Common Problems and Natural Resources

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Outline of Lecture

1. Review of standard theoretical results concerning the commons problem
   - Knight
   - Cheung
   - Levhari-Mirman, Brooks et al., Gaudet et al.
2. Analysis of 2 real-world institutions mitigating the problem
   - In Ostrom/Libecap tradition

Negative Spillovers

- Excessive access by agents with usage fixed
- Excessive usage by a fixed number of agents
- Dynamic consequences of excessive usage

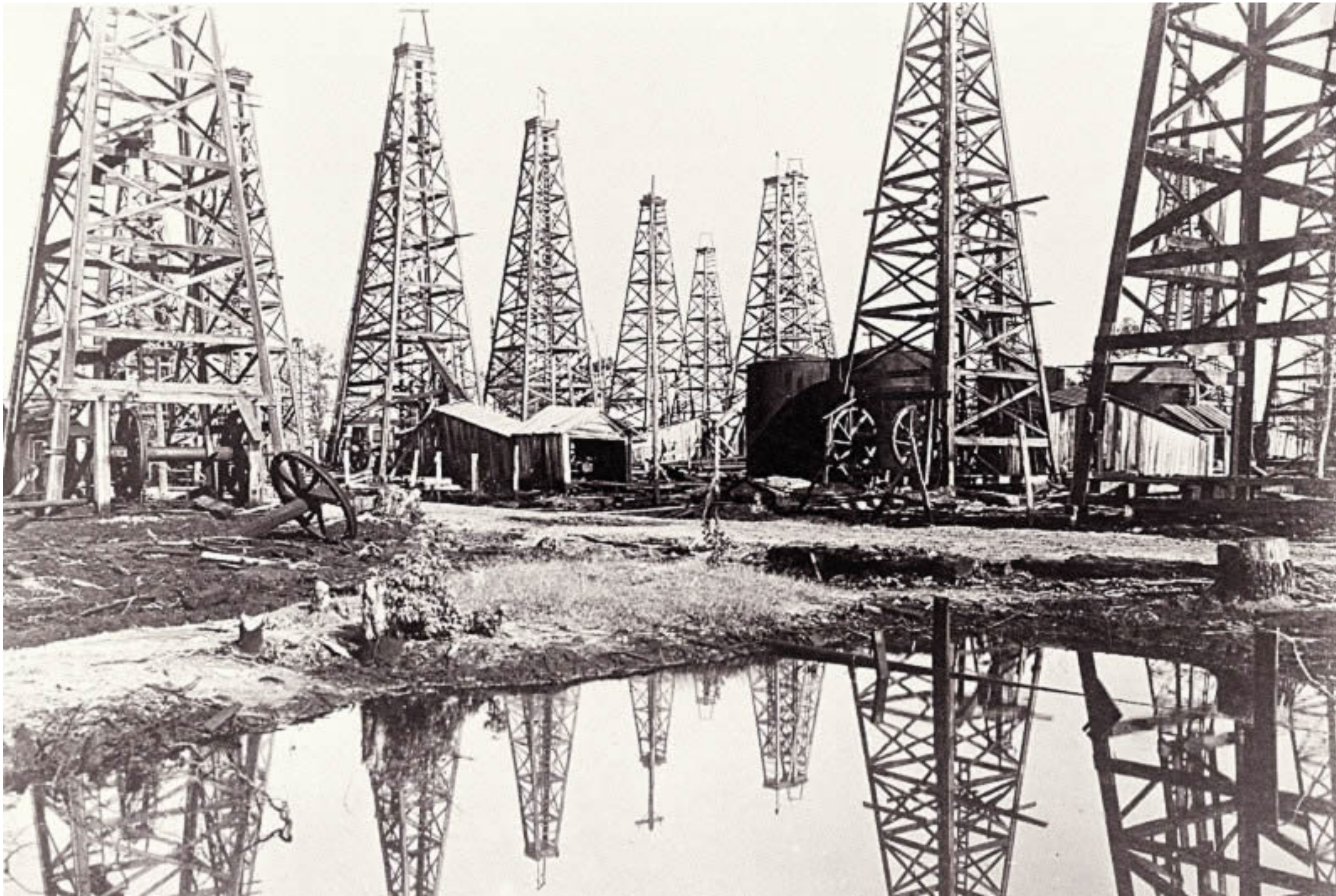
Unrestricted Access (Knight)

- If access is unrestricted, so many cars will crowd the highway that otherwise inferior alternatives become equally attractive: indirect routes, train, bike, walking…

Unrestricted Access

- If access is unrestricted, so many people will crowd the elevator that waiting for the next elevator or taking the stairs becomes equally attractive

Unrestricted Access



Restricting Access Raises Total Surplus

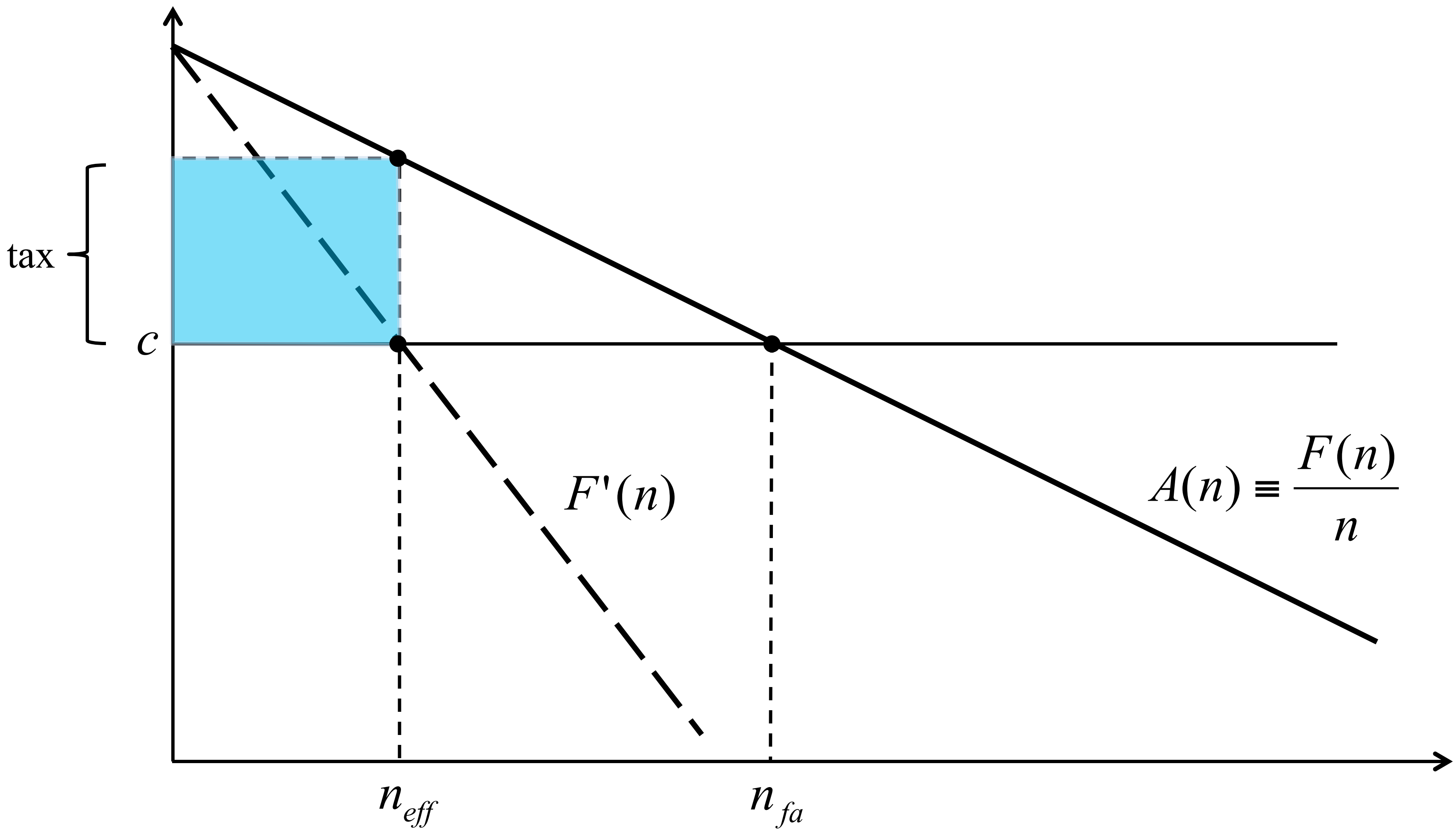
- At the equilibrium, everyone is indifferent and would be just as happy with the next best alternative (the backroads or stairs)

- If one user of the resource took the alternative instead, *everyone else* would benefit from being slightly less crowded.

- Each successive person denied access leaves behind an increasingly attractive situation and hence sustains a bigger loss. Meanwhile the benefit of less crowding to those who continue to use the resource is enjoyed by fewer people.

- Eventually there is no net benefit from denying people access to the resource and the social optimum is reached.

Rent Dissipation under Free Access



Efficiency vs. Equity

- *Total surplus* would be larger if some people were denied access.
- But if agents are identical, the *distribution* of that surplus will favor those who still have access to the highway or the elevator (or antibiotic)
- If agents are identical, one can restore equity without sacrificing efficiency
  - by randomly selecting who uses the resource.
  - or by charging an entrance fee for anyone accessing the resource. Then people would be "free to choose."

Pigouvian Fees

- When a fee is charged, entry continues until the cost of entry (which now includes the fee) equals the benefit. So *none* of the users of the resource benefits: their rents are fully dissipated.
- All the surplus gains from restricting access are captured in the revenues collected. If the person setting the fee keeps the revenues (or a fraction of them), he will set the fee to maximize the surplus
- But if he shares none of these revenues, no one else is better off than under unrestricted access.
- No wonder the other agents often resist this solution even if it maximizes surplus.

Paradoxical Consequences of Highway Improvements

- Widening the highway is expensive and may leave the commute time during rush hour exactly the same since train riders will switch to cars.

- With fewer people riding the train, the government may decide to reduce the number of trains per hour. Then even more people will take cars . So widening the highway can lead to longer commute times.

- Neither result can occur if a social planner controls highway access. That's what makes them seem paradoxical.

Applicability of the Results

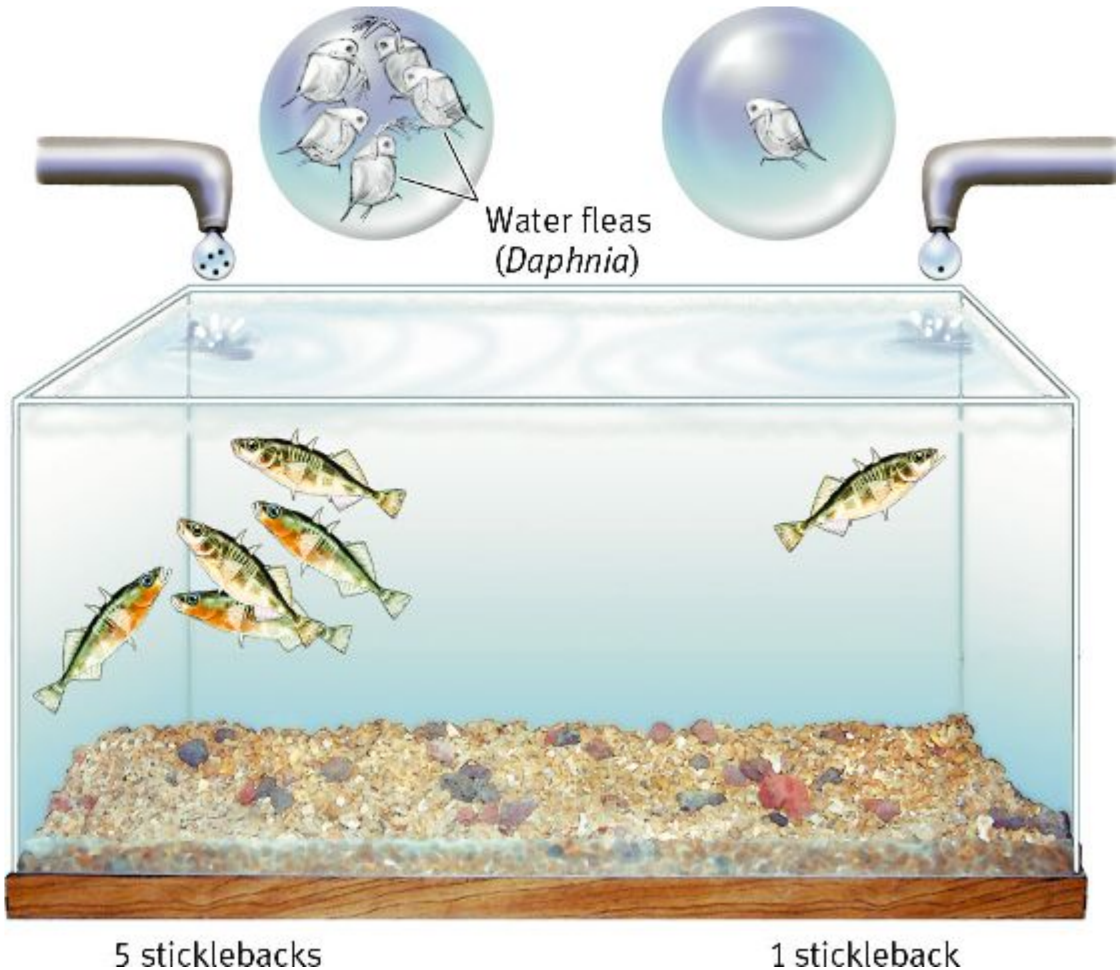
- Results are not confined to highways but apply wherever access results in negative spillovers.

Examples

1. Biological re-interpretation of paradoxes about highway improvements: feeding fish

2. I.O. re-interpretation of result about efficient toll setting: prize setting to motivate innovation

Ideal Free Distribution



For the uncongestible alternative, create as many slow food sources as there are fish.

Awarding Innovation (example: Netflix Prize)

- Suppose lots of engineers work for McDonald's restaurant at the minimum wage of c per year.

- Suppose a firm wants to get some of these engineers working to discover an innovation worth V to the firm.

- If n engineers work on the project, the probability that someone makes the discovery is given by the exogenous concave function p(n). Each engineer makes the discovery with probability p(n)/n

- The winner surrenders the property right to the innovation and collects the prize (W)

One or More Single-Prize Competitions

- Engineers enter the contest until rents are dissipated:

$$Wp(n)/n = c$$

- All surplus goes to the firm offering the prize. So it will set W to maximize surplus---the classic result about highway tolls: $\text{Max}_W \ (\text{V-W})\text{P(n) where } WP(n) = nc$

- Generalization: if **many** prize setters compete for same engineers by setting prizes simultaneously, the subsequent allocation of engineers duplicates what a social planner would choose (as long as it is socially optimal for some engineers to continue to work for McDonalds).

Second Model, Second Margin

- "**Small country**" assumption: commons problem on one lake or one oil field and price is unaffected by changes in output from that one source.
- Access restricted to N players (no entry)
- Even so, each player may spend too many hours extracting from the commons or, if his hours are restricted, may utilize multiple extractors:
    1. Multiple fishing vessels of 1 player
    2. Multiple sheep of 1 shepherd
    3. Multiple wells of 1 oil company

Steven Cheung's Reinterpretation of the Cournot Model

$$\text{Max}_{x_i \geq 0} \ \frac{x_i}{(x_i + X_{-i})} F(x_i + X_{-i}) - x_i c = x_i [A(x_i + X_{-i}) - c]$$

$$x_i > 0 \Rightarrow A(x_i + X_{-i}) + x_i A'(x_i + X_{-i}) = c$$

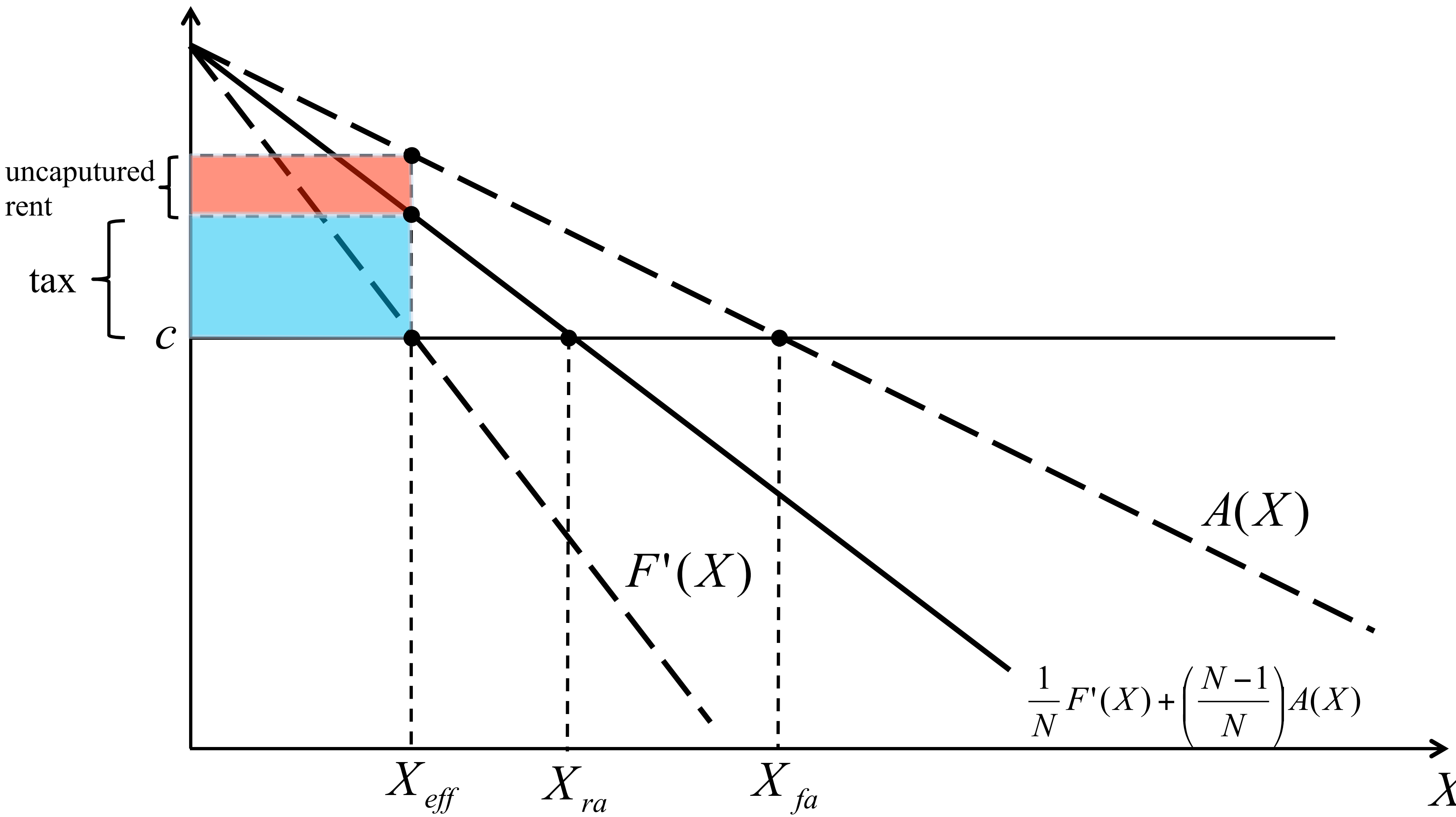
There exists a unique Nash equilibrium and it is symmetric

$$\text{so } \mathrm{x}_i = X/N$$

$$A(X) + \frac{X}{N} A'(X) = c$$

$$\frac{1}{N} \underbrace{\big(A(X) + XA'(X)\big)}_{F'(X)} + \frac{N-1}{N}\big(A(X)\big) = c$$

Restricted Access



Properties if N is Finite

- Nash equilibrium is efficient for N=1 but not for N>1.

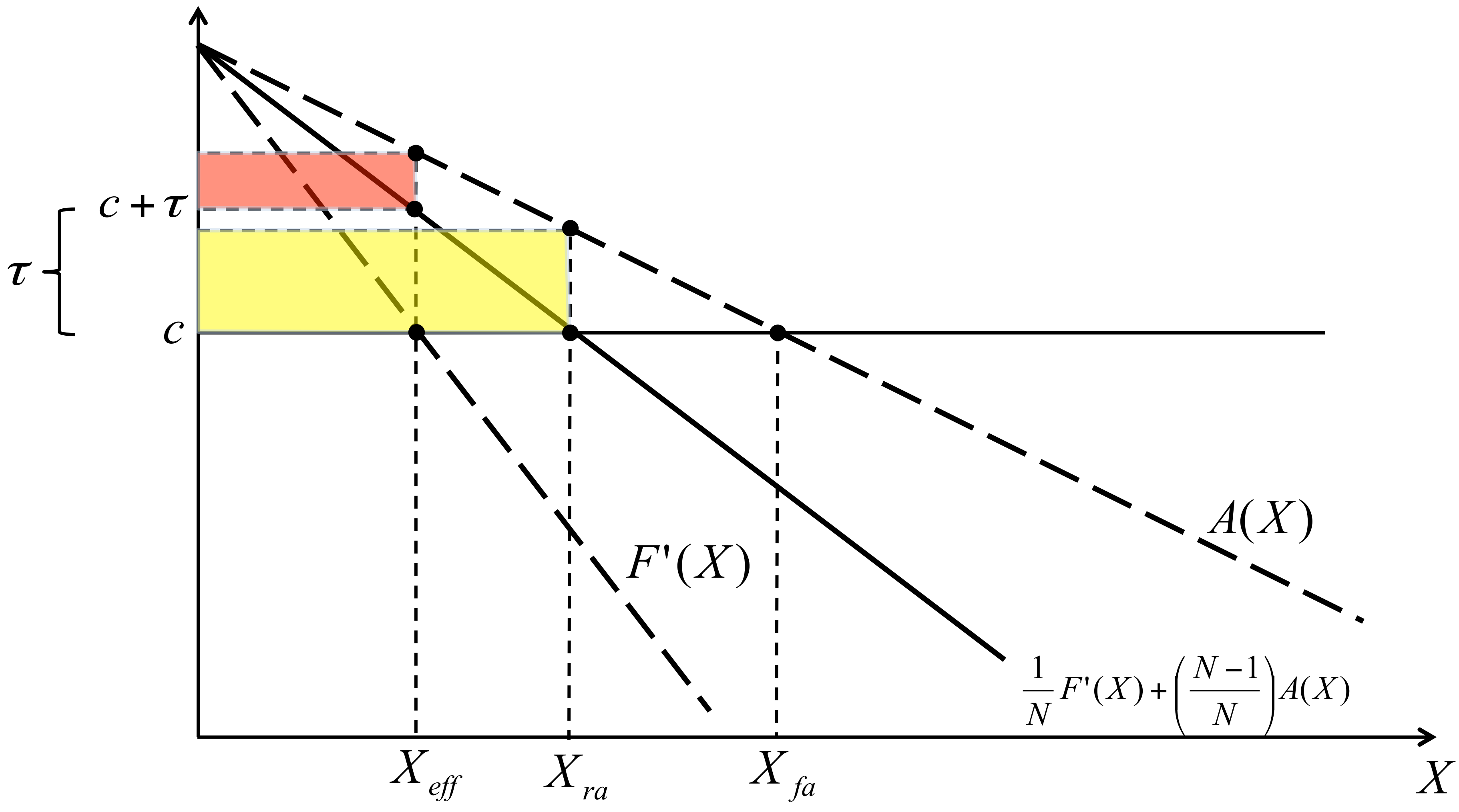
- Users have strictly positive surplus.

- Taxing use can restore efficiency (but revenue-maximizing toll setter would NOT set the efficient fee).

- If no tax revenues are redistributed, however, agents are *strictly worse* off (if F''<0) than with no tax even if the tax restores efficiency

- In the limit $(N \to \infty)$, all results of first model return (full rent dissipation, toll setter sets optimal tax, agents indifferent between equilibrium with no tax and with efficient tax which is not recycled.)

Uncaptured Rent Declines as Tax Increases



If Tax Is Not Recycled, Users Are Worse Off Even if Surplus Increases

- Aggregate payoff of users $\Pi(X)$ is strictly increasing in aggregate effort (X) and the tax reduces it:

$$\Pi(X) = XA(X) - X\{\frac{1}{N}F'(X) + \frac{N-1}{N}A(X)\}$$

$$= \{-XF'(X) + F(X)\}\frac{1}{N}.$$

$$\Pi'(X) = -\frac{X}{N}F''(X) > 0 \text{ (if and only if strict concavity).}$$

Negative Spillovers Over Time

- If one user extracts more today, less remains for others to extract tomorrow.

- Moreover, the cost of extraction may rise as the stock remaining falls.

- In addition, extracting faster than the petroleum engineer's "maximum efficient rate" (**MER**) may damage the total amount of the resource that can be recovered:
  - Oil is often trapped with no pressure left to propel it to surface
  - Saltwater intrusions in aquifers.
  - Unwanted bycatch in fishing derbies

Dynamic Game of Resource Extraction

- Extraction from the commons (be it an ocean or an oil field) is a dynamic game.
- Since there is a single state variable, solving for the Markov-perfect equilibrium on a computer is always feasible.
- Sometimes one can deduce extraction rules analytically. Literature divides in two strands:
  - Fishing for own use (beginning with Levhari-Mirman, 1980)
  - Fishing to sell on market (beginning with Reinganum-Stokey, 1985)
- No Markov-perfect models with storage as well as extraction.

Markov-Perfect Equilibria as the Number of Extractors Grows without Bound

- If the resource is a renewable growing ***really*** fast, then there can remain an incentive for each extractor to leave fish for the future.

- With nonpathological growth, however, there is no incentive to leave fish; someone else would take them. As in static case, complete rent dissipation occurs in each period.

- For pathological examples and a condition sufficient to eliminate them, see Brooks et al., *JPE* (August, 1999)

- Implication: 30 years of articles on dynamic common property problems under free access reached correct conclusions even though they did not use game theory.

Private Storage of Nonrenewable Common Property

- Virtually all of the literature assumes that everything extracted is marketed immediately.

- In fact, resources extracted from the commons are often stored and sold later when the price is higher:
  - Water is bottled.
  - Fish are frozen.
  - Oil is stored above ground.

STORAGE POOL OF THE ROXANA COMPANY, AT SMACKOVER, COVERING 34 ACRES, 50 FEET DEEP IN PLACES (S.C. Wilson, photographer)

Endogenous Price of Oil

- So far we have discussed rent dissipation from the perspective of the inputs used to produce oil.
- From the perspective of the oil produced, rent dissipation implies that average cost rises to the market price.
- We continue to assume the oil market is competitive, but we now endogenize the oil price.
- It is the expectation of higher prices in the future that induces people to store oil.

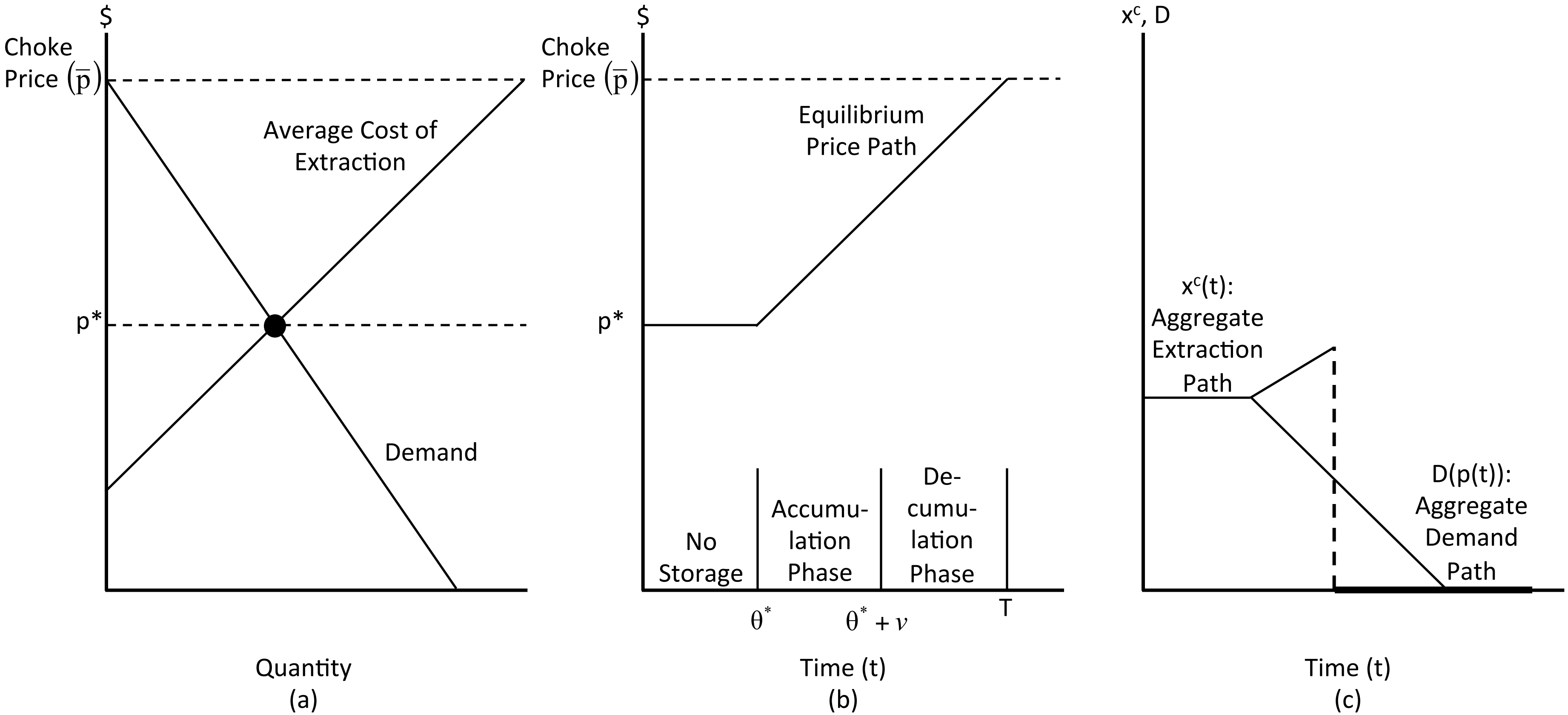

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Figure 1

Length of the Accumulation Phase

- As the average cost curve flattens, the accumulation phase becomes compressed.
- In the limit, accumulation of the stock occurs at an infinite rate during one instant.
- This phenomenon is called a "first-generation" speculative attack.
- Elsewhere in the literature (Flood et al., 2012), government policies precipitate such attacks.
- Here, the recognition that the resource is finite and that others have unlimited access to it precipitates the attack.

Why Store Oil Above Ground?

- Storage (whether acquired slowly or instanteously) arises from another commons problem.

- To verify this, consider what would happen if the oil in the common were instead privately owned. Hotelling (1931) equilibrium would result. There would be no reason to extract it and then store it for a while before selling it.

- Acquiring oil now to store until a later sale is costly and only occurs when an agent anticipates that anything he leaves in the commons will be grabbed by someone else.

- In the process of trying to grab what remains in the commons before others do, speculators completely dissipate their rents.

Two Real-World Institutions to Cope with Commons Problem

1. Catch-Sharing to curb usage
   - Government limits access
   - Requires homogeneity among agents
   - Reason not to go solo

2. Prorationing (maximum percentage of well's yardstick which can be sold)
   - Government limits access
   - Government monitors quota compliance
   - Heterogeneity results in insufficient regulation of output.

1st Institutional Solution: Competing Catch-Sharing Groups

- Japanese fishermen belong to one of the 1339 “self-management institutions” authorized by local Fishery Cooperative Associations.
- Entry is severely restricted by the local FCA in each of institutions so the main commons problem is overuse of the resource by a fixed number of fishermen.
- In 147 of these self-management institutions (11% of the total), the catch is pooled within each partnership of boats.
- Costs which are difficult to monitor are borne by each boat rather than pooled within the partnership.
- Platteau and Seki studied the glass shrimp fishery in detail: “they are homogeneous in the sense that members are natives of the same village and use the same technology.”

Motivations for Catch Sharing

- **Not** insurance: “The most prominent result [of interviews with boat skippers] is certainly the fact that stabilization of incomes was not mentioned a single time by the 12 skippers interviewed.”

  Congestion costs avoided: “risk of mutual entanglement of nets and boat collisions due to excessive proximity…, competition for the first turns in the most advantageous locations, psychological and physical stress caused by the need to rush to the coveted place…”

- “The desire to avoid the various costs of crowding while operating in attractive fishing spots appears as the main reason stated by Japanese fishermen for adopting pooling arrangements.” (Platteau and Seki, 2001)

Consequences of Catch-Sharing

(based on Heintzelman et al. (2009))

- If each of N individuals is "grouped" into his own "solo" partnership with the same rules about output sharing, aggregate effort will be excessive.
- If all N individuals are grouped together into a single partnership where each person must pay his own costs but must share his profit equally with his partners, aggregate effort will be insufficient (if $c > 0$).
- As the size of each group increases for 1 to N, aggregate effort diminishes.
- Socially optimal effort can be achieved at an intermediate group size. no net externality. Investing marginally more helps partners by as much as it hurts nonpartners.
- The result is equivalent to Pigouvian taxation with all tax revenues recycled on a per capita basis. But no government interference involved

Experimental Test of Theory

(based on Cherry et al., 2012)

- At the beginning of each round each subject is endowed with 6 tokens

- Each subject decides how to allocate his tokens between 2 projects:
  - Project A
  - Project B

- Project A:
  - For each token invested in Project A, the return per token is **c** (opportunity cost)
  - Individual's earnings from A = *c* * individual's investment in A

- Project B:
  - Return per token invested in B by group = 200 – 5 * (total investment in B)
  - Individual's earnings from B = (Return B * sum of group members' investment in B) / group size

Payoff from Allocation of 6 Tokens

- Return from Project B per token invested by group *i* is linear in the total invested by the 6 subjects in that project:

$$A(X) = 200 - 5X$$

- Payoff of subject *k*, member of group *i* from investing x_{ik}

$$\pi_{ik} = (6 - x_{ik})c + \frac{1}{m_i}[A(x_{ik} + Y_i^{-k} + X_{-i})](x_{ik} + Y_i^{-k})$$

Predicted vs Observed Mean Investment

	c = 1		c = 20		c = 55		c = 100	
Group size	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
1	5.69	5.02	5.14	4.69	4.14	3.89	2.86	2.93
2	4.95	4.47	4	3.55	2.25	2.34	0	1.26
3	4.38	3.98	3.11	3.02	0.78	1.42	0	1.17
6	3.23	3.13	1.33	1.89	0	1.15	0	0.81
	Socially efficient investment = 3.32		Socially efficient investment = 3		Socially efficient investment = 2.42		Socially efficient investment = 1.67	

Team Production and Partnership Stability: Why Not Go Solo?

- Major benefit of being the member of a multi-boat partnership is the ease of searching for lost nets
  - It took the 7 boat partnership an average of 14 manhours to find each lost net---2 hours per boat per net.
  - Searching for net in single boat likened to "searching for a contact lens in a swimming pool"
  - Cost of constructing a replacement net: 1200 man-hours

2^{nd} Institutional Solution: Oil Prorationing in Texas

- Each well on an oil field is assigned a number (the "yardstick").

- If an extractor owns multiple wells, he behaves the same as if he owned one well with a yardstick equal to that of the sum of his wells. So each extractor can be *regarded* as owning only one well.

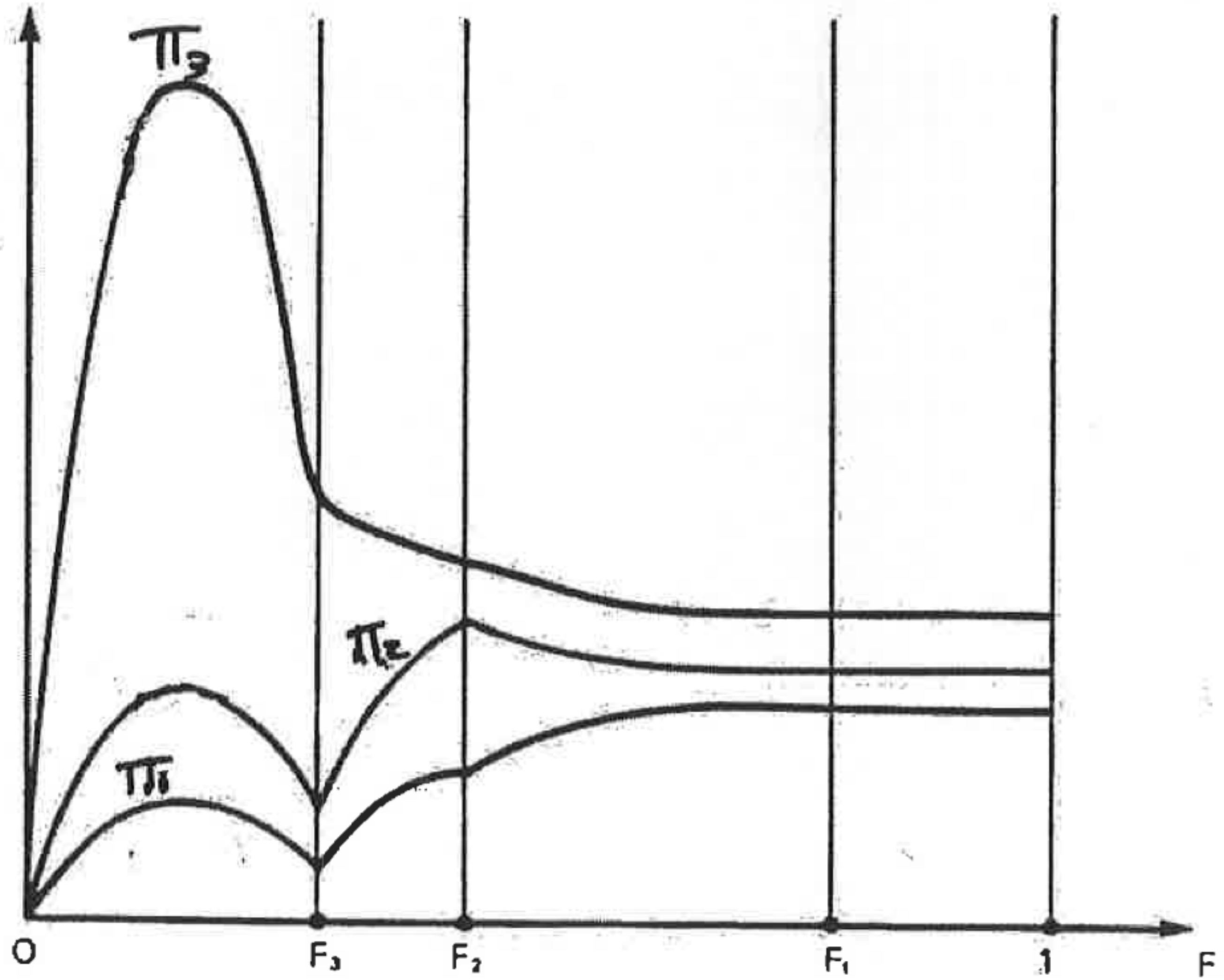
- Texas Railroad Commission sets a percentage (F) of everyone's yardstick that is the maximum the well is allowed to extract. Call that the "quota."

$$\text{Firm i's maximizes } x_i[\overline{p} - A(x_i + X_{\sim i})] \text{ s.t. } x_i \in [0, Fq_i]$$

- In Nash equilibrium, wells with yardsticks smaller than some threshold will be constrained at Fq_i while wells with larger yardsticks will be unconstrained.
- Consider the Nash equilibrium profits of each extractor as a function of the quota F: the "induced preferences," $\Pi_i(F)$.

Properties of the Induced Preferences

- **Nesting**: since, for any quota (F), firm with the smallest yardstick is allowed to produce the least, as F tightens, it binds first on the well with the smallest yardstick,… and last on the well with the largest yardstick:
- **Unconstrained monotonicity**: every extractor prefers a tighter quota if it does not bind on him.
- **Complete agreement**: If two quotas each bind on a set of extractors, they will agree on their ranking of those two quotas.
- **Continuity**: each induced preference is continuous in F.



Induced preferences: not single peaked but sufficient for median voter result

Implications

- The quota chosen if the extractors were to vote under majority rule is the ideal point of the extractor with the median yardstick.
- That quota will maximize profits from the field if all yardsticks are equal but will be too lax if heterogeneous yardstick sizes.
- If two politicians competing to be on TRC commit to platform (F), then---if only oil extractors vote---the winner would set the quota equal to the ideal point of the voter with the median yardstick (cont'd)

Implications (cont'd)

- If extractors (major oil companies) from outside Texas are removed from electorate, the platform which wins will be even less restrictive.
- Presumably, if consumers who are not extractors vote, winning platform would be even less restrictive.

Results of Prorationing

- According to Libecap and Wiggins, prorationing:
  - eliminated pumping contests exceeding MER
  - reduced wasteful aboveground storage.
- However, institution favored small extractors.
- Despite literature's small country assumption, attempts to solve commons problems may have significant price effects.

Conclusion

- As Ostrom and others have pointed out, many different solutions to the commons problem have proved workable.

- Studying the various solutions and formalizing them can provide endless fun for the applied theorists in this room.

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