

# **Firm Boundaries and External Costs in Shale Gas Production**

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January 2024

# When do markets form?

- ▶ Coase (1937, 1960): when **transaction costs** are low enough
- ▶ Large empirical literature testing comparative statics (e.g., asset specificity)
- ▶ Empirical challenges  $\Rightarrow$  few *quantifications* of transaction costs
  - ▶ Wallis and North (1986), Masten et al (1991), Atalay et al (2019), ....

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  - ▶ Wallis and North (1986), Masten et al (1991), Atalay et al (2019), ....
- ▶ This paper:
  1. New evidence on the *magnitude* and *distribution* of transaction costs
  2. Quantification of *external cost spillovers* from transaction costs

# Wastewater sharing in Pennsylvania

1. Fracking **requires water** and **generates wastewater** as a byproduct
  - ▶ 10-20M gallons for a typical shale gas well
  - ▶ 25% *slowly* returns as wastewater during extraction

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3. 10% of reuse occurs via trade (or **sharing**) between rival operators
  - ▶ Like all market transactions, sharing is subject to **transaction costs**

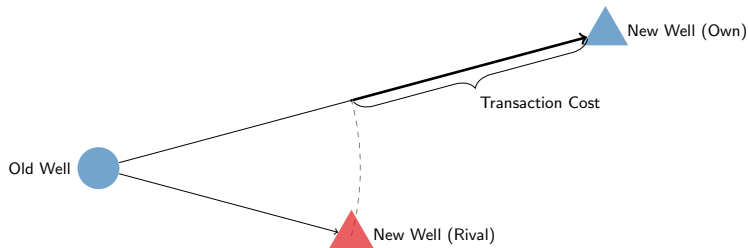
# Three questions

1. How large are the transaction costs of sharing?
2. What are their main sources?
3. Do transaction costs have significant environmental spillovers?
  - ▶ To what extent do transaction costs result in **less reuse** or **less efficient reuse**?



# Quantifying transaction costs

- ▶ Data: wastewater shipments *within* and *between* firms, at high spatial resolution
- ▶ Water is heavy  $\Rightarrow$  transporting wastewater is costly (typically, trucked)
- ▶ Idea: transaction costs  $\equiv$  “distance premia” firms incur to avoid sharing



# Key findings

1. Transaction costs are **economically large**
  - ▶ On average: \$6 per barrel of wastewater  $\Rightarrow$  over 50% of reuse surplus
2. Transaction costs exhibit **significant within-market heterogeneity**
  - ▶ \$2 per barrel standard deviation across sharing transactions
3. Transaction costs are larger when **contracting frictions** are more severe
  - ▶ Information frictions, incomplete contracts, relational contracting frictions
4. Marginal sharing transactions provide **limited environmental benefit**

## Related literature

- ▶ Quantification of the Coasean transaction costs
  - ▶ Masten Meehan Snyder 1991, Atalay Hortacsu Li Syverson 2019, ...
  - ▶ Contribution: explores **distribution** of transaction costs
- ▶ Direct environmental impacts of fracking
  - ▶ Hausman and Kellogg 2015, Black et al 2021, ...
  - ▶ Contribution: novel framework for studying wastewater policy
- ▶ Regulation of environmental externalities in oligopoly
  - ▶ Mansur 2007, Fowlie 2009, Ryan 2012, Fowlie et al 2016, Leslie 2018, Preonas 2023, ...
  - ▶ Contribution: non-strategic source of market imperfection under oligopoly

Setting

Model

Estimates

Spillovers

Conclusion

## Data: wastewater disposal records

- ▶ Monthly disposal records by well pad from Pennsylvania DEP, 2017-20
  - ▶ Monthly transfer volumes for **all** well pads / destination pairs
  - ▶ Detailed facility info (precise locations, permit numbers, ...)  $\Rightarrow$  over-the-road distances

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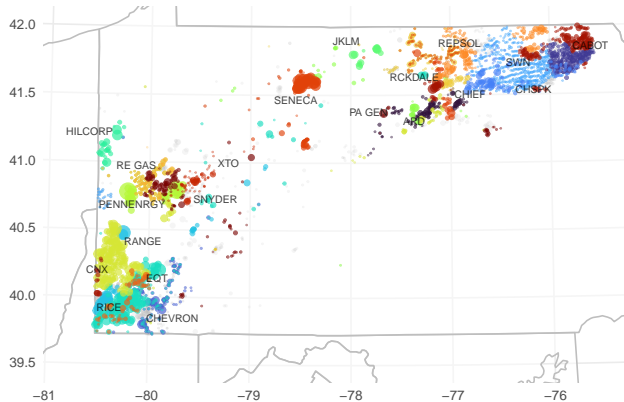
- ▶ Monthly disposal records by well pad from Pennsylvania DEP, 2017-20
  - ▶ Monthly transfer volumes for **all** well pads / destination pairs
  - ▶ Detailed facility info (precise locations, permit numbers, ...)  $\Rightarrow$  over-the-road distances
- ▶ What it doesn't have:
  - ▶ Dates, times, or modes of particular shipments
  - ▶ Contract terms
  - ▶ Prices

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- ▶ Supplementary data: completion info from FracFocus (incl. fracking inputs)

## Fact 1: decentralized production

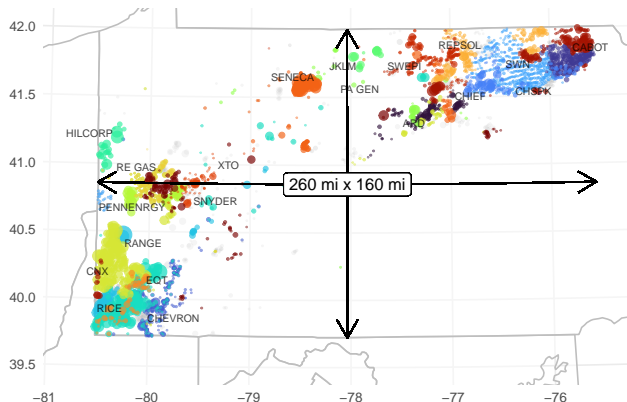
- ▶ Wastewater disposal HHI: 1,090
- ▶ Locations of twenty largest firms (by disposal volume):





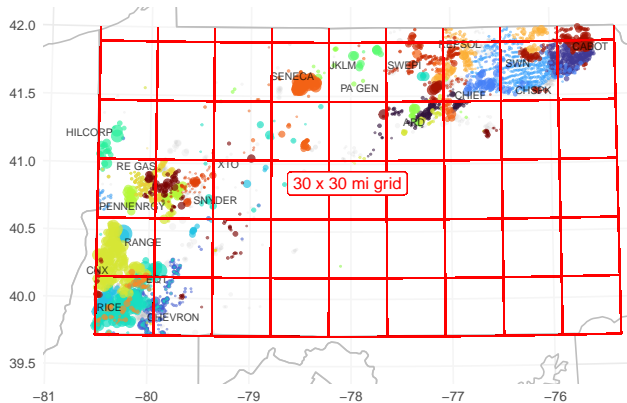
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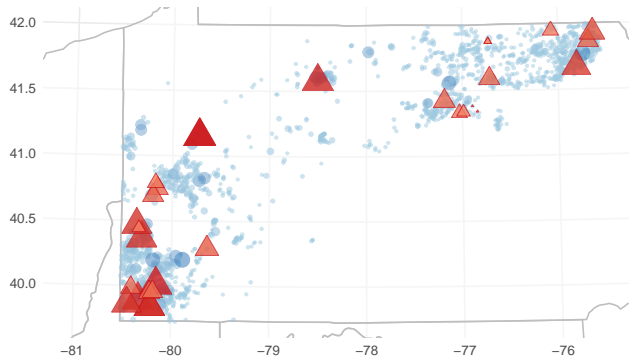
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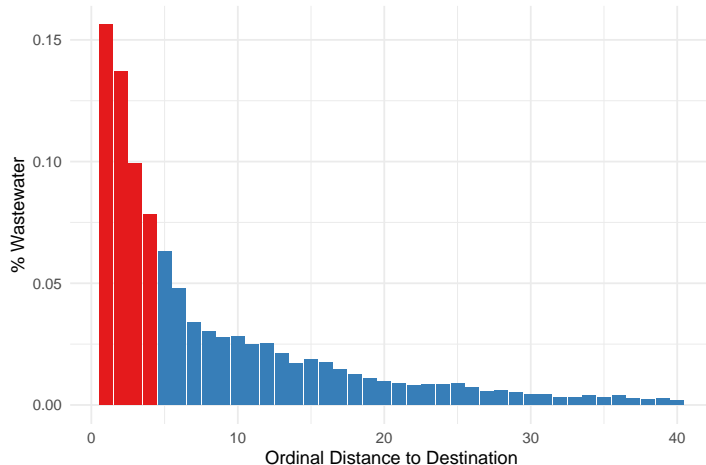
## Fact 2: more old wells than new wells

- ▶ Average month: 1,721 well pads reporting disposal vs. 55 completions
- ▶ June 2018 (well pads reporting disposal in blue, completions in red):



### Fact 3: most reuse occurs locally

- 47% of wastewater is shipped to one of the four nearest destinations:



# Prevalence of wastewater sharing

## ► Disposal market shares:

Outcome	Facility	% Vol.
Reuse	Own well/CTF	70.6
	Independent CTF	12.5
	<b>Rival well/CTF</b>	<b>8.6</b>
Final Disposal	Injection Well	8.4

## ► Three reasons for sharing:

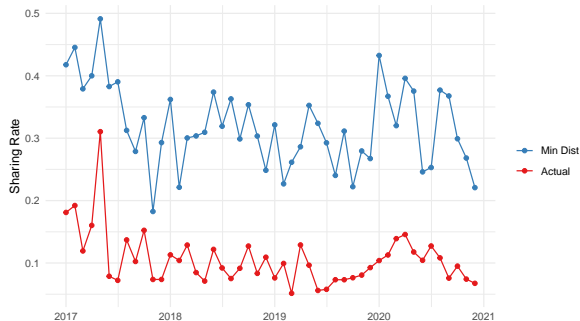
1. Temporal mismatches
2. Geographic synergies
3. Non-geographic synergies

Participation Stats

Final Disposal

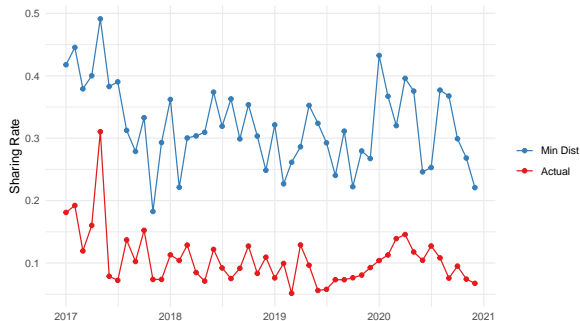
# Is there enough sharing?

- ▶ Suppose all truckloads of wastewater are substitutable within a month
- ▶ Exercise: holding local supply/demand fixed, minimize shipping distance
- ▶ Actual sharing rate vs. rate consistent with distance minimization:



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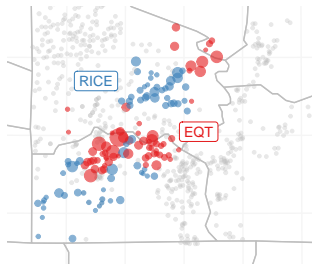
- ▶ Suppose all truckloads of wastewater are substitutable within a month
- ▶ Exercise: holding local supply/demand fixed, minimize shipping distance
- ▶ Actual sharing rate vs. rate consistent with distance minimization:



- ▶ Why? Either (1) transaction costs; or (2) technological costs

## Evidence of transaction costs: 2017 EQT-Rice merger

- ▶ Pre-merger: 2nd and 6th largest firms in Pennsylvania (by wastewater production)
- ▶ Pre-merger well pads:



- ▶ Large firms + overlapping acreage  $\Rightarrow$  significant geographic synergies

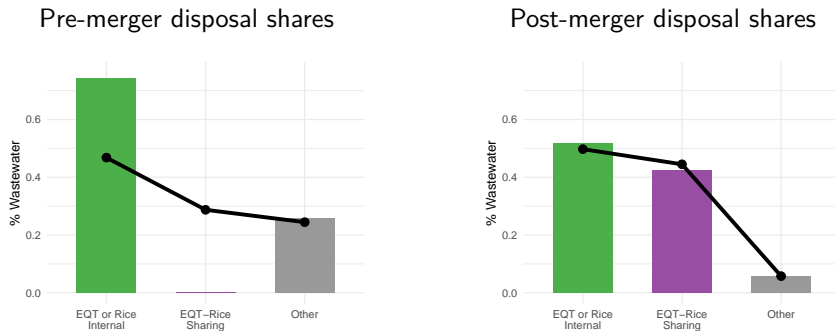


## Evidence of transaction costs: 2017 EQT-Rice merger (cont)



- ▶ No sharing pre-merger  $\Rightarrow$  43% “sharing” post-merger
  - ▶ Evidence of **transaction costs** unless technological costs changed significantly

# Evidence of transaction costs: 2017 EQT-Rice merger (cont)



- ▶ No sharing pre-merger  $\Rightarrow$  43% “sharing” post-merger
  - ▶ Matches **model-implied optimal rate** if merger eliminated transaction costs

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## How large are transaction costs?

- ▶ A **transaction** is a shipment from an old well pad  $\kappa$  to a new well  $\delta$ 
  - ▶ One transaction = one *truckload* of wastewater (110 barrels)
- ▶  $r_{\kappa\delta}^K$  and  $r_{\kappa\delta}^D$  are sender/receiver costs of reusing a truckload from  $\kappa$  at  $\delta$ , where:

$$r_{\kappa\delta} = r_{\kappa\delta}^K + r_{\kappa\delta}^D = \begin{cases} \text{Technological Cost} & \kappa \text{ and } \delta \text{ in same firm} \\ \text{Technological Cost} + \text{Transaction Cost} & \kappa \text{ and } \delta \text{ in rival firms} \end{cases}$$

- ▶ Technological costs: transportation, treatment, loading/unloading, ...

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- ▶ Technological costs: transportation, treatment, loading/unloading, ...
- ▶ **Intuition:** if  $r$  can be recovered from observed shipments, then:
  1. Within-firm shipments  $\Rightarrow$  technological costs
  2. Between-firm shipments  $\Rightarrow$  transaction costs

## Empirical framework: matching with transferable utility

- ▶ Truckloads of wastewater matched from old well pads  $K$  to new wells  $D$
- ▶ Joint costs of reuse divided via **transfers** determined in equilibrium:

$$r_{\kappa\delta} = \overbrace{r_{\kappa\delta}^K + p_{\kappa\delta}}^{\text{Sender's Costs}} + \overbrace{r_{\kappa\delta}^D - p_{\kappa\delta}}^{\text{Receiver's Costs}}$$

- ▶  $r$  is identified if water management decisions are **decentralized**
  - ▶ Shipment/receipt decisions made facility-by-facility, truckload-by-truckload
  - ▶ Price-taking firms minimize total cost across many decisions at once

## Supply: wastewater disposal as a discrete choice problem

- ▶  $Q_\kappa$  truckloads of wastewater are generated at  $\kappa$
- ▶ The operator at  $\kappa$  ships  $i$ th truckload to the least cost destination  $\delta$ :

$$\delta^* = \arg \min_{\delta \in D_0} r_{\kappa\delta}^K + p_{\kappa\delta} - \epsilon_{i\delta}$$

- ▶  $D_0 = D \cup \{0\}$  includes all new wells and the outside option (final disposal)
- ▶  $r_{\kappa\delta}^K + p_{\kappa\delta}$  is the sender's share of the joint costs of reuse at  $\delta$
- ▶  $\epsilon_{i\delta}$  is a truckload-specific, non-systematic latent cost (EV Type 1, dispersion  $\sigma_K$ )

## Demand: water acquisition as a discrete choice problem

- ▶  $C_\delta$  truckloads of water (wastewater or freshwater) are needed at  $\delta$
- ▶ The operator at  $\delta$  accepts  $j$ th truckload from the least cost source:

$$\kappa^* = \arg \min_{\kappa \in K_0} r_{\kappa\delta}^D - p_{\kappa\delta} - \eta_{\kappa j}$$

- ▶  $K_0 = K \cup \{0\}$  includes all producing wells and the outside option (freshwater)
- ▶  $r_{\kappa\delta}^D - p_{\kappa\delta}$  is the receiver's share of the joint costs of reusing wastewater from  $\kappa$
- ▶  $\eta_{\kappa j}$  is a truckload-specific, non-systematic latent cost (EV Type 1, dispersion  $\sigma_D$ )



## Equilibrium: local supply = local demand

- At  $p^*$ , markets clear **in expectation**. For all  $\kappa, \delta$ :

$$\begin{aligned}\mu_{\kappa\delta}^* &\equiv Q_\kappa \times P\left(\delta = \arg \min_{\delta' \in D_0} r_{\kappa\delta'}^K + p_{\kappa\delta'}^* - \epsilon_{i\delta'}\right) && \leftarrow \text{supply of } \kappa\text{-trucks to } \delta \\ &= C_\delta \times P\left(\kappa = \arg \min_{\kappa' \in K_0} r_{\kappa'\delta}^D - p_{\kappa'\delta}^* - \eta_{\kappa'j}\right) && \leftarrow \text{demand for } \kappa\text{-trucks at } \delta\end{aligned}$$

- $\mu_{\kappa\delta}^*$  is the expected mass of truckloads shipped from  $\kappa$  to  $\delta$  in equilibrium

## Identification: equilibrium as a convex program

- Galichon and Salanie (2022): the unique equilibrium  $\mu^*$  satisfies:

$$\begin{aligned} \min_{\mu \geq 0} \quad & \sum_{\kappa \in K} \sum_{\delta \in D} \mu_{\kappa\delta} r_{\kappa\delta} + \mathcal{E}(\mu, \mathbf{Q}, \mathbf{C}) \\ \text{s.t.} \quad & \sum_{\delta \in D} \mu_{\kappa\delta} \leq Q_{\delta} \quad \forall \kappa \in K \\ & \sum_{\kappa \in K} \mu_{\kappa\delta} \leq C_{\delta} \quad \forall \delta \in D \end{aligned}$$

- $\mathcal{E}$  is a convex **match entropy** function that depends on distributions of  $\epsilon$  and  $\eta$
- $r$  is identified by the gradient of  $\mathcal{E}$  at the equilibrium match  $\mu^*$ :

$$r_{\kappa\delta} - \frac{\partial \mathcal{E}(\mu^*, \mathbf{Q}, \mathbf{C})}{\partial \mu_{\kappa\delta}} = 0$$

# Parameterization

$$r_{\kappa\delta} = \begin{cases} \overbrace{d_{\kappa\delta} + x'_{\kappa\delta}\beta + \zeta_{\kappa}^{\mathcal{I}} + \zeta_{\delta}^{\mathcal{I}}}^{\text{Technological Cost}} & \kappa \text{ and } \delta \text{ in same firm} \\ d_{\kappa\delta} + x'_{\kappa\delta}\beta + \zeta_{\kappa}^{\mathcal{I}} + \zeta_{\delta}^{\mathcal{I}} + \underbrace{z'_{\kappa\delta}\alpha + \pi_b}_{\text{Transaction Cost}} & \kappa \text{ and } \delta \text{ in rival firms} \end{cases}$$

- ▶  $d_{\kappa\delta}$  represents distance-related costs (over-the-road shipping distance)
- ▶  $x_{\kappa\delta}$  is a vector of observable transaction characteristics (e.g., fluid composition)
- ▶  $\zeta_{\kappa}^{\mathcal{I}}$  and  $\zeta_{\delta}^{\mathcal{I}}$  are unobserved, additively separable costs of reuse within the firm
- ▶  $z_{\kappa\delta}$  is a vector of transaction characteristics (e.g., facility-type interactions)
- ▶  $\pi_b$  is an unobserved friction for firm pair  $b$

## Identification (cont)

- Data reveals  $\mu^* \Rightarrow$  system of  $|K| \times |D|$  linear equations:

$$d_{\kappa\delta} + x'_{\kappa\delta}\beta + \tilde{\zeta}_{\kappa}^{\mathcal{I}} + \tilde{\zeta}_{\delta}^{\mathcal{I}} + z'_{\kappa\delta}\alpha + \pi_b - \sigma_K \log \left\{ \frac{\mu_{\kappa 0}^*}{\mu_{\kappa\delta}^*} \right\} - \sigma_D \log \left\{ \frac{\mu_{0\delta}^*}{\mu_{\kappa\delta}^*} \right\} = 0$$

- $\beta, \zeta, \alpha, \pi, \sigma$  are identified if system is invertible

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- $\beta, \xi, \alpha, \pi, \sigma$  are identified if system is invertible
- In practice: freshwater usage  $\mu_{0\delta}^*$  is poorly observed
  - Partial identification of  $\xi$  and  $\sigma$  is possible with shipments-for-reuse alone

# Estimation

- ▶ For a given  $\theta = (\beta, \xi, \alpha, \pi, \sigma)$ , can compute the equilibrium match  $\mu(\theta)$ 
  - ▶  $\mu_{\kappa\delta}(\theta) \propto$  equilibrium prob. of observing a shipment from  $\kappa$  to  $\delta$
- ▶ Maximum likelihood estimator (shipments for reuse only):

$$\hat{\theta} = \arg \max_{\theta \in \Theta} \sum_{\kappa \in K} \sum_{\delta \in D} \hat{\mu}_{\kappa\delta} \log \left( \frac{\mu_{\kappa\delta}(\theta)}{\sum_{\kappa\delta} \mu_{\kappa\delta}(\theta)} \right)$$

- ▶ Standard MLE inference: one observation = one truckload

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- ▶ Standard MLE inference: one observation = one truckload
- ▶ In practice: pool data from many markets (one month = one market)
  - ▶ Assumption:  $\beta$ ,  $\alpha$ ,  $\pi$ ,  $\sigma$  are fixed across months, while  $\zeta$  adjusts

Setting

Model

**Estimates**

Spillovers

Conclusion



## Estimated transaction costs

- Summary stats ( $\mu$ -weighted):

	Est (miles)	SE	\$/bbl
Mean	125.7	0.07	5.71
Std Dev	48.1	0.09	2.18

- Mean transaction cost is equivalent to the cost of shipping a truck 125.7 extra miles
- \$5/mile trucking costs  $\Rightarrow$  \$5.71 per barrel of wastewater

Dispersion

Inverse CDF

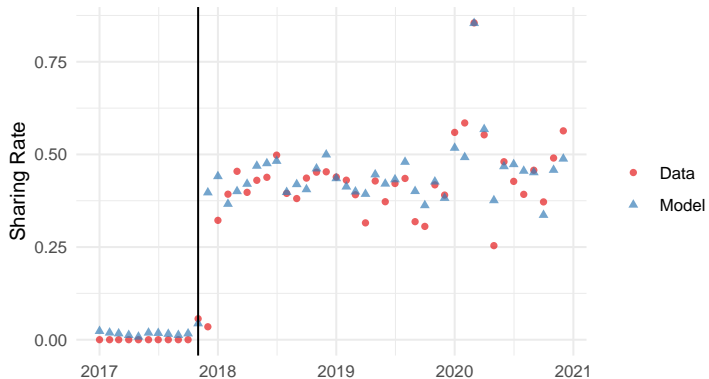
Full Estimates

# How large are transaction costs?

- ▶ Transaction costs have **direct** and **indirect** effects on firms:
  1. \$22M/year in **incurred transaction costs**
  2. \$27M/year in **excess technological costs**
- ▶ In comparison, water-related private costs are roughly \$550M/year
  1. \$400M/year in freshwater sourcing costs
  2. \$125M/year in reuse costs (transport + transaction costs only)
  3. \$25M/year in final disposal costs

## Model fit: EQT-Rice merger

- EQT-Rice “sharing” rate pre- and post-merger



More

## Sources of transaction costs

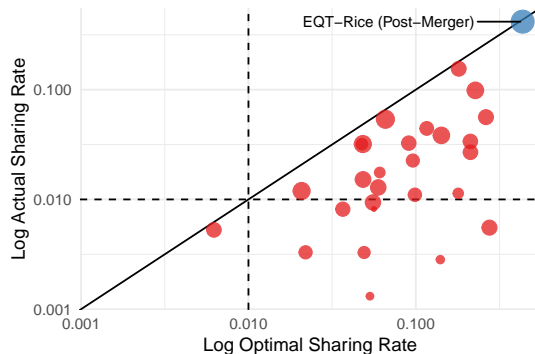
	Est (miles)	SE	\$/bbl
Sharing market cost shifters $\alpha$			
rival $\times$ poor $\rightarrow$ good env record	-	-	-
rival $\times$ good $\rightarrow$ poor env record	8.5	0.11	0.39
rival $\times$ gel $\rightarrow$ slickwater	-28.6	0.10	-1.30
rival $\times$ slickwater $\rightarrow$ gel	85.3	3.00	3.88
...			
Relationship fixed effects $\pi_b$			
mean	117.9	0.07	5.36
std dev	49.2	0.09	2.23

- $\alpha$  estimates provide evidence of **contracting frictions**
  - Inter-operator environmental liability, information frictions

Full Estimates

# Limited trade within relationships

- Actual vs. no-friction bilateral sharing rates:



- Evidence of dynamic frictions? Ex ante coordination vs. ex post opportunism
  - Difficult to communicate future fracking plans, commit to delivery schedules

# Policy implications

1. To encourage sharing, improve the contracting environment
  - ▶ Liability rules / shields (e.g., Oklahoma)
  - ▶ Disclosure of wastewater composition
  - ▶ Public pre-registration of fracking activity
  - ▶ ...
2. Interventions that ignore contracting fundamentals may fail
  - ▶ Digital platforms (i.e., Uber for wastewater)

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# Transaction costs and sustainability

- ▶ Do transaction costs substantially worsen environmental impacts?
- ▶ Potential impacts of transaction costs:
  1. **Extensive margin:** more freshwater usage, more final disposal
  2. **Intensive margin:** longer shipments, longer storage durations



# Key sources of external costs

## 1. **Freshwater consumption** (approx. \$52M/year)

- ▶ 26,000 acre-feet/year  $\times$  \$2,000/acre-foot (seawater desalination cost)

## 2. **Wastewater transportation** (approx. \$7M/year)

- ▶ 500,000 truckloads/year  $\times$  30.0 miles/truckload
- ▶ \$3.4M CO<sub>2</sub> (EPA Social Cost of Carbon); \$3.3M NO<sub>x</sub>, PM<sub>2.5</sub> (EASIUR)
- ▶ Not included: at least 1-2 trucking-related wastewater spills per year

# Bounding external cost spillovers from transaction costs

## 1. **Freshwater consumption:** $\leq \$1.2\text{M}/\text{year}$

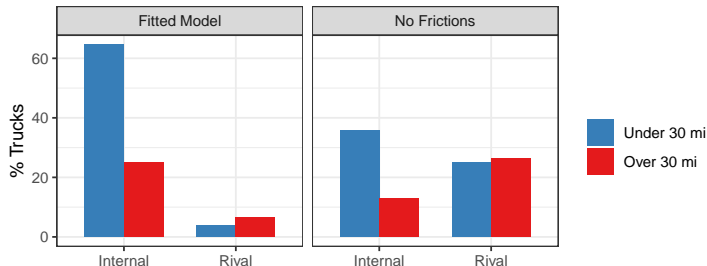
- ▶ 100% reuse  $\Rightarrow$  (tight) upper bound on excess freshwater consumption
- ▶ Transaction costs increase FW consumption by less than 2.2%

## 2. **Wastewater transportation:** $\leq \$1.8\text{M}/\text{year}$

- ▶ Minimum distance benchmark  $\Rightarrow$  (loose) upper bound on excess transportation
- ▶ Transaction costs increase transport by less than 25%

# Transaction costs can limit transportation

- Fitted model vs. counterfactual (holding extensive margin fixed):



- Here: transaction costs **decrease** transportation by 15% (roughly \$1M/year)

Illustration

Details

# Optimal regulation

- ▶ In paper: derivation of Pigouvian allocation (i.e., argmin of social costs)
  - ▶ May be costly, difficult to implement, and could worsen environmental impacts
  
- ▶ Key questions:
  1. Can one-time interventions permanently eliminate transaction costs?
  2. Are transaction costs “real,” welfare-relevant costs, or behavioral distortions?
  3. What is the social planner able to infer about transaction costs?

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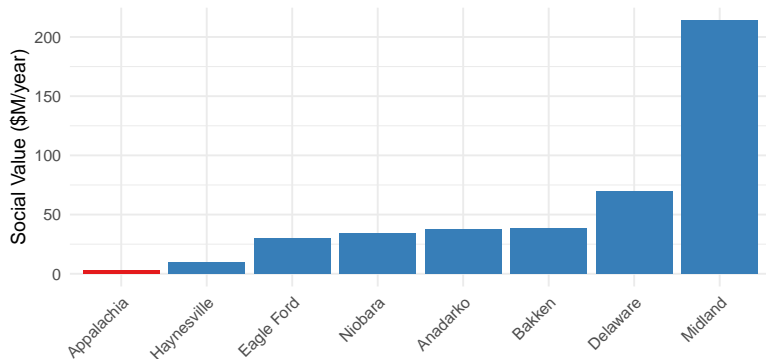
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## Excess freshwater consumption outside Appalachia

- ▶ Across major basins, expanded reuse can save over 200,000 acre-feet/year
  - ▶ Social value on the order of \$400M/year, valued at desalination costs



# Final thoughts

- ▶ New evidence on transaction costs from a unique setting
  1. Transaction costs are large, but heterogeneous
  2. Contracting frictions appear to play an outsized role
- ▶ Generic empirical framework for wastewater policy evaluation
  - ▶ Applicable in other US basins with different economics (Permian, Bakken, ...)
  - ▶ Applicable in non-US basins (Vaca Muerta, Sichuan, ...)
- ▶ In PA: private costs are significant, environmental impacts are modest

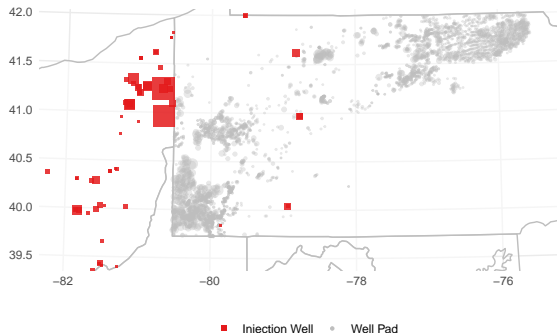
► Thank you!

► Questions/comments: [mfokeefe@u.northwestern.edu](mailto:mfokeefe@u.northwestern.edu)



## Conventional disposal and reuse

- In Pennsylvania, injection well capacity severely limited by geology, regulation



- Due to high transportation costs, 89% of wastewater is **reused** in subsequent fracking
  - Minimal treatment required  $\Rightarrow$  cost of reuse  $\approx$  cost of transportation

# Sharing patterns among twenty largest firms

1. Most firms share. In the average month:
  - ▶ 9.5 firms sent wastewater to a rival
  - ▶ 7.0 firms received wastewater from a rival
  - ▶ 3.3 firms did both
2. 58/190 pairs of firms ever shared during sample
  - ▶ 49/99 among those operating wells in the same county (98% of volume)
3. Sharing between counterparties is often infrequent
  - ▶ On average: 3.7 months per year among same-county firms that ever shared

# Full estimates

	Est	SE	\$/bbl
Mean $\phi_{\kappa\delta}$			
weighted by data	125.7	0.072	5.71
weighted by benchmark	154.2	0.081	7.01
Sharing market cost shifters $\alpha$			
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rival $\times$ slickwater $\rightarrow$ gel	85.3	2.996	3.88
rival $\times$ large $\kappa \rightarrow$ well pad	-	-	-
rival $\times$ large $\kappa \rightarrow$ CTF	25.2	0.044	1.15
rival $\times$ small $\kappa \rightarrow$ well pad	4.4	0.151	0.20
rival $\times$ small $\kappa \rightarrow$ CTF	29.6	0.261	1.35
Within-firm cost shifters $\beta$			
gel $\rightarrow$ slickwater	6.7	0.092	0.31
slickwater $\rightarrow$ gel	-8.7	0.046	-0.39
small $\kappa \rightarrow$ CTF	-5.7	0.129	-0.26
$\sigma_{\kappa} + \sigma_{\delta}$	22.5	0.006	1.02

## Match entropy function

$$\mathcal{E}(\mu, \mathbf{Q}, \mathbf{C}) = -G^*(\mu, \mathbf{Q}) - H^*(\mu, \mathbf{C})$$

- $G^*(\mu, n)$  is the generalized entropy of choice for disposal

$$G^*(\mu, \mathbf{Q}) = \sup_{U \in \mathbb{R}^{K \times D}} \left( \sum_{\kappa \in K} \sum_{\delta \in D} \mu_{\kappa\delta} U_{\kappa\delta} - \sum_{\kappa \in K} Q_{\kappa} E \left[ \max_{\delta \in D_0} U_{\kappa\delta} + \epsilon_{i\delta} \right] \right)$$

- $H^*(\mu, m)$  is the generalized entropy of choice for reuse

$$H^*(\mu, \mathbf{C}) = \sup_{V \in \mathbb{R}^{K \times D}} \left( \sum_{\kappa \in K} \sum_{\delta \in D} \mu_{\kappa\delta} V_{\kappa\delta} - \sum_{\delta \in D} C_{\delta} E \left[ \max_{\kappa \in K_0} V_{\kappa\delta} + \eta_{\kappa j} \right] \right)$$

## Match entropy function (cont)

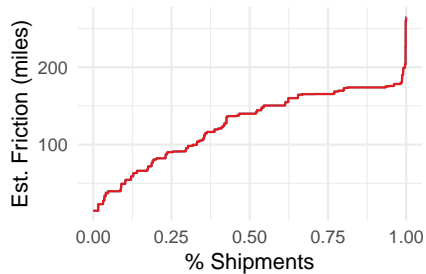
- For  $\epsilon$  and  $\eta$  EV type 1,

$$\begin{aligned}\mathcal{E}(\mu, \mathbf{Q}, \mathbf{C}) = & - \sum_{\kappa, \delta} \mu_{\kappa\delta} \left\{ \sigma_K \log \left( \frac{\mu_{\kappa\delta}}{Q_\kappa} \right) + \sigma_D \log \left( \frac{\mu_{\kappa\delta}}{C_\delta} \right) \right\} \\ & - \sigma_K \sum_k \mu_{k0} \log \left( \frac{\mu_{k0}}{Q_k} \right) - \sigma_D \sum_\delta \mu_{0\delta} \log \left( \frac{\mu_{0\delta}}{C_\delta} \right)\end{aligned}$$

Back

# Estimated transaction cost distribution

- Inverse CDF ( $\mu$ -weighted):



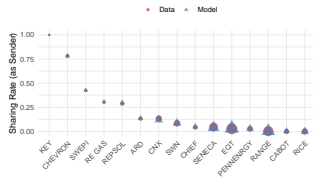
Back

## Private cost assumptions

1. Freshwater costs: \$2.15/bbl
  - ▶ Source: EQT-Rice Investor Presentation
2. Reuse costs: \$5/mile transport costs + estimated transaction costs
  - ▶ For CTFs: use estimated re-shipment distances (described in paper)
3. Final disposal cost: \$5/mile transport costs + \$2/bbl disposal fee
  - ▶ Source: low end of quoted numbers (interview)

# Model fit

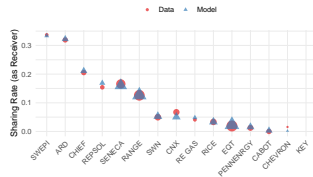
Sharing Rate (as sender, by firm)



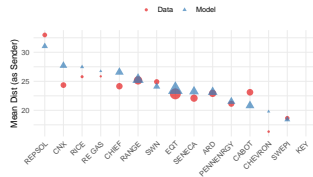
Mean Dist (as sender, by firm)



Sharing Rate (as receiver, by firm)



Mean Dist (as receiver, by firm)





## Dispersion estimates

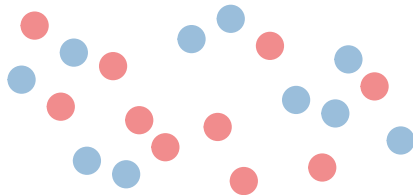
- Point estimate for dispersion:

	Est (miles)	SE	\$/bbl
$\sigma_K + \sigma_D$	22.5	0.01	1.02

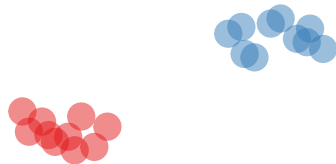
- Counterfactuals:

	Mean Dist (mi)	Share %
Data	24.86	10.60
Fitted model	24.86	10.58
$\sigma_K + \sigma_D \rightarrow 0$	21.61	9.72
$\sigma_K + \sigma_D \rightarrow \infty$	146.99	84.37

## Ambiguous effects of reducing transaction costs



● Firm 1   ● Firm 2

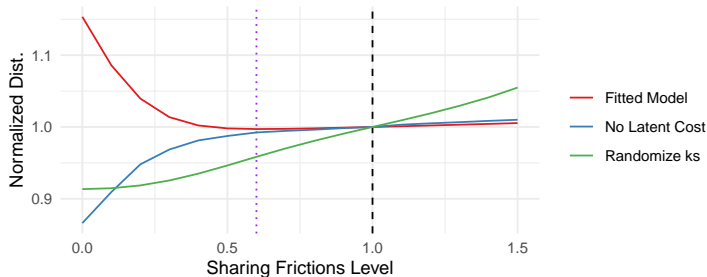


● Firm 1   ● Firm 2

Back

# Transaction costs and transportation

- Proportional re-scaling of transaction costs:



- In fitted model, removing transaction costs *increases* shipment distance by 15%
- Why? Non-random distribution of firms + matching on non-transport costs
  - As  $\phi$  shrinks, marginal matches tend to be further away

# Pigouvian regulation

- Socially optimal (Pigouvian) shipment plan  $\mu^*$  solves:

$$\min_{\mu \in \mathcal{M}(Q, C)} \Gamma(\mu) + C(\mu)$$

- $\Gamma(\mu)$  represents external costs under shipment plan  $\mu$
- $C(\mu)$  represents private costs under  $\mu$
- **Question:** should sharing frictions  $\phi$  count towards  $C(\mu)$ ?

# Are sharing frictions welfare-relevant?

- ▶ Familiar distinction from consumer markets (e.g., switching costs)
  - ▶ Some “costs” may be relevant to decisionmakers, but not the social planner
- ▶ Examples of welfare-relevant sharing frictions:
  - ▶ Wages expended in finding out about sharing opportunities
  - ▶ Wages expended in haggling / bargaining / price discovery
  - ▶ Quantifiable risks to future profits (e.g., risk of lawsuits)
  - ▶ ...
- ▶ Examples of welfare-irrelevant sharing frictions:
  - ▶ Managerial inattention / status quo bias, loss aversion, excessive secrecy, ...

## Pigouvian regulation (cont)

- ▶ Let  $s \in [0, 1]$  index the welfare-relevance of sharing frictions:
- ▶  $s\phi$  is welfare-relevant and  $(1 - s)\phi$  is not
  - ▶  $s = 0$  if sharing frictions are entirely welfare-irrelevant
  - ▶  $s = 1$  if sharing frictions are entirely welfare-relevant
- ▶ Socially optimal (Pigouvian) shipment plan  $\mu_s^*$  solves:

$$\min_{\mu \in \mathcal{M}(Q, C)} \Gamma(\mu) + C_s(\mu)$$

- ▶  $\Gamma(\mu)$  represents external costs under shipment plan  $\mu$
- ▶  $C_s(\mu)$  represents welfare-relevant component of private costs under  $\mu$

## Pigouvian tax rates

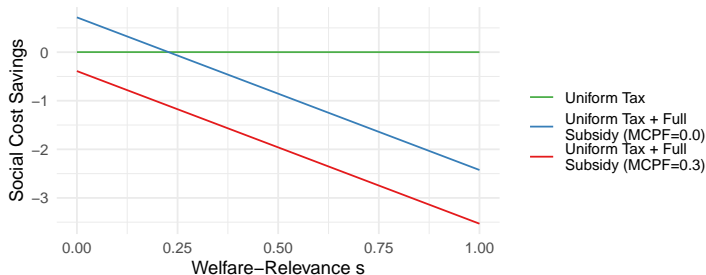
- ▶ Hypothetical policy response: Pigouvian tax on truck-miles
- ▶ Holding volume fixed,  $\mu^*$  can be implemented with a tax on truck-miles:

$$tax_{\kappa\delta}^{(s)} = \gamma - (1 - s) d_{\kappa\delta}^{-1} \phi_{\kappa\delta}$$

- ▶  $\gamma$  is the marginal external cost of trucking (calibrate to 7%)
  - ▶ If  $s < 1$ , uniform tax + sharing subsidies is optimal
  - ▶ If  $s = 1$ , uniform tax is optimal
- ▶ Two inference problems: for optimal tax, regulator needs to know  $\phi_{\kappa\delta}$  **and**  $s$ 
  - ▶ In many settings  $\phi_{\kappa\delta}$  (or an equivalent parameter) is identified, but  $s$  is not
    - ▶ Standard practice: argue  $s = 0$  or  $s = 1$  is more correct, check robustness
  - ▶ Even if firms knew  $s$ , would have incentives to shade (for larger subsidies)

## Social cost savings and regret

- Change in social costs vs. status quo (\$/bbl):



- Sharing subsidies can reduce social costs by \$0.72 per barrel vs. uniform tax, **but:**
  1. Unnecessary subsidies can increase social costs by \$2.43 per barrel (before MCPF)
  2. Not cost-effective for reasonable MCPF values
  3. External costs are increased by 13.5% (not shown)