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Strategic relationships in resource markets I

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A warm-up problem

- Consider exhaustible resource (e.g., oil), imported by a country (or, group of countries coordinating actions)
  - Policy question: when to develop and adopt a substitute?
- Monopoly seller decides on supplies at each period, understanding the buyer's policy
- This is the situation considered by Dasgupta, Gilbert, and Stiglitz (1983)
- How should the technology program be designed?

A warm-up problem

- The buyer's problem is to choose timing for the substitute (T) which has unit cost c when used at rate $y_t>0$ and development cost C(T):

$$\max_{\{T, y_t \geq 0\}} \int_0^T \{u(q_t) - p_t q_t\} e^{-\delta t} dt$$
$$+ \int_T^\infty \{u(q_t + y_t) - p_t q_t - c y_t\} e^{-\delta t} dt$$
$$-C(T).$$

- The first line is the consumer surplus flow from consuming at rate q_t, second is this flow when the substitute is in place after T, and the third is the development cost

A warm-up problem

- Assumption is that the buyer can first choose T and $\{y_t\}$, and the seller responses by solving:

$$\max_{\{q_t\}} \int_0^T p_t q_t e^{-\delta t} dt + \int_T^\infty p_t q_t e^{-\delta t} dt$$

- subject to the resource constraint:

$$\int_0^\infty q_t dt = Q_0, q_t \geq 0.$$

- Thus, the buyer commits to its policy, and the seller's best-response determines how q_t and p_t develop as a result

What is important here?

- The supply side is not under full control when policies are designed
  - Important feature that applies to climate change as well
- Policies can be used to extract rent from resource sellers
  - In this structure, timing T will be chosen such that the price path is as low as possible, and the technology might be developed before used, i.e., $y=0$ also for some $t>T$.
  - Policy maker has monopsony power
- The seller has monopoly power
  - Seems reasonable, but this is not necessary for this problem to be interesting, as we will see
- The situation has a flavor of a bargaining problem
  - Indeed, the bargaining problem here is well known in economics

Questions

- The DGS (1983) setting is a useful starting point but it is quite specific
- Under which circumstances efficiency could be implemented?
  - What instruments are sufficient?
    - Bergstrom 1982
  - Important policy question for climate change
    - Green paradox discussion
  - Import tariffs or taxes on consumption as instruments influence consumption rate direcly; commitment becomes an issue.
    - Maskin&Newbery 1990, Karp&Newbery 1993
  - Commitment leads to the connection to Coase conjecture
    - Hörner&Kamien 2004, Liski&Montero 2009

Further questions

- The order of moves: the seller is naturally the first mover
  - Supplies can be used to shape the policy
  - Gerlagh&Liski 2011
- Incomplete information: Only the seller knows how much resource there is left
  - Gerlagh&Liski 2011
- The R&D success might not be granted
  - Supplies influence how much R&D taken
  - Harris&Vickers 1995

Structure of the lectures

1. Connection between Coase and Hotelling
   – Helps to see the general structure of the problem
   – Lessons from durable good monopoly
   – Application: pollution permit market

2. Bilateral resource monopoly
   – When the seller has market power
   – The seller might influence the policy by “bribing” through its supply policy
   – Application: optimal carbon tax

3. Contracting and the resources
   – Most resources are traded in a forward market

Coase and Hotelling

- Durable-good monopoly
  - Coase conjecture (1972)
  - Among the best understood models of dynamic competition in economics
  - Great if lessons can be exported to other fields

- Exhaustible-resource monopsony
  - Builds on Hotelling (1931)
  - Conceptual connection to Coase: Karp and Newbery (1993); Hörner and Kamien (2004)

Conceptual connection

- Reasoning
  - Durable goods: monopolist faces a ceiling on cumulative demand
  - Resources: strategic agent=policy-maker caring about consumer surplus and facing a ceiling on cumulative supply

- Importance
  - Basis for thinking about the resource dependence as Coasian problem
  - Design of policies targeted at influencing resource consumption and imports
  - Optimal tariffs/taxes on oil (Bergstrom, 1982)
  - Climate policies

Coase conjecture

- Durable goods
  - arises only if consumer valuations decline as the market saturates (stock increases)
  - conjecture: monopolist sells at the lowest valuation price if consumers are patient enough (=trades are frequent)
- Resources
  - Stock is the resource stock, and the private value changing is the extraction cost
  - Conjecture: if sellers can wait, the buyer pays the highest cost price
- In both cases, the market captures the surplus
  - When transactions frequent

Model: durable goods

- We build on Kahn (1986), as do Hörner and Kamien (2004)
- P(S)=rental price when 'stock' of the good is S
- Monopolist produces at rate dS/dt=q with convex cost γ(q)
- Market price if path $(S_z)_{z>t}$ is known:

$$p_t = \int_t^\infty P(S_z) e^{-\delta(z-t)} dz$$

- Commitment solution

$$\max_{q_t} \int_0^\infty \{p_t q_t - \gamma(q_t)\} e^{-\delta t} dt$$

Model

- First-order condition:

$$P(S_t) + P'(S_t)(S_t - S_0) = \delta\gamma'(q_t) - \gamma''(q_t)\frac{dq_t}{dt}$$

- Left: marginal revenue
- Right: marginal cost
- Note the source of the commitment problem

Model: resources

Consider then the resource version this model

- Monopsony consumes the good at rate q=dS/dt where S is the stock extracted (stock in the ground: $Q_t=Q_0-S_t$)
- U(q)=concave utility
- Seller's unit cost=c(S)
- Market arbitrage condition (Hotelling rule)

$$\frac{dp_t}{dt} = \delta(p_t - c(S_t))$$

Model

- Rewrite the Hotelling rule:

$$p_t = \int_t^{\infty} \delta c(S_\tau) e^{-\delta(\tau - t)} d\tau.$$

- Durable goods price:

$$p_t = \int_t^{\infty} P(S_\tau) e^{-\delta(\tau - t)} d\tau$$

Model

- Back to resources: commitment solution

$$\max_{q_t} \int_0^\infty \{U(q_t) - p_t q_t\} e^{-\delta t} dt$$

- First-order condition

$$c(S_t) + c'(S_t)S_t = U'(q_t) - \frac{1}{\delta} U''(q_t) \frac{dq_t}{dt}$$

- Models are the same but for the symbols
  - P(S)=-δc(S)
  - ϒ(q)=–U(q)

- But we need to pay careful attention whether there is a substitute for the resource

Model

- Consider the following specification of Kahn (1986)
  - P(S)=v, constant
  - $\gamma(q)$=convex

- **Proposition**: monopoly's first-best outcome is the equilibrium

- Why? The consumer heterogeneity is absent, the monopoly can charge v at all times, and there is no commitment problem with this outcome

- This is a good benchmark for the resource case

The role of the substitute

- The analogue to resources suggests that the buyer should be able commit to first best if
  - C(S)=c, constant
  - U(q)=concave

- The buyer's first best
  - Commit not to buy ε-amount but far in the future
  - Price collapses to cost c as seller's race for early sales

- However, there is no way the buyer can commit to this, if he plans to switch to a substitute at some date, and cannot discriminate between the resource and substitute sellers

- We have to consider two cases: subsitute/no substitute

The difference

- Long-run payoff, if there is a substitute

$$W \equiv W(\bar{q}) = U(\bar{q}) - \bar{p}\bar{q}$$

  where $\bar{p} = U'(\bar{q})$ is the choke price (substitute cost)

- It is not sequentially rational to sell at price lower than the choke price (in present value), provided the buyer cannot prevent this (e.g., no discrimination)

- Rather the price is $p_0 = c + (\bar{p} - c)e^{-\delta T}$

- The only way to depress p_0 is through delay of T

The commitment solution

$$V = \max_{\{q_t, T\}} \int_0^T \{U(q_t) - p_t q_t\} e^{-\delta t} dt + \frac{1}{\delta} e^{-\delta T} W(\bar{q})$$
$$s.t.$$
$$\frac{dQ_t}{dt} = -q_t, Q_0 > 0.$$
$$\frac{dp_t}{dt} = \delta(p_t - c), p_T = \bar{p} > 0$$

- Note: boundary value of p_T is fixed, so no transversality condition (different case if p_T and thus p_0 free).
- However, we need one for T.

The commitment solution

- Current-value Hamiltonian:

$$\mathcal{H}_t = U(q_t) - p_t q_t - \lambda_t q_t + \eta_t \delta (p_t - c)$$

- Interior first-order conditions:

$$\begin{aligned}
\frac{\partial \mathcal{H}_t}{\partial q_t} &= U'(q_t) - p_t - \lambda_t = 0 \\
\frac{d\lambda_t}{dt} &= \delta \lambda_t - \frac{\partial \mathcal{H}_t}{\partial Q_t} = \delta \lambda_t \\
\frac{d\eta_t}{dt} &= \delta \eta_t - \frac{\partial \mathcal{H}_t}{\partial p_t} = q_t.
\end{aligned}$$

The commitment solution

- Choice of T:

$$\frac{\partial V}{\partial T} = e^{-\delta T}\mathcal{H}_T - e^{-\delta T}W(\bar{q}) = 0.$$

- Combining FOCs:

$$c = U'(q_t) - \frac{1}{\delta}U''(q_t)\frac{dq_t}{dt}$$

- Integrating the shadow value of price:

$$\eta_t = Q_0 - Q_t.$$

- Combining:

$$\{U(q_T) - U'(q_T)q_T\} + \delta(\bar{p} - c)Q_0 - W(\bar{q}) = 0.$$

Interpretation:

$$W(\bar{q}) - \{U(q_T) - U'(q_T)q_T\} = \delta(\bar{p} - c)Q_0 > 0$$

- Right: discount on the purchase cost from delaying the switch to the substitute
- Left: the consumption distortion

Important:

1. If no substitute (or discrimination possible), W=0. Then, p_0 is a jump state (i.e., free), with appropriate transversality conditions. It is optimal to set p=c for all, and the above reason for time-inconsistency disappears.

2. If W>0, the distortion in the purchase path depends on Q_0 which changes over time. Thus, the time-inconsistency.

Interpretation continued

- The key condition, illustrating the distortion:

$$W(\bar{q}) - \{U(q_T) - U'(q_T)q_T\} = \delta(\bar{p} - c)Q_0 > 0$$

- Recall: $W(\bar{q}) = U(\bar{q}) - \bar{p}\bar{q}$

- The buyer commits to distort consumption below q_T at T, in order to extend the consumption path, and thereby depress the price
- The commitment problem: the distortion depends on how much stock left. A feature specific to the resource model, not present in durable goods
- The equilibrium without commitment cannot be solved as a control theoretic exercise.

Equilibrium analysis: the set up

- Stages $i = 1, ..., N < \infty$
- Stock in the ground $Q_i = \bar{S} - S_i.$
- Buyer’s strategy $C = (C_1(\cdot), ..., C_N(\cdot))$
- History $h_i = ((q_1, p_1), , .., (q_{i-1}, p_{i-1})) \in \mathbb{R}_+^{2(i-1)}$
- Price reactions $P = (P_1(\cdot), ..., P_N(\cdot)),$
- We set c=0

Equilibrium analysis: the set up

- Buyer's payoff

$$V_i(h_i, C, P) = \sum_{j=i}^{N} \{U(q_j) - p_j q_j\} e^{-\delta(j-i)} + \frac{e^{-\delta(N+1)}}{1 - e^{-\delta}} W(\bar{q}).$$

- Equilibrium: (C^*, P^*) such that C maximizes $V_i(h_i, C, P^*)$ and P such that the following holds (Hotelling rule):

$$P_i(h_i, C^*) \geq \delta P_{i+1}(h_{i+1}, C^*)$$

- Equality holds whenever $Q_{i+1} > 0$

Equilibrium analysis: the set up

- For this structure, the payoff relevant history is fully summarized by the remaining stock (Kahn, 1986)

$$C_i(h_i) = C_i(Q_{i-1}) \text{ and } P_i(h_i, q_i) = P_i(Q_{i-1} - q_i) = P_i(Q_i).$$

- We look for such consumption and pricing functions when the period length becomes small, i.e., the stock is consumed frequently
- Let $t = i\Delta$ and $i \in \{1, ..., Q_0/\bar{q}\Delta\}$
- Important: the remaining number of stages will be inconsequential for continuation payoffs, and this will facilitate stationary Markov strategies

Equilibrium solution

- Rewrite the buyer's payoff for period length Δ:

$$V_t(Q_{t-\Delta}) = [U(q_t) - P_t(Q_t)q_t]\Delta + e^{-\delta\Delta}V_{t+\Delta}(Q_t)$$

- Optimal choice:

$$[U'(q_t) - P_t(Q_t) + P_t'(Q_t)q_t\Delta]\Delta - e^{-\delta\Delta}V_{t+\Delta}'(Q_t)\Delta = 0.$$

- Envelope condition:

$$V_{t+\Delta}'(Q_t) = -\sum_{j=t}^{M} P_j'(Q_j)q_j\Delta e^{-\delta(j-t)\Delta}$$

Equilibrium solution

- Hotelling rule:

$$P_t(Q_t) = e^{-\delta\Delta} P_{t+\Delta}(Q_{t+\Delta})$$

- Using the Hotelling rule in the envelope condition:

$$V'_{t+\Delta}(Q_t) = -P'_t(Q_t) \sum_{j=t}^{M} q_j \Delta = -P'_t(Q_t) Q_{t-\Delta}.$$

- Inserting to the buyer's best-response:

$$[U'(q_t) - P_t(Q_t) + P'_t(Q_t) q_t \Delta]\Delta + e^{-\delta\Delta} P'_t(Q_t) Q_{t-\Delta} \Delta = 0.$$

- In the limit Δ→0

$$U'(q_t) - P_t(Q_t) + P'_t(Q_t) Q_t = 0.$$

Interpretation

$$U'(q_t) - P_t(Q_t) + P_t'(Q_t)Q_t = 0.$$

- Almost as its static equivalent: marginal utility equalized with marginal purchase cost, but the price depends on the remaining cumulative consumption

- There is a stationary price function P(Q) because the continuation payoffs do not depend on the remaining time (assumption on N and Δ)

- From Hotelling rule $P'(Q_t)\dfrac{dQ_t}{dt} = \delta P(Q_t)$

- That is: $q_t = -\dfrac{\delta P(Q_t)}{P'(Q_t)}$

Equilibrium solution

- Inserting to the consumption rule:

$$U'\left(-\frac{\delta P(Q)}{P'(Q)}\right) - P(Q) + P'(Q)Q = 0$$

- This first-order differential equation for P(Q)≥0 on [0,∞). We have P(0) at choke level and P(Q) close to zero for Q→∞

- Can be solved explicitly when functional forms assumed. Let us set U(q)=ln(q).

- We obtain

$$P'(Q) = -\frac{\delta P(Q)^2}{1 - \delta P(Q)Q}$$

Equilibrium solution

- The previous can be solved for P(Q)

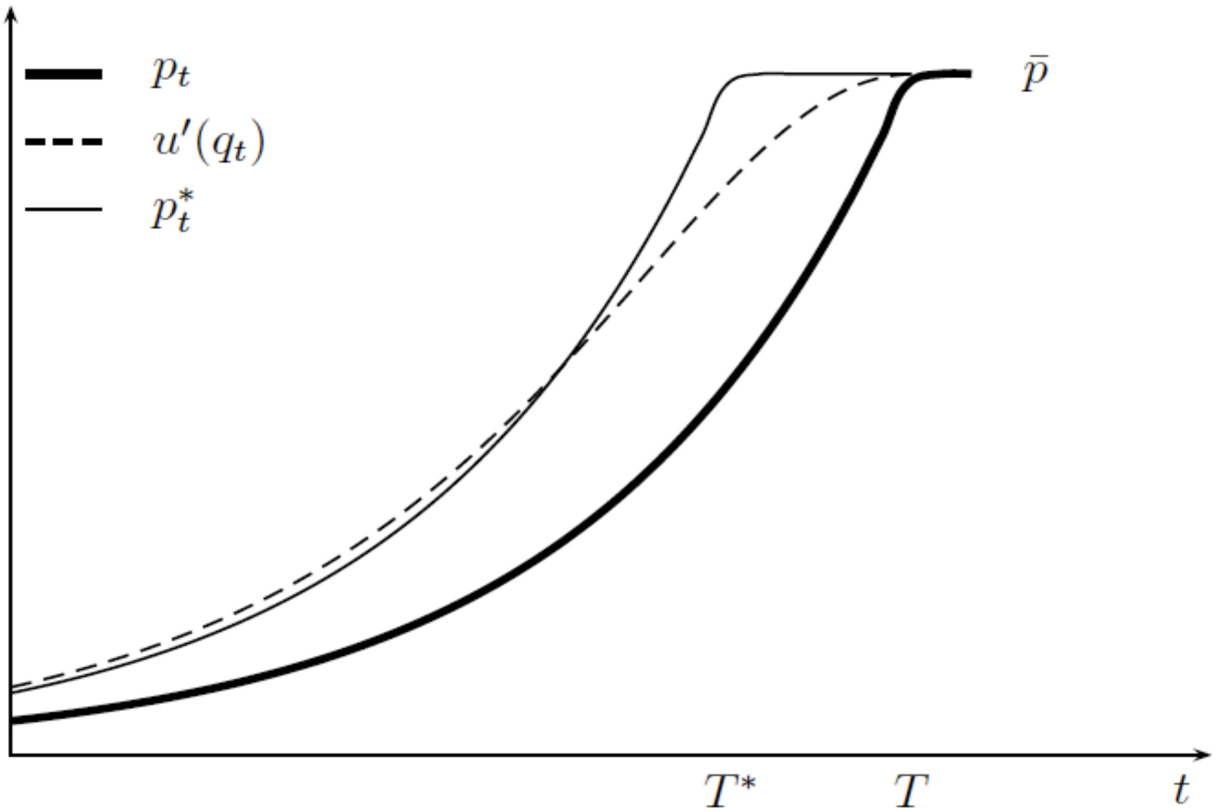
$$P(Q) = \bar{p}\sqrt{\delta^2\bar{p}^2Q^2 + 1} - \delta\bar{p}^2Q.$$

- Interestingly: $\lim_{\bar{q}\to 0} P(Q) = 0$

- The buyer captures the entire surplus, when the substitute vanishes

- When there is substitute, then the price as in the figure: the buyer delays consumption to depress the price level, compared to the social optimum

The equilibrium over time



The equilibrium outcome

Proposition 1 *Consider a given resource stock* Q_t *to be consumed by a single buyer at an arbitrarily frequently rate* ($\Delta \to 0$)*. The resource rent is shared between the buyer and the competitive suppliers as long as the buyer switches to a valuable substitute at the exhaustion of the resource* ($W(\bar{q}) > 0$)*. The rent is fully captured by the buyer as* $W(\bar{q}) \to 0$*.*

Some conclusions and remarks

- What is the analogue of the substitute in the durable-good model?
  - We would need two types of goods, durable and non-durable
  - Highly-valued durable-good segment served first, and then the competitive non-durable segment
  - Outside consumers would improve the bargaining position of the durable-good buyers
  - This interpretation is not that natural, in contrast with the resource case

Other lessions from durable goods

- Renewable resources
  - The arrival of new consumers in durable goods, Bond and Samuelson, 1984
  - This has not been done
- Bilateral bargaining and incomplete information on the seller's type
  - See Fudenberg and Tirole, 1991
  - Not done, but see Gerlagh&Liski 2011
- Reputational equilibria
  - See Gul et al. 1989

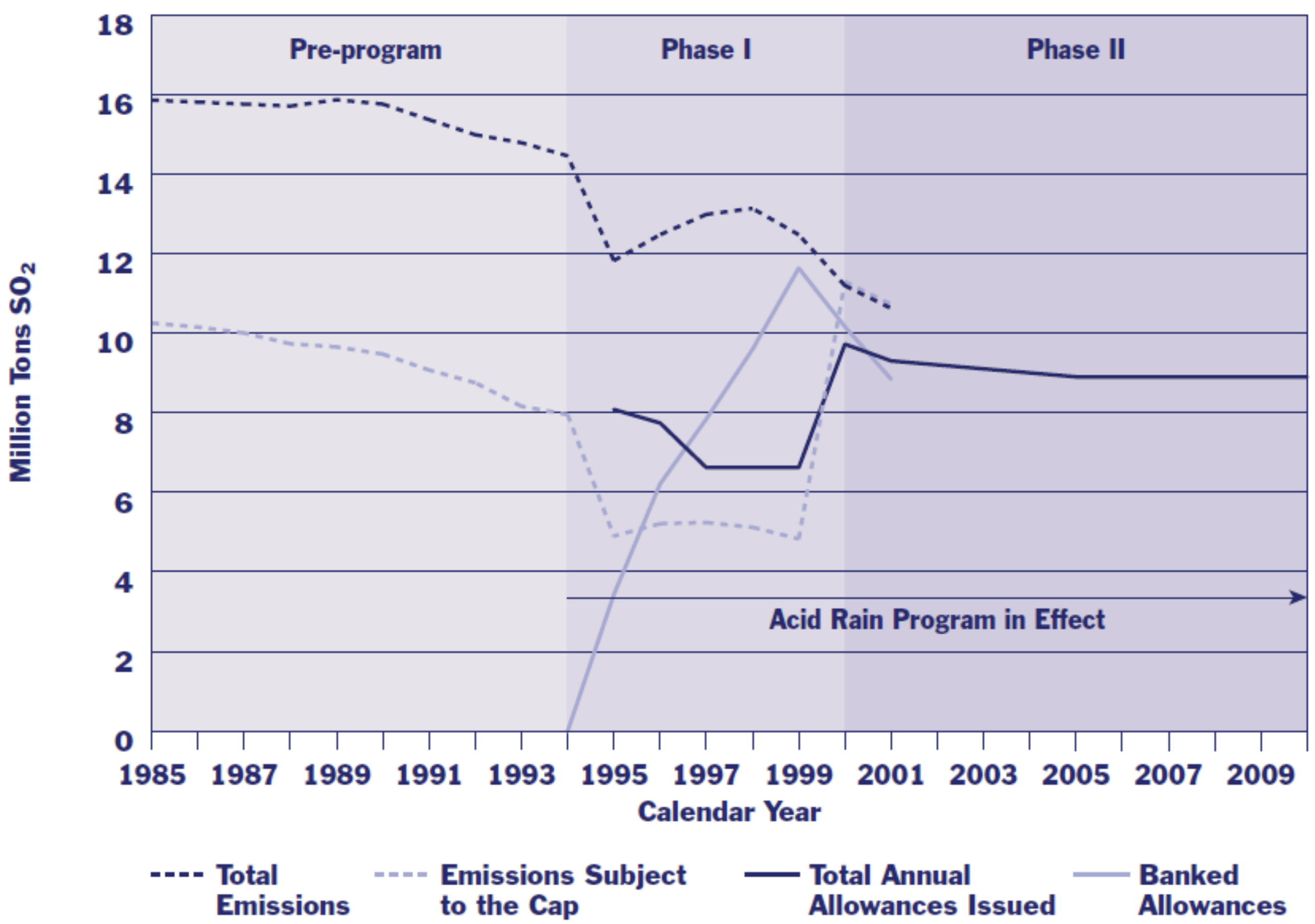
Lessons

- Conclusions for climate policies
  - Broad policy instruments do not capture rents because they do not prevent the resource suppliers from competing with the substitute
  - One needs to achieve discrimination through targeted instruments such as import tariffs or subsidies to alternative technologies
- Alternative interpretations
  - Market for pollution quotas (Liski&Montero 2011)
  - Resource markets with multiple endowments and demands

Application: dynamic pollution permit market

- Motivating example: the US SO2 program
  - Generous early allocations
  - Option to store permits for future use when allocations become tighter
  - Similar design is common
- Some firms ended up holding large fraction of the “permit bank”
- What is the effect of market power on the equilibrium path? The theory connecting to Coase theory can help to understand this.

The two phases of the SO2 program



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Source: Harrison, Ellerman, Joskow,Pew Center Report, 2003

The two phases of the SO2 program

Evolution of Largest Holding Companies' Compliance Paths in the Sulphur Market

	American Elec. Power		Southern Company		Group of Four		All firms	
Year	Permits	Emissions	Permits	Emissions	Permits	Emissions	Permits	Emissions
1995	1,194,410	739,322	1,079,502	534,392	3,607,506	2,049,809	8,694,296	5,298,617
1996	1,182,429	926,215	1,079,085	565,097	3,591,282	2,259,687	8,271,366	5,433,351
1997	883,634	959,556	991,297	591,411	3,001,934	2,312,083	7,108,052	5,474,440
1998	883,634	871,738	991,297	642,093	3,001,728	2,229,636	7,033,671	5,298,498
1999	883,634	723,589	991,297	614,790	3,001,809	2,088,510	6,991,170	4,944,666
2000	663,514	1,136,095	734,464	1,048,296	2,121,591	3,307,858	9,714,830	11,202,052
2001	663,514	998,620	734,464	957,872	2,119,625	3,090,712	9,307,565	10,631,343
2002	663,514	979,653	734,464	959,338	2,119,625	3,059,693	9,282,297	10,175,057
2003	653,062	1,039,413	728,778	988,245	2,103,487	3,161,696	9,123,376	10,595,945
2004	653,062	1,017,878	728,778	969,568	2,103,487	3,096,652	9,123,376	10,432,326
2012	653,062	890,164	728,778	847,915	2,103,487	2,708,114	9,123,376	9,123,376
TOTALS								
Cumulative by 1999	5,027,741	4,220,420	5,132,478	2,947,783	16,204,259	10,939,725	38,098,555	26,449,572
diff. 1999		807,321		2,184,695		5,264,534		11,648,983
Cumulative by 2003	7,671,345	8,374,201	8,064,648	6,901,534	24,668,587	23,559,684	75,526,623	69,053,969
diff. 2003		−702,856		1,163,114		1,108,903		6,472,654
Cumulative by 2012	13,548,903	16,960,388	14,623,650	15,080,208	43,599,970	49,681,131	157,637,007	157,054,629
diff. 2012		−3,411,485		−456,558		−6,081,161		582,378

Source: Liski-Montero, Economic Journal 2011

A simple model

- Large number of polluting sources
  - u=counterfactual emissions over time
  - a=allowances/permits over time
  - s_0=initial stock allocation given at t=0
  - $c_i(q)$=abatement costs for sources
- Competitive equilibrium:

Marginal costs equalized $p_t = c_i'(q_t^i)$

Hotelling rule $\mathrm{d}p_t/\mathrm{d}t = rp_t, \text{ for } 0 \leq t < T,$

Exhaustion $s_0 = \int_0^T (u - a - q_t)\, \mathrm{d}t.$

Terminal condition $q_T = u - a,$

A simple model

- Assume a dominant firm (e.g., cartel) and a fringe of competitive agents
- Market power depends on stock allocations relative to efficient allocations, as defined here:

DEFINITION 1. *Efficient consumption shares of the initial stock, s_0, are defined by*

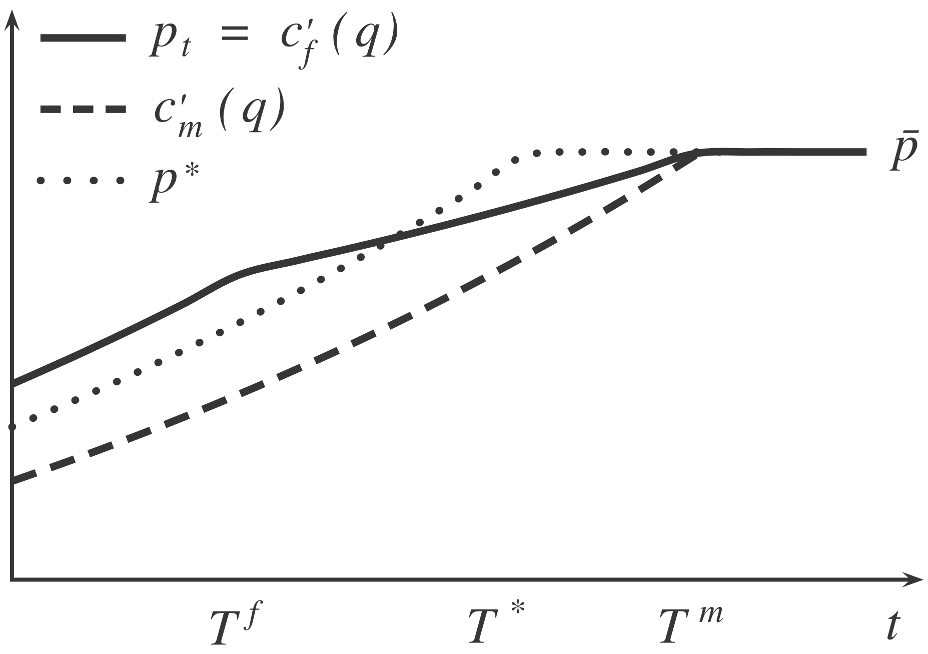
$$s_0^{m*} = \int_0^{T^*} (u^m - q_t^{m*} - a^{m*})\mathrm{d}t$$

$$s_0^{f*} = \int_0^{T^*} (u^f - q_t^{f*} - a^{f*})\mathrm{d}t,$$

where the pair $(q_t^{m*}, q_t^{f*})_{t\geq 0}$ is the socially efficient abatement path.

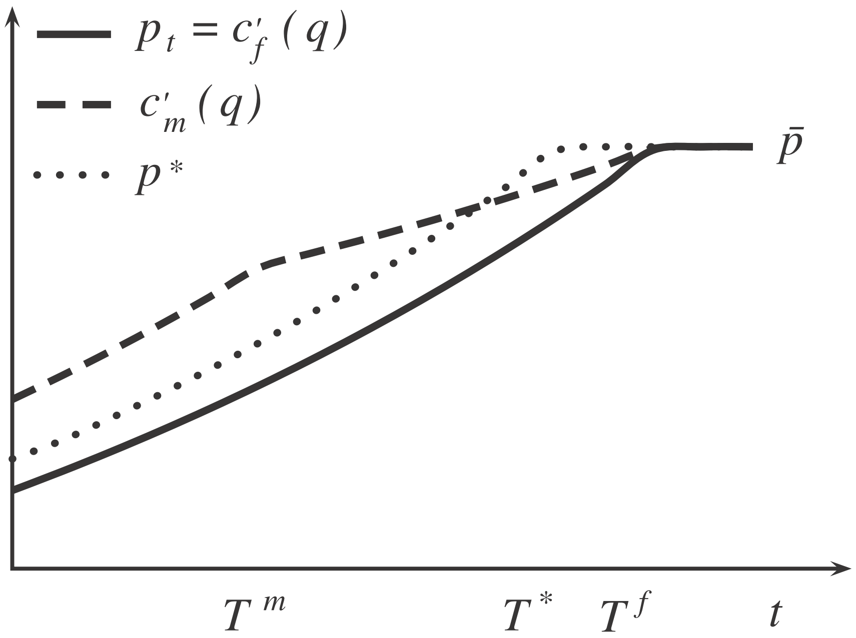
The large firm as a seller

- When allocation s^m exceeds the efficient allocation, the standard exhaustible-resource model follows:



The large firm as a buyer

- When allocation s^m falls short the efficient allocation, the time-consistency restrictions limit the market power:



The conclusion for the SO2 program

- All major players where short of their intertemporal needs, so that the equilibrium was in the domain of the buyer power

- Marker power not likely to be a major concern