Make, Buy, or Share: Wastewater Management in the Marcellus Shale

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Regulating externalities in imperfectly competitive markets

- How large are interfirm contracting frictions? Should regulators care?
  - Transportation, electricity generation & retailing, drug discovery, consumer data, ...
- I present evidence from a novel setting: fracking wastewater management
  1. In Pennsylvania, most fracking wastewater is reused in subsequent drilling
  2. Reuse is difficult to coordinate across the firm boundary $\Rightarrow$ excessive trucking
  3. Trucking creates environmental externalities (emissions, traffic, spills)
- I develop an empirical framework to clarify implications for environmental policy
  - Reducing contracting frictions benefits firms, but may increase trucking intensity
  - Integration can crowd out interfirm contracting, increasing social costs

Related literature

- Regulation of environmental externalities under imperfect competition
  - Mansur 2007, Fowlie 2009, Ryan 2012, Fowlie et al 2016, Leslie 2018, Preonas 2023
- Direct estimation of transaction costs
  - Masten Meehan Snyder 1991, Atalay Hortacsu Syverson Li 2019
- Understanding efficiencies in horizontal & vertical integration
  - Baker and Hubbard 2004, Forbes and Lederman 2009, 2010, David et al 2013
- Empirical studies of matching markets
  - Choo and Siow 2006, Bajari and Fox 2013, Dupuy and Galichon 2014, Agarwal 2015

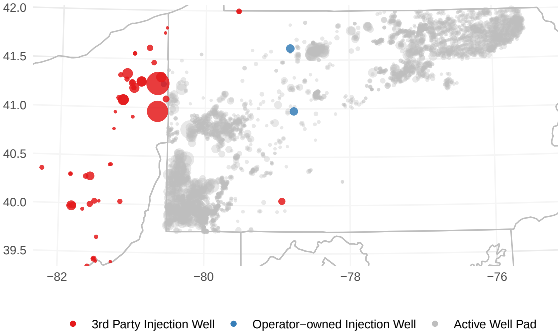
Water dynamics for a typical well

- Completions require hundreds of thousands of barrels of water in a few weeks
- Afterwards, 10-30% returns to surface (initially rapid, but continues for life of well)

Source: USGS

Injection well disposal

- Injection disposal wells are less accessible in Pennsylvania than in other regions



Disposal & reuse market shares

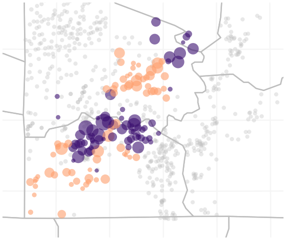
- Instead, firms rely on **reuse** in subsequent completions
  - Minimal treatment required $\Rightarrow$ cost of resuse $\approx$ cost of transportation
- 87% reuse rate in sample period (10% sharing):

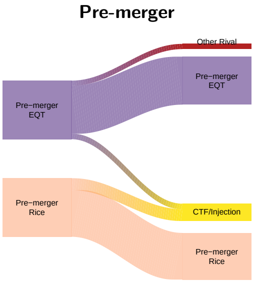
Mode	Ownership	% Waste
Reuse	Internal	63.7
	3rd party	13.5
	Rival	10.0
Injection well	-	9.4
Other	-	3.4

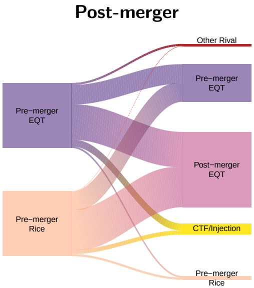
- Mix of internal & external transactions $\Rightarrow$ possible to identify firm boundary

Evidence of transaction costs

1. After 2017 EQT-Rice merger, significant flows across pre-merger firm border:







2. OT benchmark: industry trucking miles could be 30-40% lower (with 34% sharing)

- Sources: Infrequent drilling $\Rightarrow$ quasi-rents? Wastewater quality issues?

Map

Overview

- Data: monthly disposal records by well pad
- Two-sided reuse market $\Rightarrow$ matching with transferrable utility (Choo and Siow 2006, Galichon and Salanie 2022)
  - Firms with wastewater choose reuse locations to minimize costs
  - Firms with reuse capacity minimize water acquisition costs
- Key assumption: the firm is a collection of independent local decisionmakers
  - Internal transfer prices reflect shadow cost of using scarce capacity

Preferences

- For truckload i originating at well pad κ, the cost of disposal at δ is:

$$c_{i\delta} = d_{\kappa\delta} + \overbrace{\phi^{\kappa}_{\kappa\delta} + \phi^{\delta}_{\kappa\delta} + mc_{\delta}}^{\phi_{\kappa\delta}} + \overbrace{p_{\kappa\delta} - \phi^{\delta}_{\kappa\delta} - mc_{\delta}}^{\tau_{\kappa\delta}} - \sigma_{\kappa}\varepsilon_{i\delta}$$

  - $d_{\kappa\delta}$ is the over-the-road transportation distance from κ to δ in miles
  - $\phi_{\kappa\delta}$ is a gross transaction cost, including the marginal cost of disposal at δ
  - $\tau_{\kappa\delta}$ is a markup over the total cost of disposal at δ

- For delivery slot j at facility δ, the benefit of accepting wastewater from κ is:

$$\pi_{\kappa j} = \tau_{\kappa\delta} + \sigma_{\delta}\eta_{\kappa j}$$

- $\varepsilon_{i\delta}$ and $\eta_{\kappa j}$ are additively separable, (nested) logit errors (Galichon and Salanie 2022)

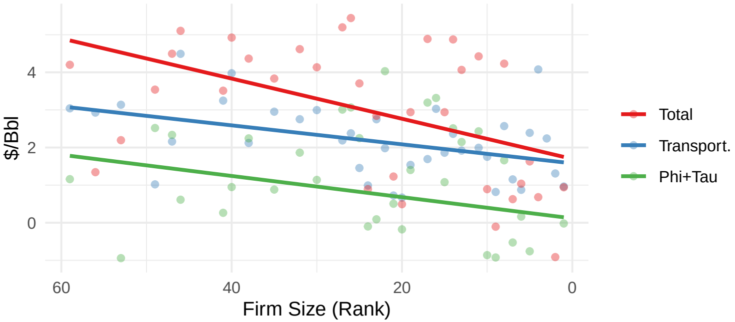
Main parameter estimates

- In practice: assume a constant $\phi_{\kappa\delta} = \phi_{rival}$ for all sharing transactions
- Point estimate implies ϕ_{rival} is equivalent to shipping truck 170.6 miles
- If trucking costs are $5/mile, implies transaction costs of about $8.50/bbl

Details Full Results Cost Decomposition

Transaction costs & returns to scale

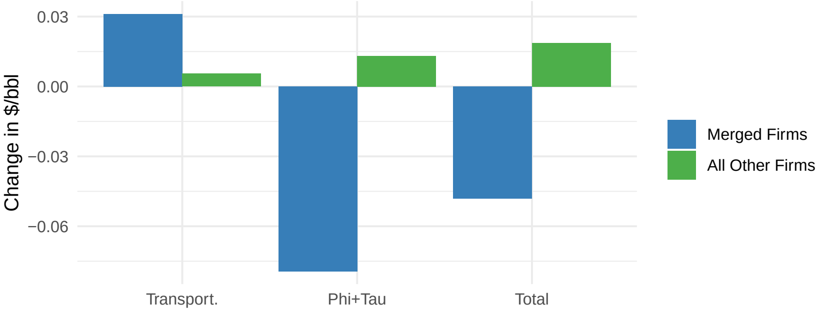
- Mean expected disposal costs per barrel (excluding ε and η):



- Large firms drill more frequently $\Rightarrow$ more opportunities for internal reuse
  - Foregone markups, foregone transaction costs, often shorter distances

Effects of hypothetical mergers on trucking intensity

- On average, observable costs for merged entity fall, but trucking intensity increases



- Shorter sharing transactions displaced by longer, lower ϕ internal transactions
- Thinner sharing mkt $\Rightarrow$ increased trucking & non-trucking costs for non-merging parties

Could reducing contracting frictions reduce trucking intensity?

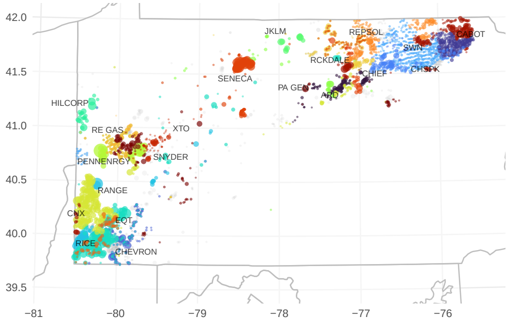
- Suppose a regulator could eliminate specific frictions (e.g., with quality certifications)
- In the model, reducing $\phi_{rival} \not\Rightarrow$ reduced trucking distances
  - More likely to match with nearby rivals, and also more distant ones with better ε
- Empirically the "optimal" ϕ_{rival} is positive & only reduces trucking by 0.5%
- Comparison: Pigouvian tax of \$0.20/truck-mile acheives same reduction

Conclusion

- Novel setting with unusual variation that permits identification of firm boundaries
- Evidence of significant & socially costly misallocation due to transaction costs
- Empirical framework highlights challenges for regulatory intervention
  - Improved coordination from mergers/institutions can increase relevant social costs

- Thank you!
- Questions/comments: MatthewOKeefe2023@u.northwestern.edu

Locations of 20 largest firms



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Equilibrium & estimation

- Equilibrium characterized by a markup matrix τ such that for all κ, δ:

$$Q_\kappa \rho_{\kappa\delta} = C_\delta q_{\kappa\delta}$$

  - $Q_\kappa \rho_{\kappa\delta}$ is κ's (expected) demand for disposal at δ
  - $C_\delta q_{\kappa\delta}$ is δ's (expected) demand for wastewater from κ

- Known outside options $\Rightarrow$ eqm markups uniquely determined (Graham, 2011)
  - Here: use assumptions on prices in injection well market pin down price level

- Similar to gravity model & trade data $\Rightarrow$ estimate via PPML

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Cost decomposition

- Costs evaluated at \$5/mile, assuming 100 barrel trucks

Disposal Mode	Transport.	Tx. Cost + Markups			Total
		ϕ	τ	$\phi + \tau$	
Internal Pads	1.49	0.00	-0.71	-0.71	0.77
Rival Pads	2.90	8.53	-6.12	2.41	5.31
Injection Well	7.52	0.00	2.02	2.02	9.54

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Main parameter estimates

	Direct Only		Incl. CTF	
	CS	*Nested*	*CS*	*Nested*
ϕ_{Rival}	-165.7	-225.5	-152.4	-170.6
σ_d	8.0	7.1	22.5	8.8
σ_k	14.2	25.8	2.3	18.1
$\lambda_{k,Int}$	-	0.012	-	0.826
$\lambda_{k,Riv}$	-	0.983	-	0.999
$\lambda_{d,Int}$	-	0.809	-	0.884
$\lambda_{d,Riv}$	-	0.784	-	0.991

- Sharing with a rival zero miles away $\approx$ internal reuse 170.6 miles away
  - In comparison, distance from far SW to far NE wells is $\approx$ 300 miles
  - If trucking costs are \$5/mile, implies transaction costs of about \$8.50/bbl

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