HARVARD ENVIRONMENTAL ECONOMICS PROGRAM

Research Workshop
for
Pre-Doctoral Fellows and Alumni

Thursday-Friday, September 19 – 20, 2019
Harvard Kennedy School
Cambridge, Massachusetts

Dynamic Behavior and Strategic Interactions Among Petroleum Producers

C.-Y. Cynthia Lin Lawell
(Ph.D. in Economics, 2006)
Cornell University

Harvard Environmental Economics Program Research Workshop
September 2019

The world petroleum market is extremely important …

Source: `peakoil.com`

The world petroleum market is extremely important …

Source: `peakoil.com`

The world petroleum market is extremely important …

Source: `peakoil.com`

… The world petroleum market is highly controversial …

Source: www.arabianbusiness.com

… The world petroleum market is highly controversial …

Source: www.arabianbusiness.com

The production and consumption of oil and natural gas raise concerns about:

- air pollution
- climate change
- fossil fuel price volatility
- energy security
- fossil fuel scarcity

… AND The world petroleum market is notoriously complex.

Source: www.dispatchtribunal.com

… AND The world petroleum market is notoriously complex.

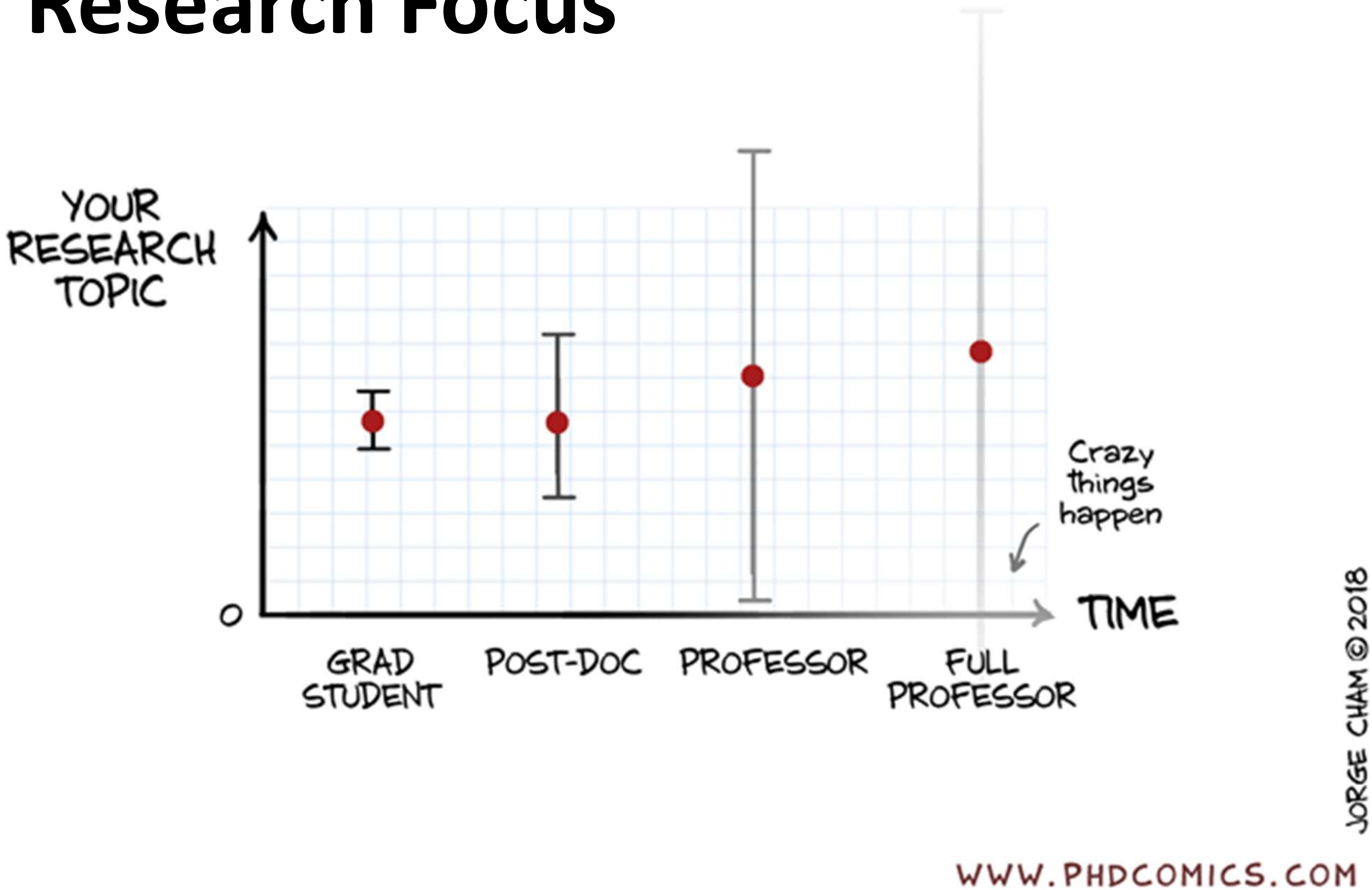
Source: www.dispatchtribunal.com

- Many observers regard the world oil market as a puzzle
- Detailed data, particularly from state-owned firms, is difficult to obtain
- OPEC strategy and whether OPEC behaves as a cartel remains a mystery

Research Objectives

- Develop and estimate a parsimonious model of the notoriously complex world oil market that generates results that align with economic theory and previous assessments of the industry
  - Structural econometric model of a dynamic game incorporates the dynamic behavior and strategic interactions among petroleum-producing firms
- Use the model to assess the effects of counterfactual scenarios on the industry
- Design environmental policies that maximize net benefits to society

Research Focus



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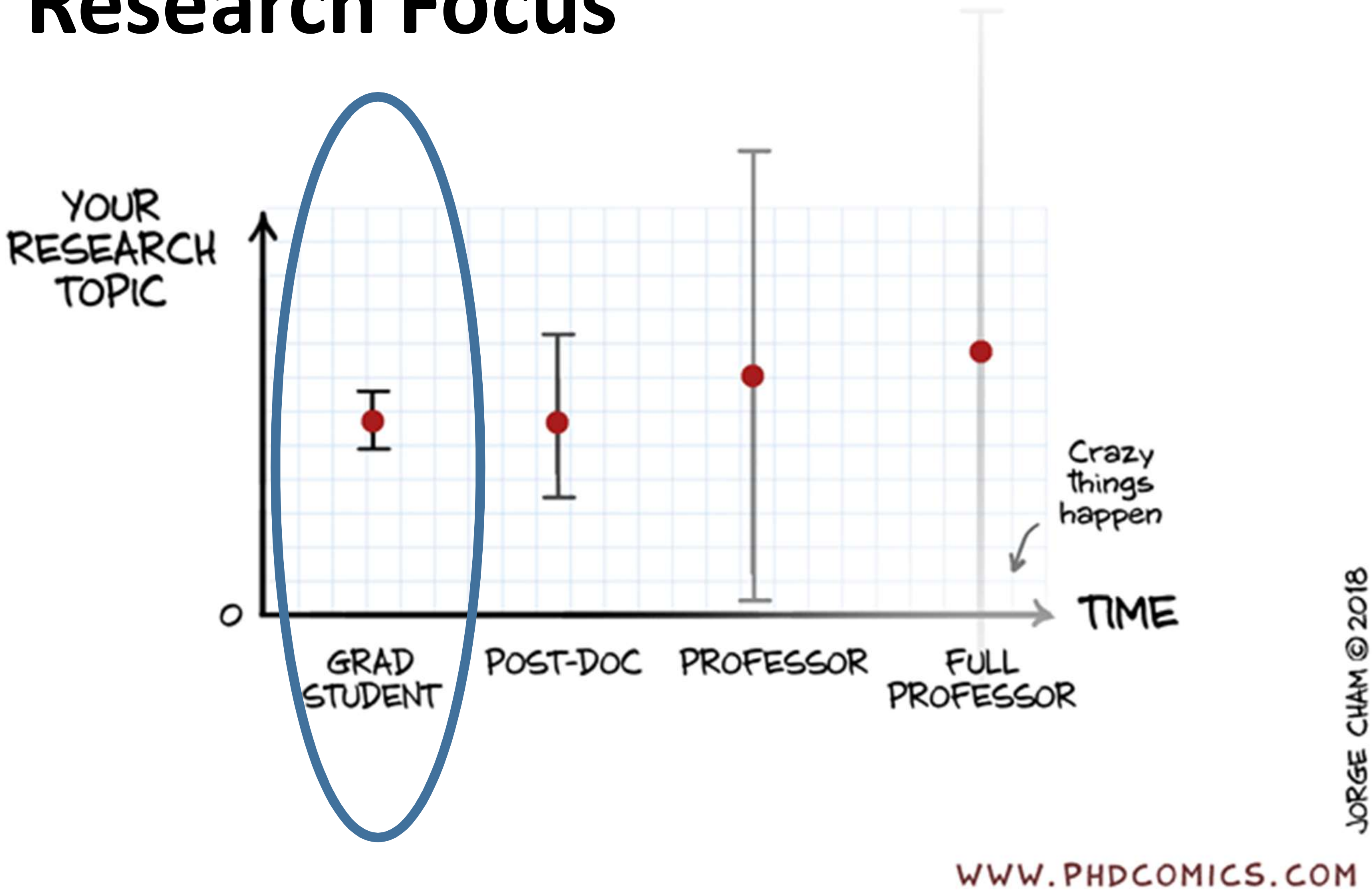
Research Focus



Source: `http://phdcomics.com/comics/archive.php?comicid=2031`

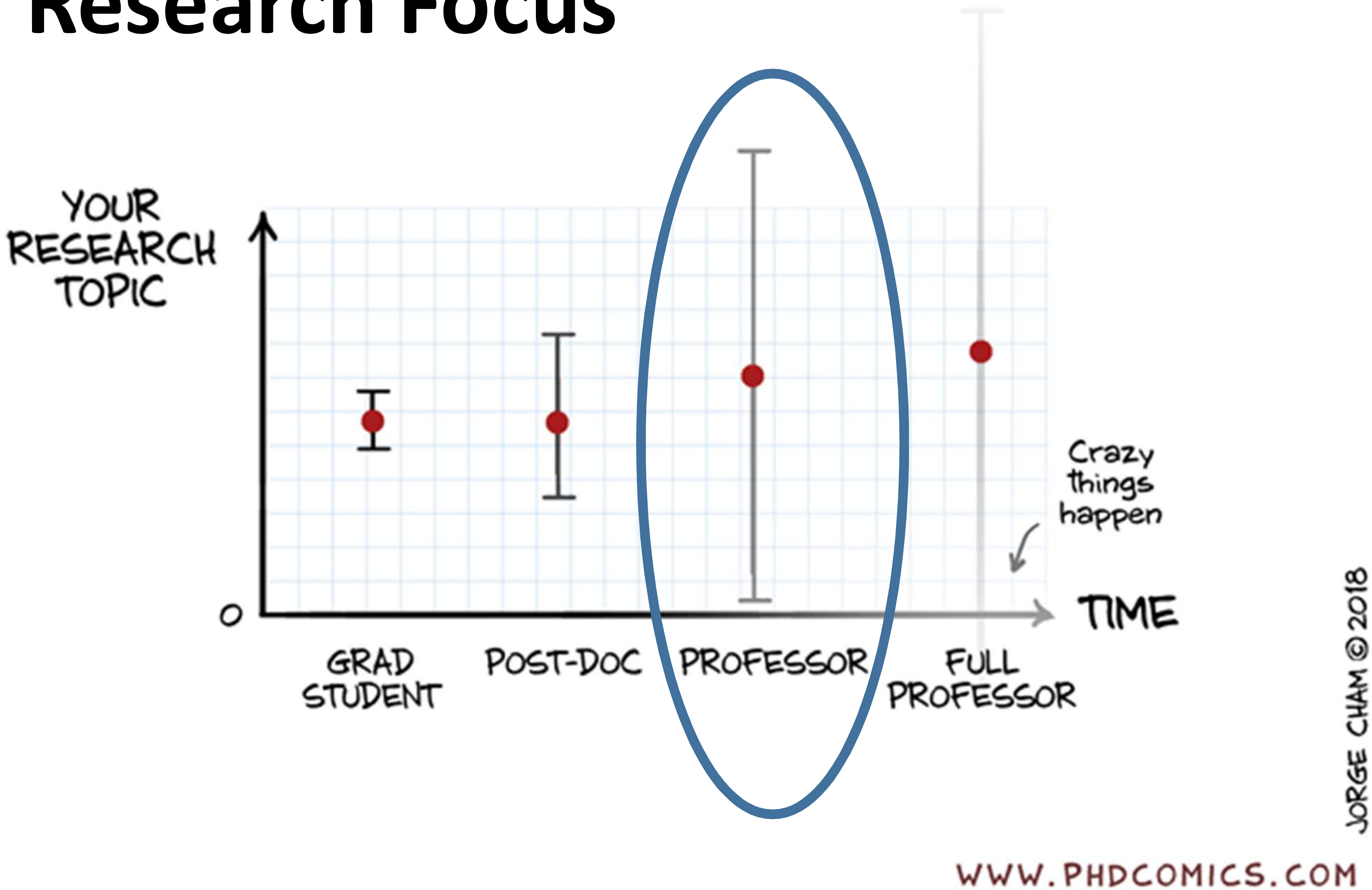
Ph.D. Research

C.-Y. Cynthia Lin. (*RESTAT*, 2013).

Strategic decision-making with information and extraction externalities: A structural model of the multi-stage investment timing game in offshore petroleum production.

Review of Economics and Statistics, 95 (5), 1601-1621.

Research Focus



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Ongoing Research

A Structural Econometric Model of the Dynamic Game Between Petroleum Producers in the World Petroleum Market

Khaled H. Kheiravar
California Air Resources Board

C.-Y. Cynthia Lin Lawell
Cornell University

Amy Myers Jaffe
Council on Foreign Relations

Dynamic Game
(Kheiravar, Lin Lawell and Jaffe, 2019)

- Petroleum-producing firms make decisions about:
  - Production
  - Investment
  - Mergers and acquisitions

- We allow firms that are at least partially state-owned to have objectives other than profit maximization alone.

- Equilibrium concept:
  - Markov Perfect Equilibrium

Econometric Estimation
(Kheiravar, Lin Lawell and Jaffe, 2019)

- Step 1:
  - Estimate world oil demand and regional natural gas demand
  - Estimate policy functions for the firms' decisions regarding exploration, development, production, mergers, and acquisitions
  - Estimate the transition density for the state variables
- Step 2:
  - We find the parameters that minimize profitable deviations from the optimal strategy as given by the policy functions estimated in the first step
- *Innovation:*
  - Value functions are interdependent owing to the possibility of mergers and acquisitions
  - A firm's value function depends on the expected value of other firms with which it has the option to merge or acquire
  - We address the endogeneity of value functions using a fixed point algorithm

Data
(Kheiravar, Lin Lawell and Jaffe, 2019)

- We apply our model to annual firm-level panel data on the top 50 oil and natural gas producing firms in the world

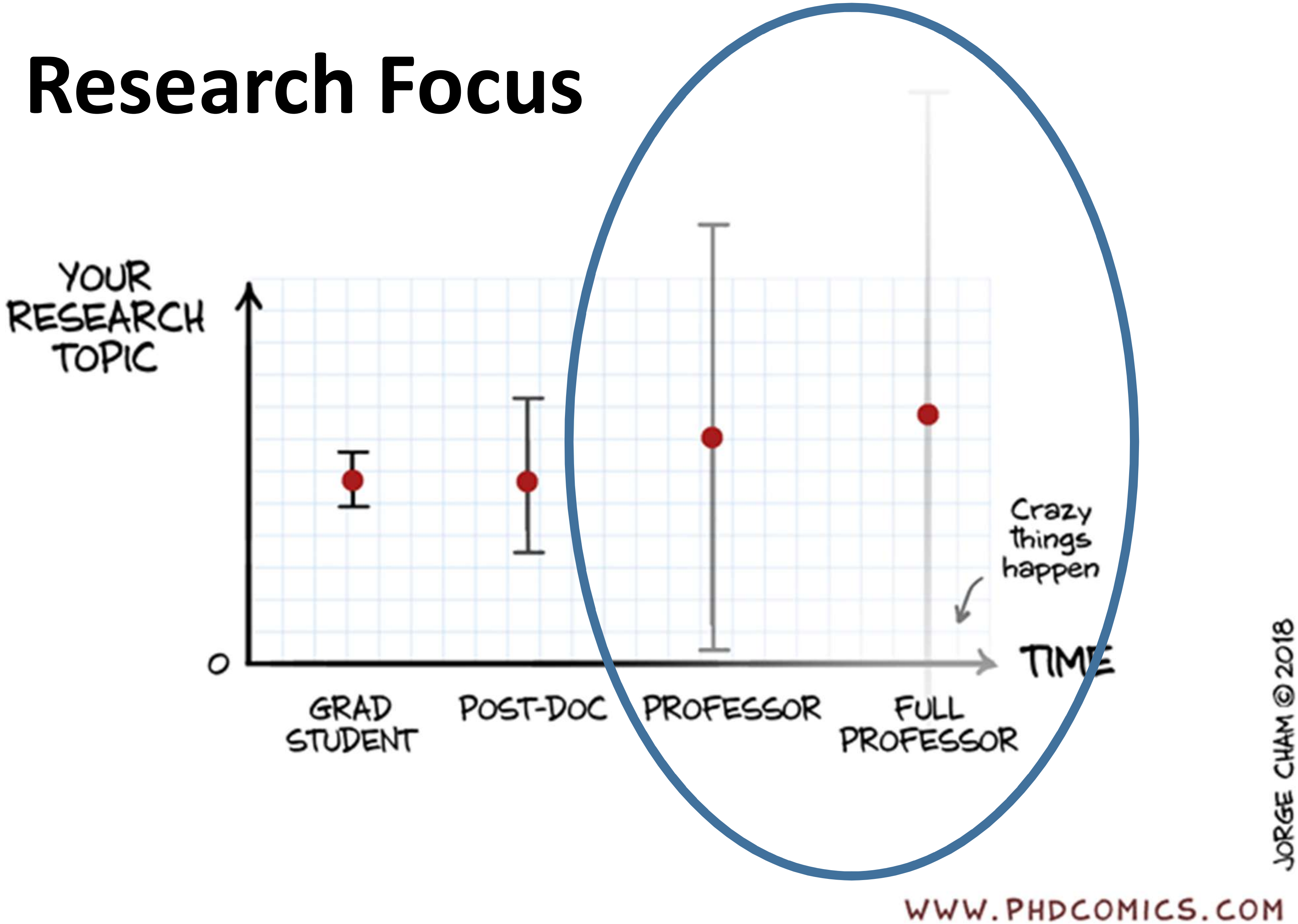
Results
(Kheiravar, Lin Lawell and Jaffe, 2019)

- Our parsimonious model of the notoriously complex world oil market generates results that align with economic theory and previous assessments of the industry.
- Although we do not assume or impose that OPEC producers collude to maximize joint profits, but instead infer their strategy and payoffs from the data, we find that OPEC behaves in such a way that is consistent with its mission and also with cartel behavior.

Future Research

- We hope to extend our model to incorporate environmental externalities arising from oil and natural gas production and consumption
- Enable us to simulate and analyze sophisticated counterfactual scenarios regarding global environmental policy
- Design environmental policies that maximize net benefits to society.

Research Focus



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Disclosure Policy and Investment in Oil and Gas Exploration

Thomas R. Covert [1] Richard L. Sweeney [2]

September 2019

[1]Chicago Booth
[2]Boston College

Information spillovers make competitive exploratory drilling inefficient. Could secrecy solve this problem?

- Resources are uncertain, spatially correlated, and can only be learned by drilling. When competitors are neighbors, there will be a free riding problem:
    - I want Rich to drill first, to see what happens in his well
    - … but he wants me to go first!
- Hendricks & Kovenock (RAND, 1989) analyzed this problem, and found that competing firms can't invest as efficiently as a planner would.
- Common policy solution to free riding: let firms keep **secrets**
- Our goal: in theory terms, does secrecy help? Does it look like it did in a natural experiment?

Hendricks and Kovenock (1989) in a nutshell

- Two firms (τ, ρ) own adjacent parcels
- Each receives a private signal (s) about the underlying resource quality (X)
- Chose to drill in period 1 or period 2 (or let lease expire)
- If τ waits, and ρ drills in period 1, τ observes X, and can make an efficient drilling decision in period 2

Equilibrium play has a straight-forward symmetric Bayes Nash equilibrium

In equilibrium, there are cutoffs $s_1 > s_2$:

- In period 1, τ drills if $s > s_1$
- If τ doesn't drill in period 1, but ρ does, τ observes X and makes efficient investment decision in period 2.
- If ρ doesn't drill, τ drills in period 2 if $s > s_2$

This is *inefficient* relative to what a planner would do with control and knowledge of both signals.

We adapt HK model to allow for incomplete social learning

- Under well confidentiality laws ρ can keep X a secret if it drills in period 1
- Since drilling itself is likely too noticeable to hide, τ still learns something about ρ's *signal*
- We solve for symmetric Bayes Nash equilibria in this revised game

What happens if Rich, ρ, and/or Thom, τ, are allowed to keep their observation of X a secret?

- With secrecy, equilibrium play still has a cut-off structure
  - again, drill early if $s >= t_1$, but $t_1 < s_1$
  - if one player drills early, and the other doesn't, laggard makes a **risky** second period decision, if $s >= t_2$, with $t_2 < s_2$
  - if no one drills early, drilling **never** happens
- Intuition: gains to waiting are lower if you learn less, but if you saw your competitor wait, that is worse news than before
- Theorem: there is more and earlier drilling when firms can keep their drilling results secret
- *Almost* a theorem: secrecy is less efficient than no secrecy. Some free-riding might be better than none.

How might secrecy affect the market for drilling rights?

- Competition creates efficiency losses, even without secrecy. Might secrecy affect the likelihood of separate vs. concentrated ownership of drilling rights?
- Our intuition: because secrecy *decreases* the benefits of being a drilling right owner in a competitive drilling game, it might reduce the incidence of separate ownership in the first place.
- If a firm wins both leases P% of the time, generating total value V^E, and otherwise generating V^C, then the expected value is:

$$PV^E + (1 - P)V^C$$

Value of secrecy depends on its effects on P and V^C

Natural Experiment on Secrecy in Appalachian Shale Basins

- Most states allow *short* secrecy periods: 3 months - 1 year. Pennsylvania used to allow firms to keep production secret for **5 years**.

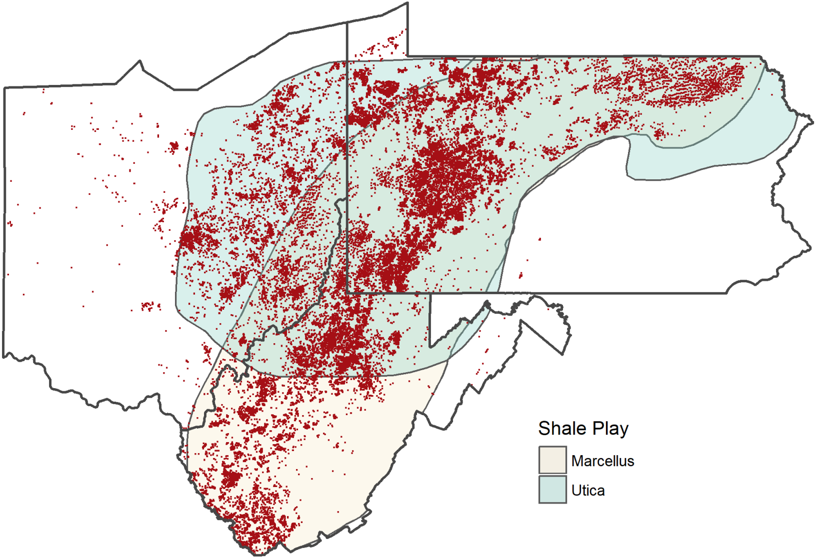
- In 2010, the Pennsylvania revised their secrecy rule, bringing it in line with similar rules in West Virginia and Ohio, states which share both borders and shale formations with Pennsylvania.

- Empirical question: what is the causal effect of secrecy on the value (gas revenues minus drilling costs) of shale gas exploration and production?
  - Use data on *leasing* and *drilling* to capture effects of secrecy on both the allocation of drilling rights, and, conditional on those, the efficiency of drilling.

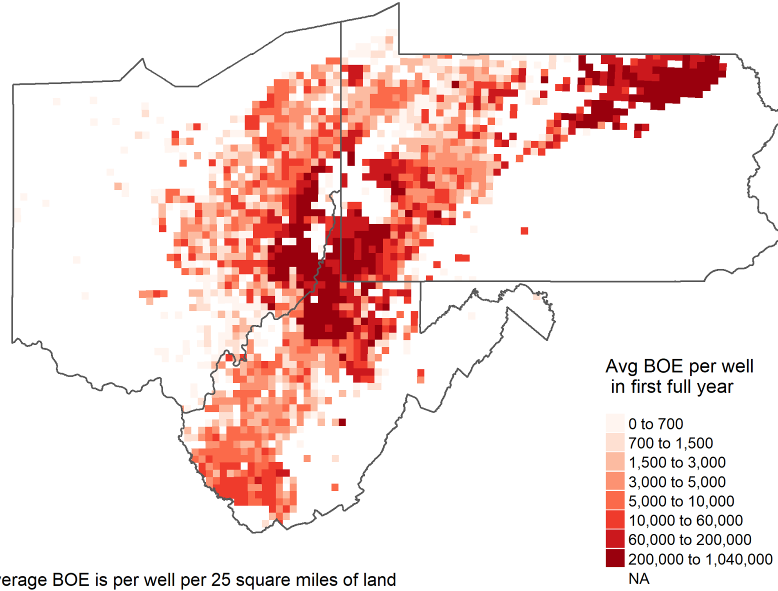
Data and empirical strategy

- PA confidentiality 5 years until 2010, then effectively 1.
- OH (6 months) and WV (1 year) unchanged.
- $\sim 500,000$ leases from DrillingInfo and Jim Bourbeau (largest land services company in Appalachia)
  - Shape, date, location, lessee/lessor, assignments...
- Difference in differences estimates: compare leasing, drilling and output within a shale basin, across states, before and after law change.
- Triple diffs: *conditional* on allocation of leases, compare drilling and output in split vs. common ownership cases

Plenty of Drilling/Leasing in Appalachia

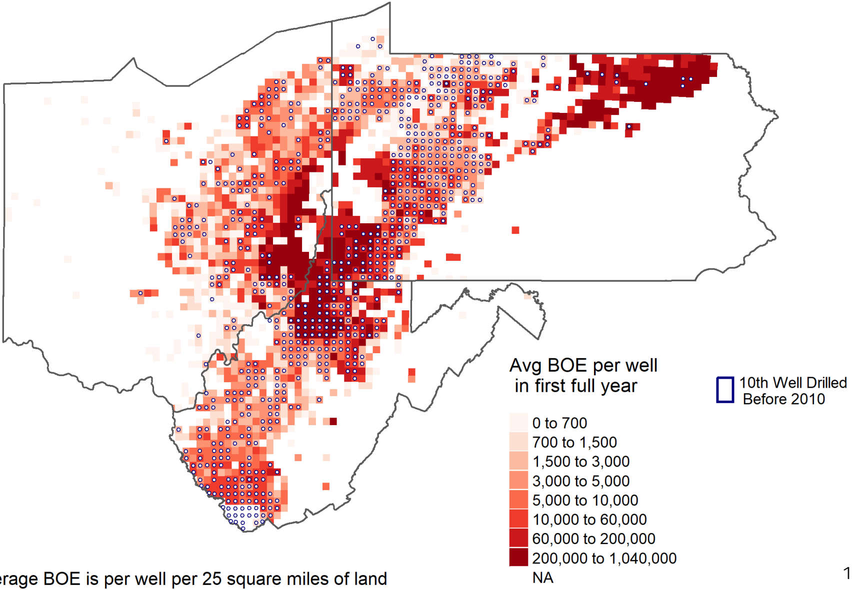


Plenty of Resource Heterogeneity



*Average BOE is per well per 25 square miles of land

Plenty of Resource *Uncertainty*



*Average BOE is per well per 25 square miles of land

Summary

- Strategic incentives reduce social welfare in environments with informational spillovers and costly investment, like oil and gas exploration.
- We extend a model of perfect social learning to one where information revelation is incomplete, find that secrecy (probably) reduces welfare further, conditional on split ownership.
- Have a plan to take the model to data in Pennsylvania.
- Research has implications as shale boom continues to play out globally.

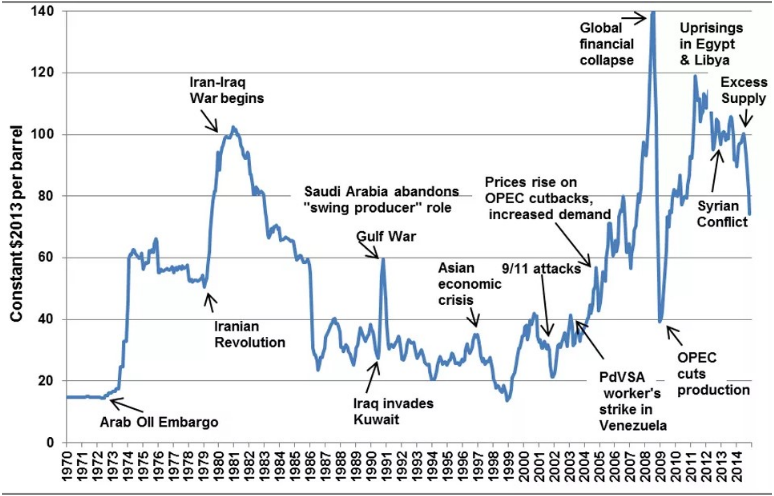
Oil Price Episodes and the U.S. Economic Production Network

Stuart Iler

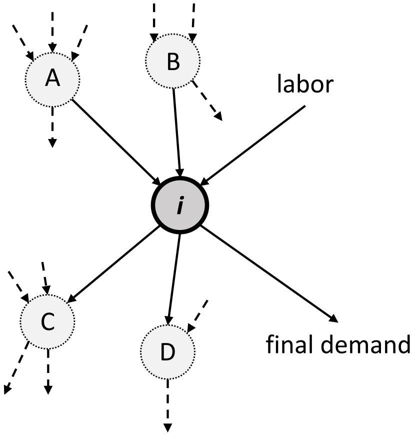
HEEP Research Workshop

September 20, 2019

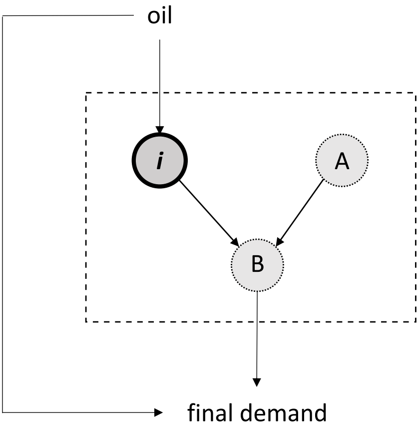
U.S. Department of Energy: Historical Oil Prices



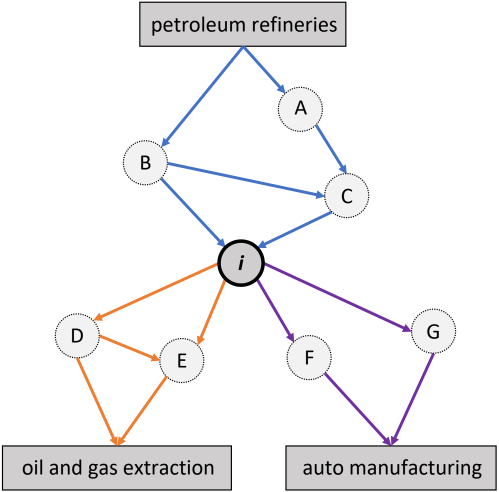
Economic Production Networks



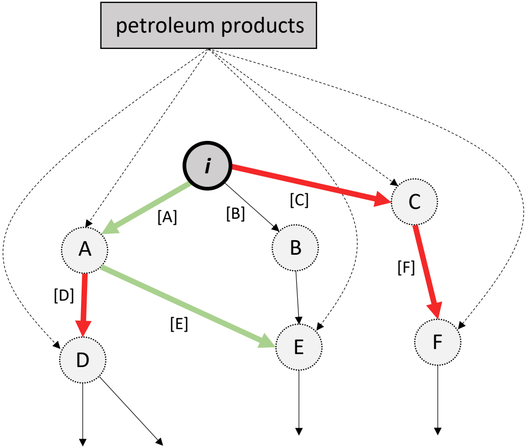
Three-Industry Example



Variable Construction: Supply and Demand Paths



Variable Construction: Demand-Side Input Patterns



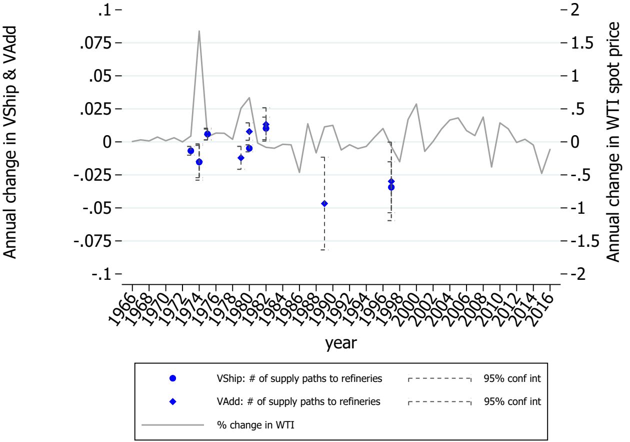
Regression

The primary specification is:

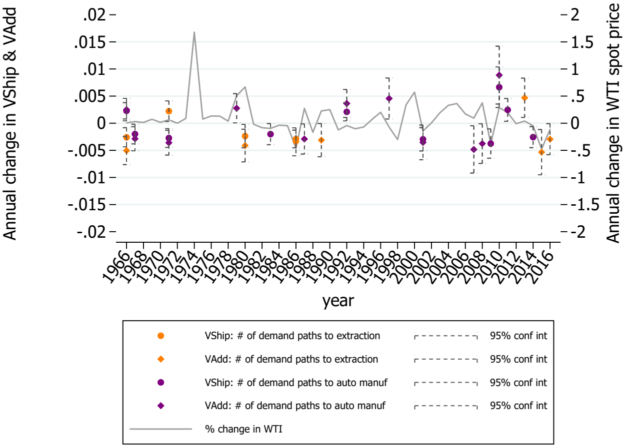
$$
\begin{aligned}
y_{it} = \alpha + Y_t + 2\text{digit}_i \cdot Y_t + emp_{it} + \\
& \beta_{refining} \cdot \log(\text{supply\_paths\_refining}_i) + \beta_{refining,t} \cdot \log(\text{supply\_paths\_refining}_i) \cdot Y_t + \\
& \beta_{extract} \cdot \log(\text{demand\_paths\_extract}_i) + \beta_{extract,t} \cdot \log(\text{demand\_paths\_extract}_i) \cdot Y_t + \\
& \beta_{auto} \cdot \log(\text{demand\_paths\_auto}_i) + \beta_{auto,t} \cdot \log(\text{demand\_paths\_auto}_i) \cdot Y_t + \\
& \beta_{dcomp} \cdot \log(\text{down\_ratio\_comp}_{h(i)}) + \beta_{dcomp,t} \cdot \log(\text{down\_ratio\_comp}_{h(i)}) \cdot Y_t + \\
& \beta_{dsubs} \cdot \log(\text{down\_ratio\_subs}_{h(i)}) + \beta_{dsubs,t} \cdot \log(\text{down\_ratio\_subs}_{h(i)}) \cdot Y_t + \\
& \beta_{ucomp} \cdot \log(\text{up\_ratio\_comp}_{h(i)}) + \beta_{ucomp,t} \cdot \log(\text{up\_ratio\_comp}_{h(i)}) \cdot Y_t + \\
& \beta_{usubs} \cdot \log(\text{up\_ratio\_subs}_{h(i)}) + \beta_{usubs,t} \cdot \log(\text{up\_ratio\_subs}_{h(i)}) \cdot Y_t + \varepsilon_{it}
\end{aligned}
$$

where y_{it} is either the percentage change in the value of shipments or the percentage change in value added, Y_t is a set of year fixed-effects, 2digit_i is a set of 2-digit-NAICS fixed effects, emp_{it} is the percentage change in employment, $h(\cdot)$ maps from 6-digit-NAICS industries to their 3-digit-NAICS counterparts, and the other regressors are calculated as described previously.

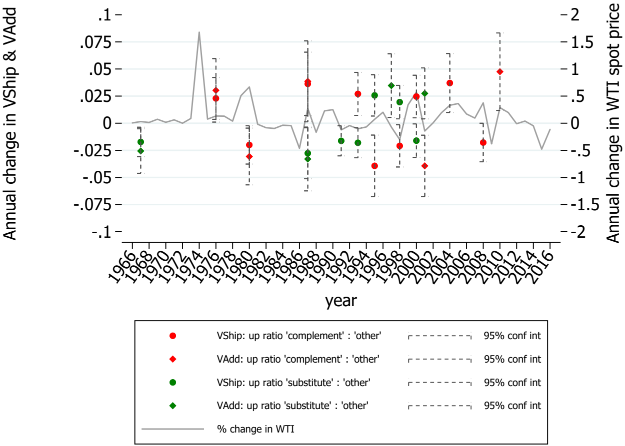
Results: Supply Path Covariate



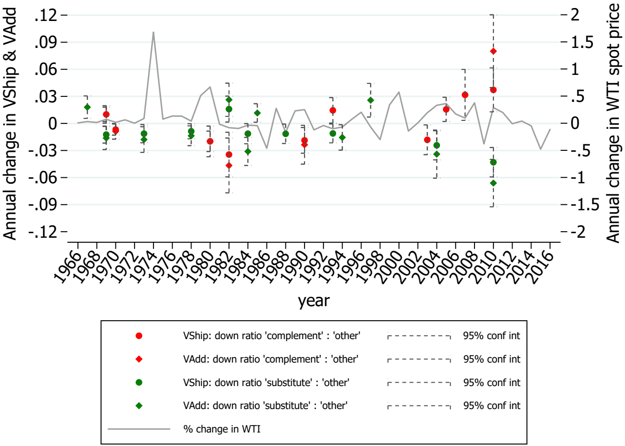
Results: Demand Path Covariates



Results: Supply-Side Input Covariates



Results: Demand-Side Input Covariates



Appendix: Covariate Summary Statistics

Variable	Mean	Std Dev	Min	Max
supply_paths_refining	31.08	16.81	0	96.72
demand_paths_extraction	0.42	0.92	0	6
demand_paths_auto	2.61	5.87	0	37
down_complement_paths	0.197	0.115	0.010	0.433
down_substitute_paths	0.194	0.174	0.136	0.839
up_complement_paths	0.353	0.163	0.078	0.696
up_substitute_paths	0.094	0.081	0.014	0.382
down_ratio_comp	0.445	0.541	0.011	7.165
down_ratio_subs	0.753	2.585	0.018	38.176
up_ratio_comp	0.894	0.775	0.090	3.779
up_ratio_subs	0.279	0.507	0.022	2.923

Appendix: Covariate Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) supply_paths_refining	1.00						
(2) demand_paths_extraction	-0.01	1.00					
(3) demand_paths_auto	-0.02	0.71	1.00				
(4) down_complement_paths	0.07	0.21	0.27	1.00			
(5) down_substitute_paths	0.02	-0.08	-0.10	-0.10	1.00		
(6) up_complement_paths	-0.01	-0.09	-0.12	-0.10	0.45	1.00	
(7) up_substitute_paths	0.17	0.02	-0.03	0.17	-0.10	0.15	1.00

Appendix: Covariate Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) supply_paths_refining	1.00						
(2) demand_paths_extraction	-0.01	1.00					
(3) demand_paths_auto	-0.02	0.71	1.00				
(4) down_ratio_comp	0.10	0.01	0.04	1.00			
(5) down_ratio_subs	0.04	-0.07	-0.07	0.88	1.00		
(6) up_ratio_comp	0.08	-0.09	-0.14	0.11	0.17	1.00	
(7) up_ratio_subs	0.14	-0.03	-0.09	0.03	0.05	0.73	1.00

Appendix: Non-Interaction Terms

	value of shipments	value added
supply paths to referineries	-0.00577**	-0.00725***
	(0.00252)	(0.00233)
demand paths to oil/gas extraction	-0.00190**	0.000139
	(0.000776)	(0.00124)
demand paths to auto manufacturing	0.00237***	0.00177*
	(0.000689)	(0.00102)
downstream ratio of complement : other	-0.00828**	-0.0114**
	(0.00377)	(0.00460)
downstream ratio of substitute : other	0.00253	0.0117**
	(0.00382)	(0.00513)
upstream ratio of complement : other	-0.0107*	-0.0134
	(0.00613)	(0.0100)
upstream ratio of substitute : other	0.00828	0.0125
	(0.00537)	(0.00826)
N	10,779	10,779
adj. R^2	0.650	0.482

Standard errors clustered by industry.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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