arora and Gambardella (1994)
 - ▶ "Changing technology of technological change" creates opportunities for specialist R&D firms
 - ▶ Not all innovations can be codified
 - ▶ Collaborative relationships facilitate informal knowledge transfer

Data

Sample

- ▶ 30,469 wells in Pennsylvania with initial production 2007-2015
- ▶ 7,028 wells in unconventional reservoirs (90% horizontal)
- ▶ 5,543 with well completion reports available from DEP
- ▶ 2,799 with fracking contractor recorded (mostly 2010-2015)

Data sources

- ▶ DEP Well Completion Reports
 - ▶ physical inputs (water, sand, chemicals)
 - ▶ operational parameters (stages, zones, pressures)
 - ▶ contractors
- ▶ FracFocus and SkyTruth (chemicals)
- ▶ DrillingInfo (production)

Operators have Heterogeneous Hiring Behaviors

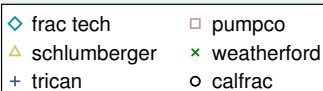
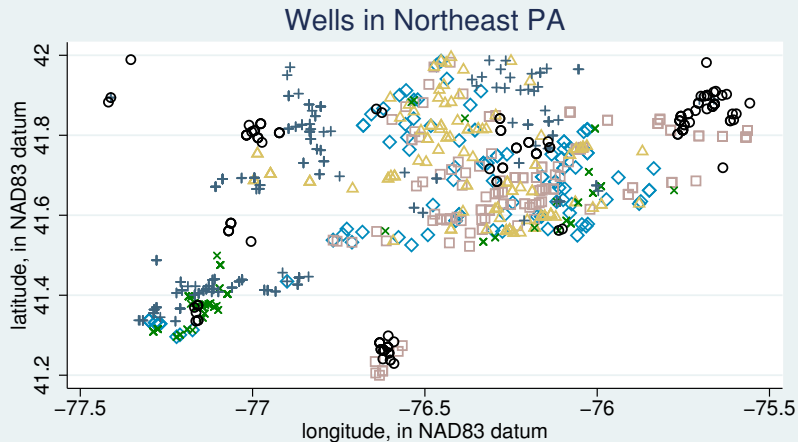
Contractor	anadarko	cabot	cpk	consol	eog
appalachian					62
baker hughes		69	3		1
calfrac			9	90	
cudd		18			
frac tech	1	2	81		
fts intl		54			
halliburton	24	7			
nabors		32			
precision	26				
pumpco		66	108		
schlumberger		1	126		
superior		39			
trican	116		29		
us well			2		
weatherford		4	37		

Explanations for Heterogeneous Behaviors

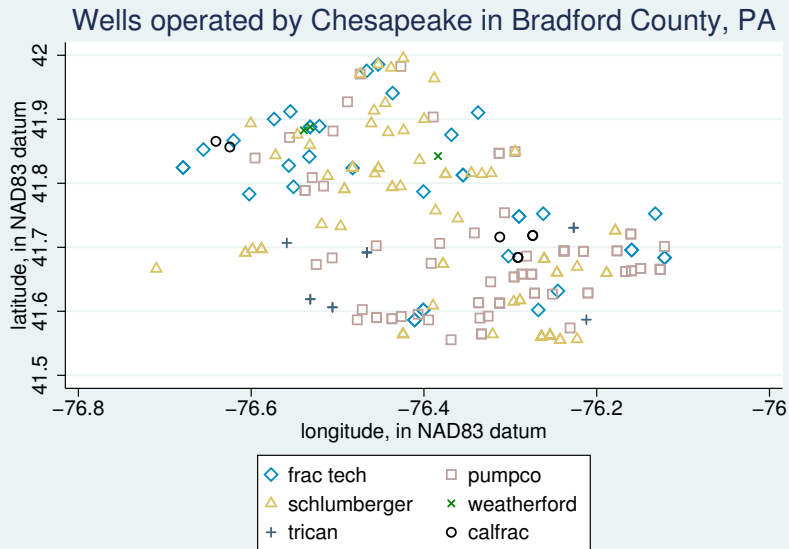
Hypotheses

1. Contractors have specialized geographic knowledge
2. Contracts have defined term or number of wells
3. Capacity limitations necessitate using different contractors
4. Repeated switching minimizes bargaining power & thus costs
5. Operators learn through hiring a diversity of contractors

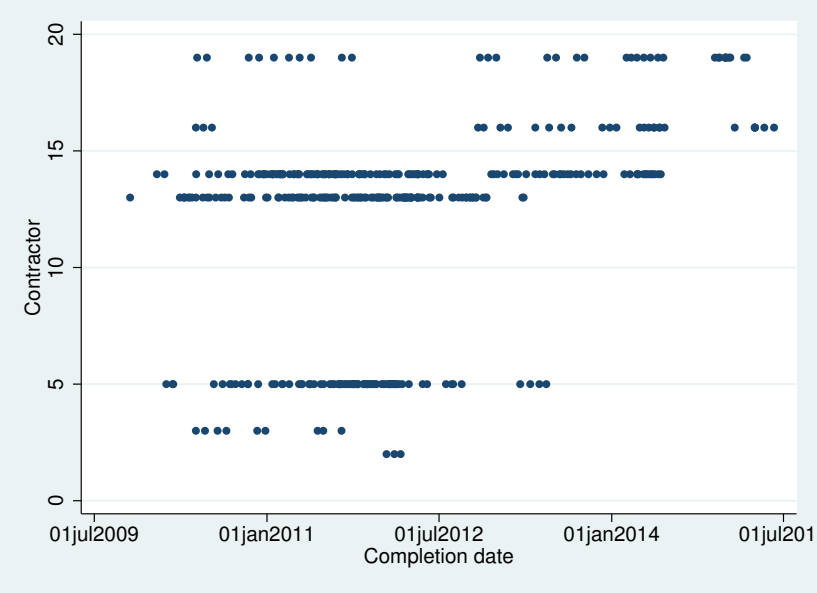
No Discernable Geographic Patterns



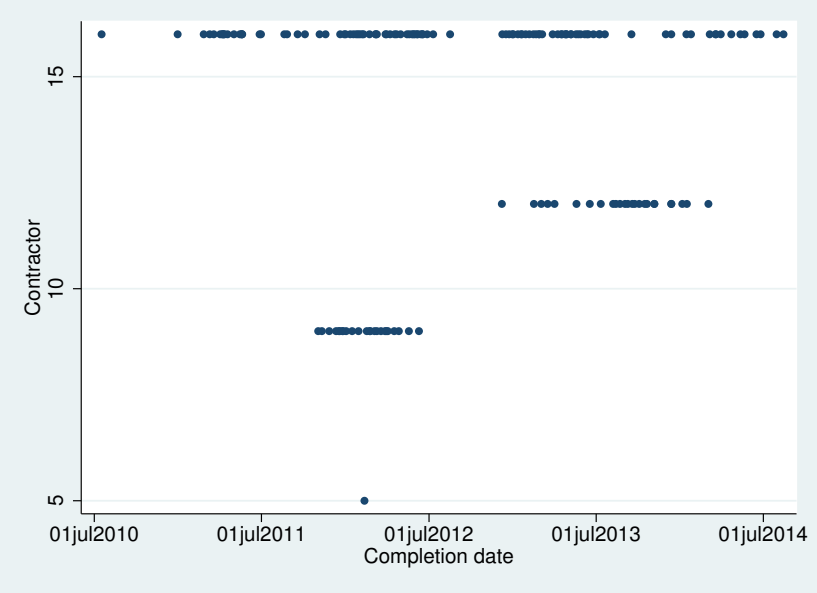
No Discernable Geographic Patterns (within operator)



No Discernable Temporal Patterns (Chesapeake)



Some Temporal Patterns (Anadarko)



Explanations for Heterogeneous Strategies

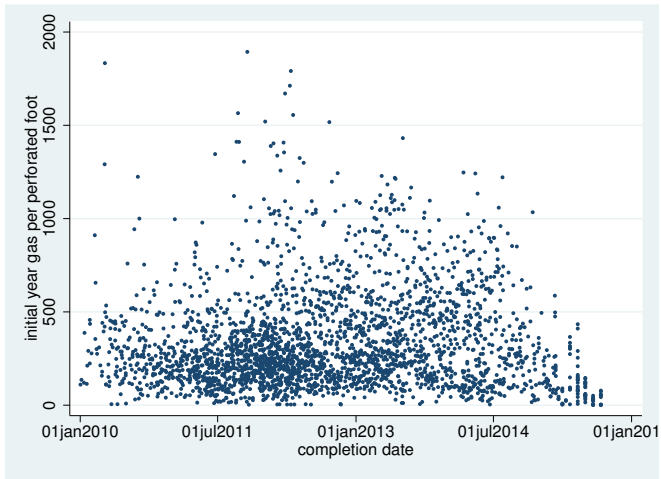
Hypotheses

1. Contractors have specialized geographic knowledge
 - ▶ Evidence does not support
2. Contracts have defined term or number of wells
 - ▶ Mixed evidence (but could also support hypothesis 5)
3. Capacity limitations necessitate using different contractors
4. Repeated switching minimizes bargaining power & thus costs
5. Operators learn through hiring a diversity of contractors
 - ▶ Contractor diversity positively correlated with productivity growth
 - ▶ Input vectors change after new contractor relationship

Distribution of Output Over Time

Mean output roughly constant; median output increasing

- ▶ Operators fracked most promising sites first
- ▶ Price movements may affect observed production (at 6-month resolution)



Change in Operator-Level Conditional Mean Productivity

As a first, ad hoc, very approximate, approach:

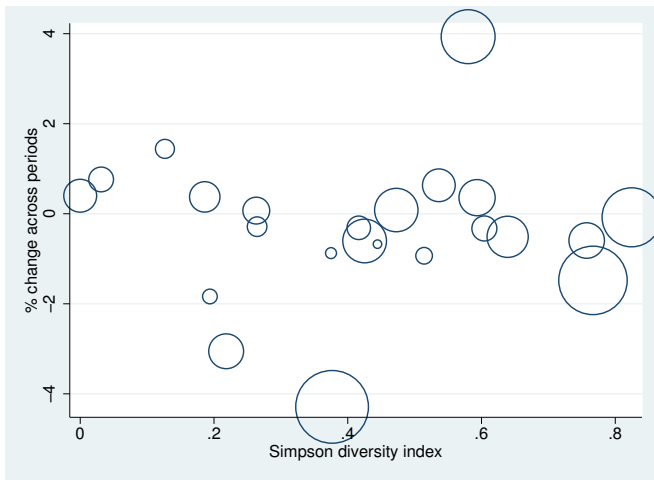
Regress initial gas per foot $IGPF$ on county and month dummies with operator \times period fixed effects

$$IGPF_{ijmc} = \alpha_c + \lambda_m + \theta_{j \times p} + \epsilon_{ijmc}$$

- ▶ Recover fixed effects vector, θ_j , conditional mean productivity of operator j (before/after 1/1/2012).
- ▶ Calculate percentage change before-after for each operator j
- ▶ Compare growth rate to contractor diversity

Conditional Productivity Growth and Contractor Diversity

Weak positive correlation ($r = 0.15$, not significant at $p = 0.1$)



Comparing Input Vectors

Does contractor switching precede input vector changes?

Measure input similarity with pairwise comparisons

Sorensen Index:

$$S_{ij} = \frac{2X_{ij}}{X_i + X_j}$$

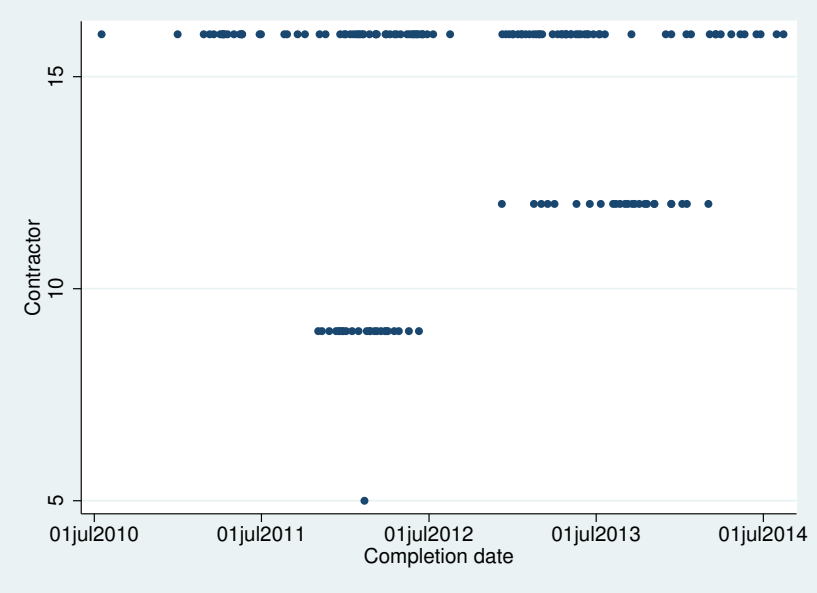
X_{ij} = Number of inputs common to both fracks

X_i, X_j = Number of inputs unique to i (j)

- ▶ Index from 0 (completely dissimilar) to 1 (identical)
- ▶ Captures only presence/absence of inputs (not intensity or magnitude)
- ▶ Currently captures only physical inputs (not, e.g., # stages)

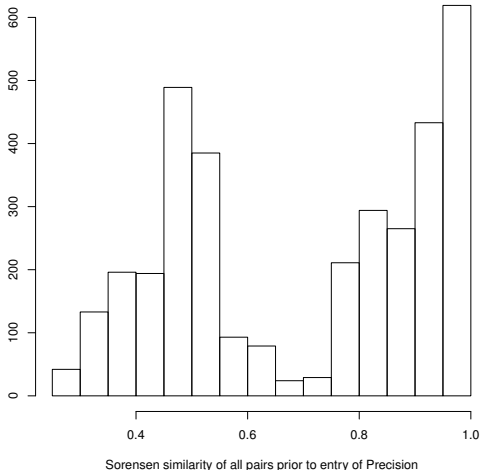
Clustering Analysis (in development)

Contractor Switching at Anadarko



Pairwise Similarity Prior to 12/31/12

Anadarko used two types of recipes prior to starting relationship with Precision Completion & Production Services

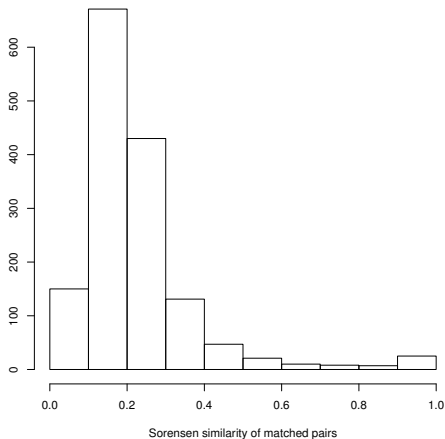


Matched Pairwise Similarity Before & After 12/31/12

Anadarko recipe changed substantially after starting relationship with Precision

Kolmogorov-Smirnov test rejects equality of distributions

($p < 0.05$)



Summary and Next Steps

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Next Steps

- ▶ Systematic method to assess effect of switching on output
- ▶ Systematic assessment of knowledge diffusion on input vectors
- ▶ Explore whether frequent-switching strategy increases costs (e.g., by extending job duration)
- ▶ Structural model of learning through subcontractors?