Strategic relationship in resource markets III

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The Problem: forward contracting in oligopolistic resource markets

- Nash Cournot equilibrium in exhaustible-resource oligopoly (Hotelling model: $MR_t^i = \delta MR_{t+1}^i$)
- usual organization of trade in these models: only spot transactions
- most resource commodities traded in forward markets also
- how does forward contracting of deliveries affect the equilibrium path

- we will exclusively focus on the strategic reasons associated to forward contracting and NOT on hedging reasons coming from demand/supply uncertainty (which are also present in perfectly competitive markets)

What is forward trading? (Allaz and Vila, JET 1993)

- Cournot market preceded by a forward market for a reproducible commodity
- consider two periods $t = 0, 1$ and two firms i, j with constant marginal costs c
- forward sales at $t = 0$ are denoted by f^i, f^j
- production at $t = 1$ are denoted by q^i, q^j
- inverse demand in the spot market is given by $p^s = a - (q^i + q^j)$

Spot subgame at $t = 1$ given (f^i, f^j)

- Spot profits are:

$$\pi_i^s = p^s(q^i + q^j)(q^i - f^i) - cq^i$$

- $f > 0$ makes marginal revenue to jump up

$$\Longrightarrow q^i = \frac{a - c + 2f^i - f^j}{3} > q_i^{pure\ spot}$$

$$\Longrightarrow p_s = \frac{a + 2c - f^i - f^j}{3} < p_s^{pure\ spot}$$

Forward subgame at $t = 0$

- forward sales chosen:

$$\pi_i = \delta\underbrace{[p^s(f^i, f^j)q^i(f^i, f^j) - cq^i(f^i, f^j)]}_{\text{Cournot profit}} + \underbrace{[p^f - p^s(f^i, f^j)]}_{\text{arbitrage profit}} f^i$$

- but arbitrage profit$= 0$, so $f^i = (a - c)/5$ and firms end up contracted

- if $f^j = 0$, $f^i > 0$ in an effort to get the Stackelberg share

- Firms face a prisoners' dilemma; market has become more competitive (i.e., greater production)

back to exhaustible-resources

- reproducible goods: pro-competitive effect based on expansion of output
- exhaustible-resource is a capacity constraint, firms cannot expand production
- are oligopoly rents then left intact? (see Lewis&Schmalensee [1980] and Ulph&Ulph [1989] for this conjecture)

This lecture

- based on Liski&Montero, R&R RAND J.
- the pro-competitive effect is there but the mechanism is different from Allaz&Vila
- it can be significant: when initial resource stocks of the two firms are the same, the SPE path approaches perfect competition as transactions become more frequent

- however: assymetries in initial stocks help firms to credibly escape part of the competitive pressure of forward contracting
- unique feature of the resource model: contracting and the resulting equilibrium depends on resource endowments

Relevance/Related Literature

- basic textbook description in resource economics assumes spot competition:
  - large literature on exhaustible-resource markets under oligopolistic market structure
  - none of these papers consider forward markets
  - futures markets are not a commitment device, but quite the opposite (except in some asymmetric cases)

- capacity constraints in oligopoly: recent papers in dynamic price competition (Dudey, QJE 1992; Biglaiser-Vettas 2008; Talluri and Martinez, 2010)
- forward trading in oligopoly : Allaz & Vila (1993); Mahenc & Salanie (2004); Liski & Montero (2006), all in JET
- forward trading in practice (mainly electricity markets)
  - Wolfram (AER, 1998): little effect in the UK power pool, despite firms were highly contracted
  - Wolak (IEJ, 2000): significant effect in the Australian market

- Fabra and Toro (IJIO, 2005): forward contracts facilitated collusion in the Spanish market
- Bushnell et al (AER 2008): strong effect in California, New England and PJM
- Others: Fabra and de Frutos (2010); Liski and Kauppi (2008)

Two-period model

- there are two periods, $t = 1, 2$, two firms, i, j, and no extraction costs, $c = 0$
- firms' initial stocks are: s_1^i and s_1^j
- firms' spot deliveries in period t are: q_t^i and q_t^j
- per-period (spot) demand: $p_t^s = a - (q_t^i + q_t^j)$
- discount factor: $\delta < 1$

- firms attend the spot market in $t = 1, 2$ by simultaneously choosing quantities q_t^i and q_t^j
- firms are also free to sell/buy forward contracts that call for delivery of the good at any of the spot markets that follow (competitive consumer/speculators clear the market):

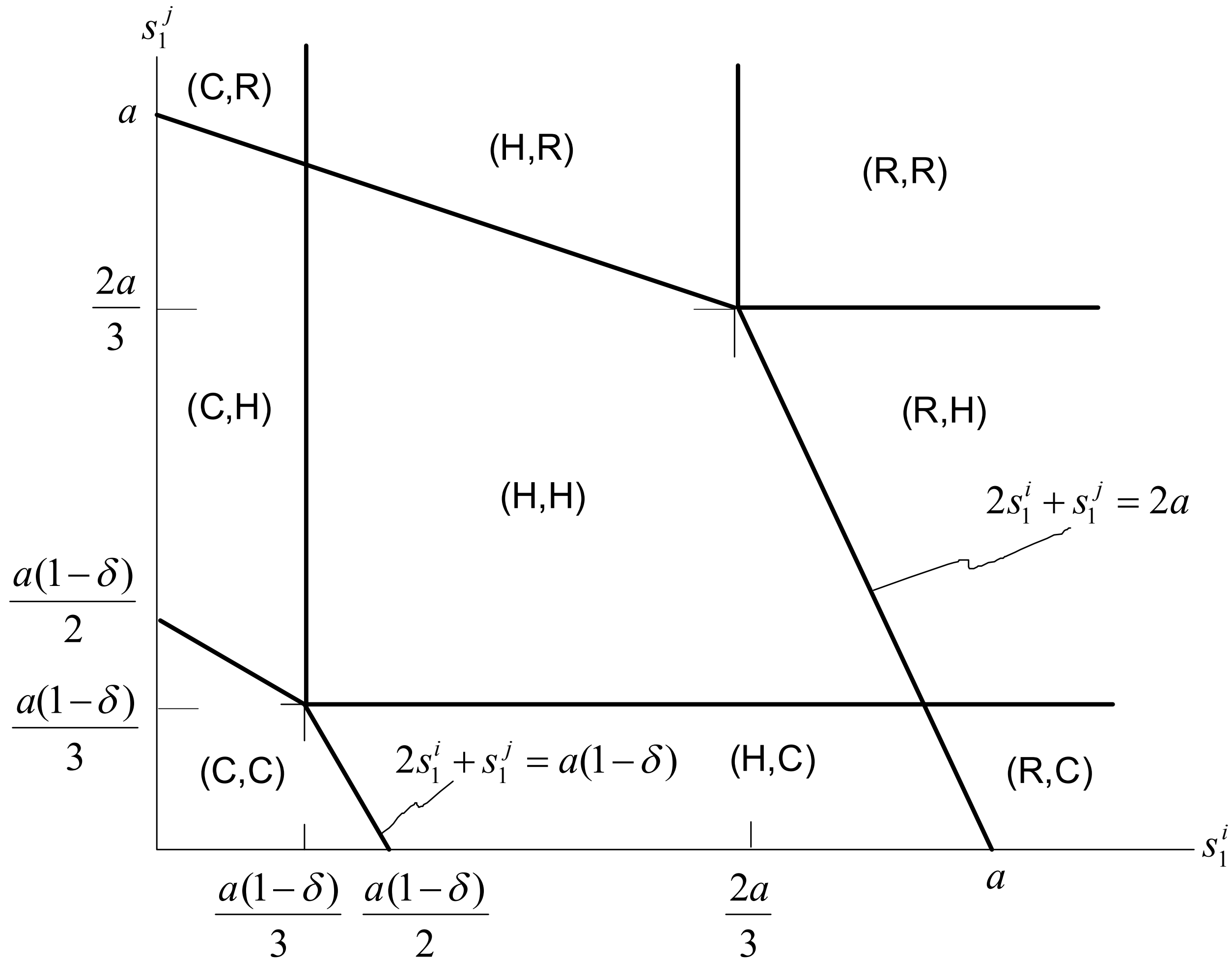
$$\underbrace{\text{forward — spot}}_{t=1} \quad — \quad \underbrace{\text{forward — spot}}_{t=2}$$

- forward transactions by i in period 1: $f_{1,1}^i$ and $f_{1,2}^i$
- forward transactions by i in period 2: $f_{1,2}^i$

- forward clearing price (i.e., striking price) at t when taking a forward position for $\tau \geq t$ is: $p^f_{t,\tau}$

Subgame Perfect Equilibrium

- Look first at the pure-spot equilibrium
- If stocks are neither too large nor too small (Hotelling world):
  - $s_1^i = q_1^i + q_2^i$ for both i and j
  - $\delta a > a - 2q_1^i - q_1^j = \delta(a - 2q_2^i - q_2^j) > 0$
- Stocks can be of any size (but there are only two periods); see figure


s_1^j
a
(C,R)
(H,R)
(R,R)
$\frac{2a}{3}$
(C,H)
(R,H)
(H,H)
$2s_1^i + s_1^j = 2a$
$\frac{a(1-\delta)}{2}$
$\frac{a(1-\delta)}{3}$
(C,C)
$2s_1^i + s_1^j = a(1-\delta)$
(H,C)
(R,C)
s_1^i
$\frac{a(1-\delta)}{3}$
$\frac{a(1-\delta)}{2}$
$\frac{2a}{3}$
a

Introduce forward trading

- A strategy for player i specifies
  - a vector of forward quantities or positions for period 1, $\mathbf{f}_1^i = (f_{1,1}^i, f_{1,2}^i)$
  - an output for period 1 as a function of $\mathbf{f}_1^i$ and $\mathbf{f}_1^j$
  - a forward position for period 2, $f_{2,2}^i$, as a function of $\mathbf{f}_1^i$, $\mathbf{f}_1^j$ and remaining stocks s_2^i and s_2^j
  - an output for period 2, q_2^i, as a function of $F_2^i = f_{1,2}^i + f_{2,2}^i$, F_2^j and remaining stocks s_2^i and s_2^j

Consider the symmetric case: $s_1^i = s_1^j$

- Let also, for now, $f_{1,2} = f_{2,2} = 0$
- suppose that firms take positions $f_{1,1}^i$ and $f_{1,1}^j$ at the forward stage in period 1
- in a Hotelling world, the equilibrium condition for the spot subgame that starts at t must solve

$$MR_1^i = \delta MR_2^i$$

that is,

$$a - 2q_1^i - q_1^j + f_{1,1}^i = \delta(a - 2q_2^i - q_2^j)$$

and

$$q_1^i + q_2^i = s_1^i$$

solving

$$q_1^i(f_{1,1}^i, f_{1,1}^j) = \frac{a(1-\delta) + 3\delta s_1^i + 2f_{1,1}^i - f_{1,1}^j}{3(1+\delta)} \quad (1)$$

$$q_2^i(f_{1,1}^i, f_{1,1}^j) = s_2^i = s_1^i - q_1^i \quad (2)$$

- how much forward to sell/buy in equilibrium?
- best response functions in the forward subgame at $t = 1$ are given by

$$f_{1,1}^i(f_{1,1}^j) = \frac{a}{4}(1-\delta) - \frac{1}{4}f_{1,1}^j$$

so the equilibrium forward quantities are

$$f^i_{1,1} = f^j_{1,1} = \frac{a}{5}(1-\delta)$$

- firms race for higher capacity share at $t = 1$ (the market with higher prices)
- contracting reduces (in equilibrium) the price gap $p_1 - \delta p_2 > 0$
- the market has become more competitive
- firms face a similar prisoner's dilemma

- what if $f^i_{1,2}, f^j_{1,2}$ are also endogenously determined?
- in equilibrium we must have

$$a - 2q^i_1 - q^j_1 + f^i_{1,1} = \delta(a - 2q^i_2 - q^j_2 + f^i_{1,2})$$

- which leads to

$$f^i_{1,1} - \delta f^i_{1,2} = \frac{a}{5}(1 - \delta)$$

- what is important for competition is the composite $f^i_{1,1} - \delta f^i_{1,2}$, not the individual values of $f^i_{1,1}$ and $f^i_{1,2}$ (this carries through the general model)

PROPOSITION 1: If $s_1^{CH} < s_1^i = s_1^j \leq s_1^{HR}$, the SPE outcome for both i and j is given by

$$\text{(i) } f_{1,1}^i - \delta f_{1,2}^i \equiv H_1^i = \frac{a}{5}(1-\delta)$$

$$\text{(ii) } f_{1,2}^i \geq \frac{5}{1+\delta}\left[s_1^i - \frac{4a}{5}\right]$$

$$\text{(iii) } f_{2,2}^i + f_{1,2}^i \equiv F_2^i \geq \frac{3}{1+\delta}\left[s_1^i - \frac{a(11-\delta)}{15}\right]$$

$$\text{(iv) } q_1^i = \frac{1}{3(1+\delta)}\left(\frac{6}{5}a(1-\delta) + 3\delta s_1^i\right)$$

$$\text{and (v) } q_2^i = s_2^i = s_1^i - q_1^i > 0$$

Asymmetric stocks

- what if $s^j < s^i$?
- suppose further we are in Hotelling world: $s^i \in [a(1-\delta)/2, a(11-\delta)/15]$
- firm j's Stackelberg solution is to sell everything in $t = 1$ as long as

$$s^j \leq \frac{1}{2}a(1-\delta)$$

- forward trading allows the small firm to credibly commit to sell only in the first (more profitable) market (see figure 2)

PROPOSITION 2: If

$$\frac{1}{4}a(1-\delta) < s_1^j \leq \frac{5-2\sqrt{2}}{5}a(1-\delta) \equiv s_1^{ST},$$

firm j implements its Stackelberg (i.e., first-best) solution: There is a two-period equilibrium where i does not contract at all (i.e., $f_{1,1}^i = 0$) and j commits to sell only in period 1 by contracting $f_{1,1}^j$ according to

$$f_{1,1}^j \geq f_{\min}(s_1^j) \equiv \frac{4}{3}s_1^j - \frac{1}{3}a(1-\delta)$$

General model

- $1, 2, ..., n, ..., T$ depletion periods in equilibrium
- two effects boosting competition:

  1. firms face the prisoners' dilemma n times in period n; later the period, the more competitive it is

  2. early markets; competition from future propagates to the present

- $t = 1, ..., N < \infty$ periods
- Forwards in t: firms choose $\mathbf{f}_t^i = (f_{t,t}^i, f_{t,t+1}^i, ..., f_{t,N}^i)$
- Spot stage in t: firms decide deliveries q_t^i and q_t^j
- History: the initial stocks, s_1^i and s_1^j, and $(\mathbf{f}_1^i, \mathbf{f}_1^i, ..., \mathbf{f}_{t-1}^i, \mathbf{f}_{t-1}^i)$ and $(q_1^i, q_1^i, ..., q_{t-1}^i, q_{t-1}^i)$

A forward-sale strategy for firm i is a collection of functions

$$\mathbf{f}^i = (\mathbf{f}_1^i(\cdot), ..., \mathbf{f}_N^i(\cdot))$$

A spot-sale strategy for firm i, on the other hand, is a collection of functions

$$\mathbf{q}^i = (q_1^i(\cdot), ..., q_N^i(\cdot))$$

Given some strategy profile $(\mathbf{f}, \mathbf{q})$ and history h'_t, firm i's payoff at the spot stage in t is

$$W_t^i(h'_t, \mathbf{f}, \mathbf{q}) = p_t^s(\cdot)q_t^i + \sum_{k=1}^{t} p_{k,t}^f f_{k,t}^i - p_t^s(\cdot)F_t^i(t) + \delta V_{t+1}^i(h_{t+1}, \mathbf{f}, \mathbf{q})$$

where $V_{t+1}^i(h_{t+1}, \mathbf{f}, \mathbf{q})$ is the continuation payoff at the forward stage in $t+1$ and $h_{t+1} = (h'_t, q_t^i, q_t^j)$.

firm i's payoff at the forward stage in t is simply

$$V_t^i(h_t, \mathbf{f}, \mathbf{q}) = W_t^i(h_t', \mathbf{f}, \mathbf{q}).$$

The strategy profile $(\hat{\mathbf{f}}, \hat{\mathbf{q}})$ constitutes a subgame-perfect equilibrium (SPE) if for any t and history h_t

$$\hat{\mathbf{f}}_t^i(h_t) = \arg\max_{\mathbf{f}_t^i} V_t^i(h_t, (\mathbf{f}^i, \hat{\mathbf{f}}^j), \hat{\mathbf{q}}) \tag{3}$$

and for any t and history h_t'

$$\hat{q}_t^i(h_t') = \arg\max_{q_t^i} W_t^i(h_t', \hat{\mathbf{f}}, (\mathbf{q}^i, \hat{\mathbf{q}}^j)) \tag{4}$$

where $\mathbf{f}^i = (..., \mathbf{f}_t^i, \hat{\mathbf{f}}_{t+1}^i(\cdot), ..., \hat{\mathbf{f}}_N^i(\cdot))$ and $\mathbf{q}^i = (..., q_t^i, \hat{q}_{t+1}^i(\cdot), ..., \hat{q}_N^i(\cdot))$.

We can describe the equilibrium explicitly for symmetric stocks:

Proposition 1 *Consider $N < \infty$. Let T be the equilibrium stock-depletion time, where $2 \leq T < N$. Then, the symmetric SPE deliveries are given by*

$$q_t^i = \left\{ \frac{a}{3} \left[\sum_{h=0}^{n-2} \delta^h - (n-1)\delta^{n-1} \right] \left[1 + \frac{t}{3+2t} \right] + \delta^{n-1} s_t^i \right\} \frac{1}{\sum_{h=0}^{n-1}}$$

where $t = 1, 2, ..., T-1$ and $n = n(t) = T - t + 1$ (number of periods to reach exhaustion in equilibrium).

What use? We can consider the how the contract positions develop as the limits to trading opportunities vanish.
When period length vanishes, the equilibrium becomes symmetric:

Proposition: As $\Delta \to 0$, SPE deliveries per firm approach the socially efficient deliveries at any given $t > 0$.

Concluding remarks

Next steps:

- can firms sustain collusion in this market?
  - threat for trigger strategies is now competitive equilibrium
  - this is a finite horizon game (but Gul 1987)