Economics 134 L13. Oil markets

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Natural resources

We will spend the next few lectures looking at natural resources:

- oil, cartels (today)
- conservation, biodiversity (L14)
- water (L15)
- forests, wildfires (L16)

Plan

Conceptual issues with oil markets
- Motivating facts
- Price and costs
- OPEC

1. Imperfect competition
   - Monopoly
   - Oligopoly

2. Finite resource
   - Constrained optimization
   - Hotelling's rule

3. Pigouvian taxation

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1. Oil production cost < price

TABLE 4—UNIT COSTS ACROSS THE GLOBAL OIL INDUSTRY, 1970–2014

	1970–1979	1980–1989	1990–1999	2000–2014
Number of active fields	4,766	7,088	9,760	12,085
Mean oil price	20	40	21	59
Mean global production (mB/year)	20,861	21,489	23,984	26,298
OPEC	9,979	7,289	9,606	11,249
Mean global reserves (mB)	737,928	728,532	661,815	517,559
OPEC	392,912	365,891	328,914	254,730
Unit costs (baseline specification):				
95th percentile Saudi Arabia	5.8	13.6	4.4	10.4
Median Saudi Arabia	2.3	5.6	2.3	5.4
95th percentile OPEC	6.7	18.6	7.6	20.1
Median OPEC	2.4	5.9	2.8	6.1
95th percentile non-OPEC	6.7	15.6	9.2	28.2
Median non-OPEC	3.6	7.0	4.1	9.7

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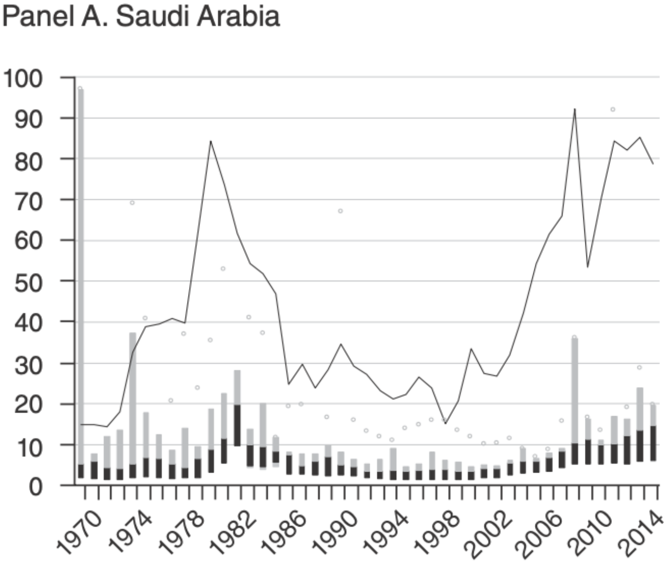

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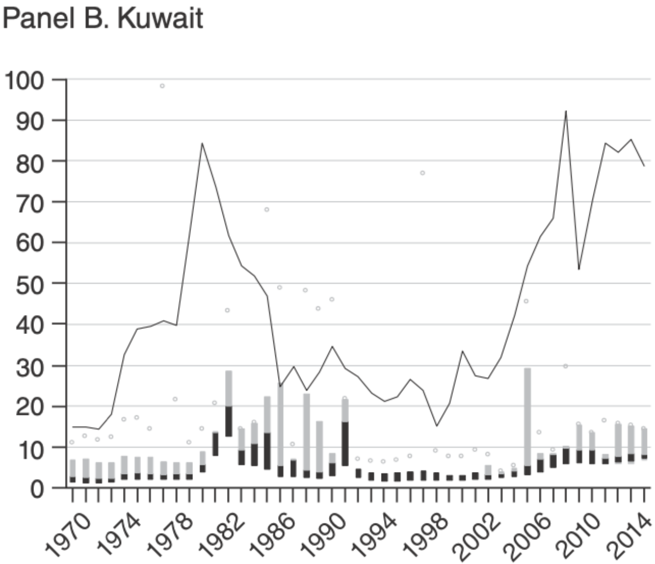

2. Market shares, OPEC and non-OPEC

TABLE 1—LARGEST CRUDE PRODUCERS, PERCENT OF GLOBAL PRODUCTION, 1970–2014

OPEC		Non-OPEC	
Saudi Arabia	11.8	United States	14.4
Iran	5.4	Russia	13.0
Venezuela	3.8	China	4.1
UAE	3.1	Mexico	3.7
Nigeria	2.8	Canada	3.3
Iraq	2.7	United Kingdom	2.4
Kuwait	2.6	Norway	2.4

Notes: Global production from 1970–2014 was 1,156 billion barrels. Collectively, these 14 countries account for 85.4 percent of global production.

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Monopolist's problem

Up until now, we've focused on **competitive** markets, where firms take the final good price P as given, so that

$$\pi(q) = P \cdot q - c(q)$$

which is maximized when $\pi'(q^*) = P - c'(q^*) = 0$ (price equals marginal cost).

Now consider a **monopolist** supplier, whose decision influences price:

$$\pi(q) = P(q)q - c(q).$$

This is maximized when

$$\pi'(q^m) = \underbrace{P'(q^m)q^m}_{\text{distortion}} + P(q^m) - c'(q^m) = 0 \tag{1}$$

for the monopolist's profit-maximizing q^m.

Welfare

How is this inefficient? We can think about the inverse demand curve, $P(q)$, as the marginal willingness to pay for the q^{th} unit, so that consumer surplus is

$$\int_0^q P(x)dx.$$

Welfare is then

$$W(q) = \int_0^q P(x)dx - c(q).$$

Because the derivative of consumer surplus is

$$\frac{\partial}{\partial q}\left[\int_0^q P(x)dx\right] = P(q),$$

the first-best quantity, q^{FB}, satisfies

$$\frac{\partial W}{\partial q} = P(q^{\text{FB}}) - c'(q^{\text{FB}}) = 0.$$

Diagnosing the inefficiency

Suppose that $P(q) = q^{-1/\theta}$, where $\theta > 0$ is the **price elasticity of demand**. Then, $P'(q) = -\frac{1}{\theta} q^{-1-1/\theta}$ or $P'(q)q = -\frac{1}{\theta} P(q)$.

The monopolist's first-order condition (1) becomes $\left(1 - \frac{1}{\theta}\right) P(q^m) = c'$, or

$$P(q^m) = \underbrace{\frac{1}{1 - \frac{1}{\theta}}}_{\text{markup}} c'(q^m).$$

That is, the monopolist charges a **markup** above marginal cost in proportion to the inverse elasticity of demand:

- when $\theta \to \infty$ (demand becomes infinitely elastic), then pricing is competitive (equal to marginal cost)
- as $\theta \downarrow 1$ (consumers are less sensitive to price), demand becomes inelastic and markups rise
- typically, $\theta \geq 1$ within the range of plausible q^m (otherwise, the monopolist could send $q^m \to 0$ and make infinite profits)

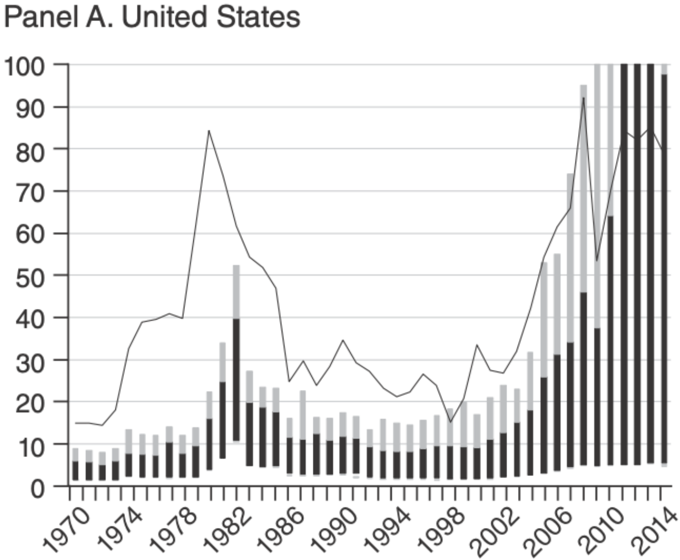
Oligopolist's problem

Now suppose that our firm only influences **part** of the market (they are an "**oligopolist**").

OPEC market share, 1970–2014

FIGURE 2. OPEC MARKET SHARE AND OIL PRICE, 1970–2014

Fringe production — production costs (non-OPEC)



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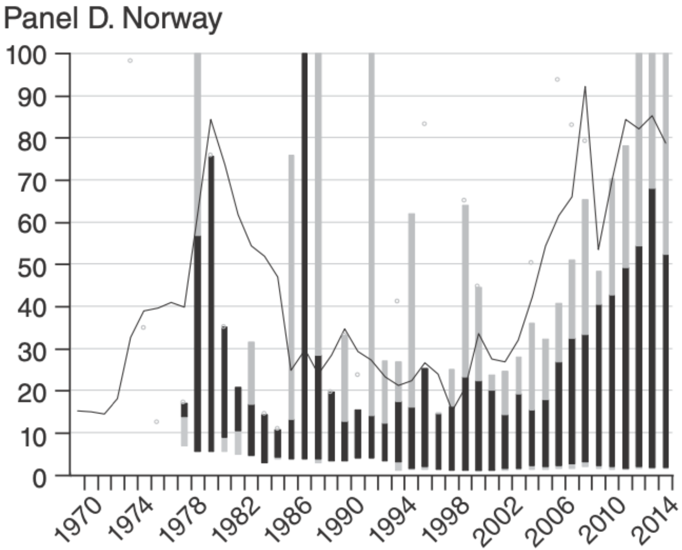

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That is, suppose that in addition to our firm's q, some amount of oil $\hat{q}$ is produced exogenously, and (aggregate) demand translates into a global oil price of

$$P(\hat{q} + q) = (\hat{q} + q)^{-\frac{1}{\theta}}.$$

This implies that now

$$\frac{\partial P}{\partial q} = -\frac{1}{\theta}(\hat{q} + q)^{-1-1/\theta}$$

or $\frac{\partial P}{\partial q} \cdot q = -\frac{1}{\theta} \frac{q}{\hat{q}+q} P(\hat{q} + q)$, so that the oligopolist's first-order condition becomes $(1 - \frac{1}{\theta} \cdot s) \cdot P(\cdot) = c'(q)$.

Markups are now mediated by **market share**, $s = \frac{q}{\hat{q}+q}$.

Oil as a finite resource

TABLE 3—RESERVES AND PRODUCTION, 2014

	Reserves (mB)	Share of world reserves (percent)	$\frac{\text{Reserves}}{\text{Annual production}}$
Non-OPEC	218,054	50	10
Russia	46,134	11	12
Canada	36,622	8	43
United States	31,735	7	7
Norway	6,962	2	10
OPEC	220,561	50	19
Saudi Arabia	74,194	17	18
Venezuela	17,523	4	19
Kuwait	15,723	4	16
Nigeria	7,952	2	10

Notes: Data are for 2014. Total reserves for the world in 2014 were 438 billion barrels. The ratio of reserves-to-production was 14. OPEC countries are listed in Section IIB. Countries are included in OPEC in all years if they had ever had active membership between 1970 and 2014. Reserves are reported using P50 measures at a world price of $70 per barrel.

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Oil as a finite resource

Back to the monopoly case. Now suppose that extraction costs, $c(q)$, are **zero**.

However, there is only a **finite** amount of oil in the ground, $\overline{q}$.

For simplicity, suppose that

- there are two periods, today and tomorrow
- demand is the same in both periods, $P_1(q_1) = q_1^{-1/\theta}$ and $P_2(q_2) = q_2^{-1/\theta}$
- the firm discounts profits between periods with an interest rate r.

Now the firm solves

$$\max_{q_1, q_2 \geq 0} \left[P_1(q_1)q_1 + \frac{1}{1+r} P_2(q_2)q_2 \right] \tag{$\star$}$$

subject to the **resource constraint** that $q_1 + q_2 \leq \overline{q}$.

Oil as a finite resource, cont'd

We can solve problem ($\star$) with the Lagrangian, defined as

$$\mathcal{L}(q_1, q_2; \lambda) = P_1(q_1)q_1 + \frac{1}{1+r}P_2(q_2)q_2 - \underbrace{\lambda\left[q_1 + q_2 - \overline{q}\right]}_{\text{resource constraint}}.$$

Specifically, we solve

$$\max_{q_1, q_2, \lambda \geq 0} \mathcal{L}(q_1, q_2; \lambda).$$

This gives us three first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial q_1} = \left(1 - \frac{1}{\theta}\right) P_1(q_1) - \lambda = 0 \qquad (\text{FOC}_{q_1})$$

$$\frac{\partial \mathcal{L}}{\partial q_2} = \frac{1}{1+r}\left(1 - \frac{1}{\theta}\right) P_2(q_2) - \lambda = 0 \qquad (\text{FOC}_{q_2})$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = \overline{q} - q_1 - q_2 = 0 \qquad (\text{FOC}_{\lambda})$$

Solving for optimal extraction

Two reasons this is interesting.

1. Optimal extraction (pricing) looks just like before, except with the scarcity or **shadow** value λ instead of $c'(q)$; e.g., from (FOC$_{q_1}$), we have

$$P_1(q_1) = \frac{\lambda}{1 - \frac{1}{\theta}}$$

$\hookrightarrow$ Zero marginal cost, but positive price.

2. Oil prices grow over time in proportion to the interest rate, since $P_2(q_2) = (1 + r)\frac{\lambda}{1-\frac{1}{\theta}}$, so

$$\frac{P_2}{P_1} = 1 + r.$$

This result is known as **Hotelling's rule**.

For completeness, we can also solve for the equilibrium allocation:

$$1 + r = \frac{P_2}{P_1} = \frac{q_2^{-1/\theta}}{q_1^{-1/\theta}}$$

or

$$q_2 = (1 + r)^{-\theta} q_1,$$

and plugging this into $q_1 + q_2 = \overline{q}$, we get

$$q_1 + \underbrace{(1 + r)^{-\theta} q_1}_{q_2} = \overline{q},$$

and so we can solve for

$$q_1^* = \frac{\overline{q}}{1 + (1 + r)^{-\theta}}.$$

This makes sense:

- If we care equally about today and tomorrow ($r = 0$), then we split extraction equally between today and tomorrow ($q_1^* = q_2^* = \frac{1}{2}\overline{q}$).
- Otherwise, we extract slightly more today than tomorrow!

Externalities

Oil also creates externalities.

- Approximately 0.43 metric tons of CO_2 per barrel of oil [https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references]
- Oil spills — e.g., Exxon Valdez (Deepwater Horizon) spill on 20 April 2010
  - $2.1 billion in cleanup costs
  - $900M civil settlement to US, Alaska
  - $500–600M to private parties
  - $500M punitive damages

Deepwater Horizon

Externalities

Back to the (unconstrained) monopoly case with convex extraction costs $c(q)$. Now suppose that oil creates an externality, $D(q)$.

Then the first-best level of extraction is

$$P(q^{\mathrm{FB}}) - c'(q^{\mathrm{FB}}) - D'(q^{\mathrm{FB}}) = 0.$$

Suppose that we would like to tax τ per-unit q. Then the monopolist's problem is

$$\max_{q \geq 0} \; P(q)q - \tau q - c(q),$$

so that $q^m(\tau)$ solves

$$\left(1 - \frac{1}{\theta}\right) P(q^m(\tau)) - \tau - c'(q^m(\tau)) = 0.$$

We want the firm to pick q^{FB}. Which tax will accomplish this?

Optimal taxation with imperfect competition

Two distortions in the monopolist's problem when $\tau = 0$:

$$\underbrace{\left(1 - \frac{1}{\theta}\right)}_{\text{restrict output}} P(q^m(\tau)) - \underbrace{c'(q^m(\tau)) - \tau}_{\text{missing externality}} = 0.$$

The optimal tax should be

$$\tau = \left(1 - \frac{1}{\theta}\right) D'(q^{\text{FB}}) - \frac{1}{\theta} c'(q^{\text{FB}})$$

because then $\left(1 - \frac{1}{\theta}\right) P(\cdot) - \left(1 - \frac{1}{\theta}\right) D'(\cdot) - \left(1 - \frac{1}{\theta}\right) c'(\cdot) = 0$, or $P(\cdot) - c'(\cdot) - D'(\cdot) = 0$, which is the first-best.

Key points:

1. Want to **subsidize** output to eliminate market power
2. Use a **lower** Pigouvian tax to mitigate market power effects
3. In the "knife-edge" case in which $D'(\cdot) = \frac{1}{\theta - 1} c'(\cdot)$, the optimal tax is **zero**

OPEC and global warming

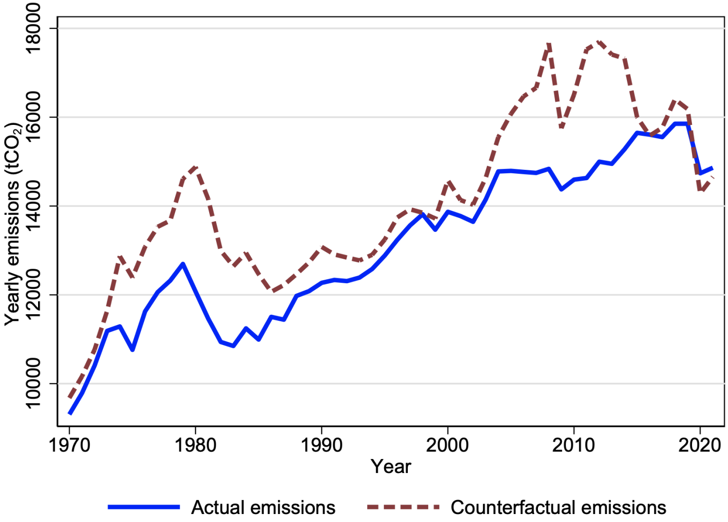
New work assessing these effects:

John Asker, Allan Collard-Wexler, Charlotte De Canniere, Jan De Loecker, Chris Knittel (2024). "Two wrongs can sometimes make a right: The environmental benefits of market power in oil." NBER Working Paper, 33115, November.

Authors find that OPEC avoided **67 gigatonnes of CO_2** from 1970–2021

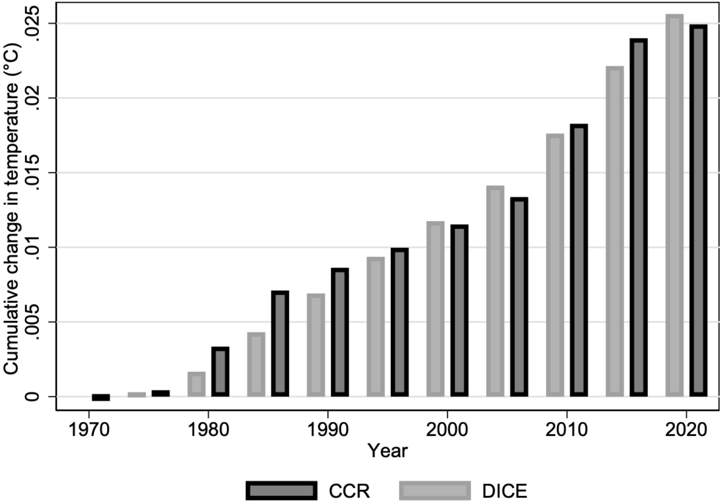
- about two years of current global emissions
- 17.8% of the carbon budget needed for the 1.5°C Paris Agreement target

Global emissions, with and without OPEC



Source: Asker et al. 2024, Figure 9.

Global temperatures 0.025°C higher without OPEC



Cumulative increase in global temperature in a perfectly competitive oil market relative to actual oil supply, using two climate models, CCR and DICE (Asker et al. 2024, Fig. 11).

Next time

On Wednesday, we will discuss conservation!