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OLIGOPOLISTIC MANIPULATION OF SPOT MARKETS AND THE TIMING OF FUTURES MARKET SPECULATION

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Abstract

We consider the impact upon activity in a futures market for a natural resource of an oligopolistic market structure in the production of the resource for supply to the spot market. In our model, a futures market is open twice before a (single) maturity date, which coincides with the third period of spot market activity. Duopoly producers manipulate spot market prices at maturity so as to influence the value at maturity of futures contracts they hold (or have sold).

Futures market activity results from differences in opinion about the underlying demand for the resource, in a game of inconsistent incomplete information. Given the inconsistent beliefs, a rational speculator predicts the extent of manipulation by producers.

While the speculator has the option of closing out his futures position prior to maturity, and thereby not exposing himself to manipulation, in subgame-perfect equilibrium he chooses to hold open positions until maturity. Whenever players are not too risk-averse (relative to differences in beliefs), all futures trading occurs the first time the futures market is open.

Net short positions at maturity are unaffected by the timing of trading, and are Pareto-efficient, due to using take-it-or-leave-it contracts. Multiple prices of futures contracts coexist simultaneously in subgame-perfect equilibrium. Typically, some player simultaneously signs two futures contracts at different prices, not necessarily buying on one and selling on the other.

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Introduction

In the conventional approach to modeling futures markets for basic commodities, a central prediction is empirically untenable and key strategic questions relating to exercise of market power cannot readily be addressed. If traders have rational expectations (or more generally, rationally update beliefs drawn from consistent priors) contract terms which both parties to a futures trade would strictly prefer (to not trading) cannot exist, given cognizance of the other party's willingness to trade [Kreps (1977), Milgrom and Stokey (1982)]. A prediction of a zero aggregate volume of speculative activity, in response to the slightest degree of risk aversion or transaction costs, is both inescapable and readily invalidated. Hedging motives can explain only a small fraction of the huge volume of trading on commodity futures markets, and cannot explain the presence of many of the traders.

A central purpose of the alternative model we investigate here is to support a prediction that both parties to a speculative transaction may be behaving rationally. The model shows that abandoning rational expectations need not imply abandoning rational behavior: we posit that traders update their priors rationally in response to new market information, but not in response to the inconsistent priors of other traders. In fact, we simplify by eliminating all private information, basing gains from trade solely upon what Varian (1989) calls "differences in opinion", thus creating a game of inconsistent incomplete information [Selten (1982)].

Market power arises in futures markets not through barriers to trading, but indirectly, through producers' influence on the spot market price of the underlying basic commodity [Anderson (1990)]. When futures traders are conventionally modeled as price-takers, producers' influence and the resulting interaction between spot and futures prices gets buried. We illustrate how these issues come naturally forward in a simple model of a Cournot duopoly producing an exhaustible resource.

Oligopoly producers who are active in futures trading have an incentive to alter the time path of extraction so as to enhance the profitability of their futures positions. The common conjecture that speculators respond to this manipulation by closing out their futures positions prior to maturity simply does not hold up in equilibrium. We demonstrate this in the simplest possible model: three periods of spot market activity, the last the sole maturity date of take-it-or-leave-it futures contracts traded in the first two periods. A single speculator is added to the two producers. The findings of a rush to trade, oligopolistic manipulation at maturity, and yet open positions at maturity, clearly do not depend upon the expositional limitations to two producers, one speculator, two futures market periods, or take-it-or-leave-it contracts.

Section 1 describes the game. Section 2 derives its subgame equilibrium in t=2, while Section 4 does the same for t=1. Section 3 discusses the updating of beliefs. The resulting time path of prices and other qualitative characteristics of subgame-perfect equilibrium outcomes are discussed in Section 5. We conclude with a rough sketch of inferences for situations with futures trading for several sequential maturity dates.

1. The game

There are three players, a speculator S and two producers A and B, of an exhaustible resource. The latter have known initial stocks s_{a0} and s_{b0}. Each producer faces the intertemporal constraint that the initial stock has to be depleted in period 3, the maturity date of the futures contracts considered, or

$$s_{a0} = q_{a1} + q_{a2} + q_{a3} \tag{1.1}$$

$$s_{b0} = q_{b1} + q_{b2} + q_{b3} \; . \tag{1.2}$$

There are indeed three periods during which spot transactions take place. Current extraction rates (or current shipments, if stocks are available for shipment) are represented by q_{it} (i=a,b; t=1, 2,3) and equal to current consumption, so that there are no stocks on the demand side.[1] Each period exhibits the instantaneous inverse market demand curve

$$p_t(q_{at} + q_{bt}) = \frac{\omega_t}{\beta} - \frac{1}{\beta}(q_{at} + q_{bt}) \qquad t = 1, 2, 3 \quad (2)$$

with $\beta>0$.[2] The underlying strength of market demand is represented by $\alpha>0$, which is random. In each spot market, $\omega_t=\alpha+\gamma_t$ is observed. The γ_t are independent of each other and have mean zero. The three players have inconsistent prior expectations of α, which will form the basis for futures trading. These priors are assumed to be common knowledge.[3]

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1. In Sections 2.1 and 4.1, we discuss opportunities for producers to manipulate extraction, and thus the value of futures contracts. If the model were complicated to allow consumers to hold stocks across spot markets, then far from undercutting manipulation, this complication would actually reduce producers' costs of manipulation, by allowing a smaller change in extraction to have the same effect on spot prices.
2. Prices are present prices, net of extraction and transport costs. The constant price path $\hat{p}$ defined below would correspond to a current (real) price path rising at a constant rate of interest. Variable interest rates would obscure the equilibrium timing pattern explored here.
3. A host of complications arise if the fact of inconsistent priors is common knowledge, but the priors themselves are private information. Some complications have yet to be considered in the literature on signaling games and refinements (van Damme (1989) and references cited there), and would clearly be beyond the scope of the present endeavor.

During the first two periods, there is futures trading on an "open outcry" futures market for take-it-or-leave-it contracts. In the third period, open futures positions are closed out at the spot price p_3.

The rules of the game are then as follows:

Step 1: Nature chooses a commitment order, which is a permutation of the order (A, B, S), each drawn with equal probability.

Step 2: The futures market opens. The players simultaneously make irrevocable announcements, each announcing an offer to sell and/or an offer to buy. Each offer is a take-it-or-leave-it price, quantity pair.

Step 3: The player designated first in the commitment order irrevocably accepts or rejects each offer made by another player.

Step 4: The player designated second in the commitment order irrevocably accepts or rejects each offer made by another player and not yet accepted.

Step 5: The player designated third in the commitment order irrevocably accepts or rejects each offer made by another player and not yet accepted. The futures market closes.

Step 6: The producers simultaneously determine their t=1 extraction plans.

Step 7: The sum $\omega=\alpha+\gamma_1$ is revealed as a result of the transactions that occurred in the spot market.

Step 8: The futures market reopens. The players simultaneously make irrevocable announcements of buy and sell orders, as in step 2.

Step 9: The player designated first in the commitment order irrevocably accepts or rejects each offer made by another player.

Step 10: The player designated second in the commitment order irrevocably accepts or rejects each offer not yet accepted.

Step 11: The player designated third in the commitment order irrevocably accepts or rejects each offer not yet accepted. The futures market closes.[4]

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4. Keeping the same commitment order each time the futures market is open allows us to focus questions of the timing of futures contracting on issues of beliefs, risk aversion and spot market manipulation.

If a different commitment order were used in the t=1 futures market, a player i who could dictate terms to player j by waiting until t=2 to trade will refuse to trade on j's terms in t=1. When risk aversion is sufficiently slight, j may be able to attain for himself the incremental gains from trading in t=1 over t=2 by offering an efficient contract giving i precisely the amount of gains from trade available by waiting until t=2. Thus, the calculation of these gains in section 4.2 is relevant to this elaboration as well.

It would add both realism and substantial complexity to require that announcements be made in steps 2 and 8 before the relevant commitment order is known [cf. Harstad and Phlips (1990)]. With that requirement, trade in t=1 would be artificially influenced by the probability of being able to extract all the gains from trade in t=2. As the net short positions we derive would clearly be unaffected by such alterations, we deem the added complexity unwarranted.

In another vein, the whole notion of a commitment order may be viewed as an overly stark focus on trading during the final few seconds before the futures market closes. We have not found a more palatable alternative. Imposing a bargaining solution, directly or by applying an equilibrium

(Footnote continues on next page)

Step 12: The producers determine, simultaneously, their t=2 extraction plans (and, implicitly, their t=3 extraction plans because of the intertemporal constraint on their stocks). The game ends.

Step 13: The spot price p_3 is revealed.

We now proceed to solving the game backwards.

2. Subgame-perfect equilibrium in t=2

2.1. The extraction subgame in t=2

In t=2, the objective functions for i=A,B to be maximized with respect to q_{i2} and q_{i3}, subject to constraint (1), are

$$q_{i2}p_2(q_{i2} + q_{j2}) + (q_{i3} - N_i)\, p_3(q_{i3} + q_{j3}) \,, \qquad (3)$$

where N_i is player i's net short position on the futures market.[5]

(Footnote continued from previous page)

selection argument to the plethora of equilibria resulting from simultaneous contract acceptance, is an unwise choice. Once bargaining over the gains from trade is introduced, the constraint keeping such bargaining from spilling over into extraction market cartelization becomes untenable. Any spillover loses analytic separability and with it all sensible discussion of timing and manipulation.

5. Full objective functions are certainly equivalent levels of profit from activities in both extraction and futures markets. Equation (3) omits terms that do not vary with q_{i2} and q_{i3}, and presumes that prices are net of extraction and shipping costs.

Equilibrium behavior in the t=2 extraction market (or step 12 of the game) is obtained by a standard Cournot simultaneous maximization exercise, which yields:

$$q_{a2} = \frac{s_{a0} - q_{a1}}{2} + \frac{N_b}{6} - \frac{N_a}{3}$$

$$q_{b2} = \frac{s_{b0} - q_{b1}}{2} + \frac{N_a}{6} - \frac{N_b}{3} . \qquad (4a)$$

This implies

$$q_{a3} = \frac{s_{a0} - q_{a1}}{2} - \frac{N_b}{6} + \frac{N_a}{3}$$

$$q_{b3} = \frac{s_{b0} - q_{b1}}{2} - \frac{N_a}{6} + \frac{N_b}{3} . \qquad (4b)$$

If producer A has taken a net short position ($N_a>0$) on the futures market, then A pumps less in period 2 and more in period 3 than in the absence of the futures market. If producer B also has a net short position, this counteracts the reduction in A's extraction rate in period 2 and the increase in period 3. The counteraction is less pronounced, however, so that the industry's extraction path is affected.

Substitution of q_{a2} and q_{b2} into the price equation (2) gives

$$p_2 = \hat{p} - \theta(s_{a0} + s_{b0} - 3(q_{a1}+q_{b1}) - N_a - N_b) \qquad (5a)$$

$$p_3 = \hat{p} - \theta(s_{a0} + s_{b0} - 3(q_{a1}+q_{b1}) + N_a + N_b) \qquad (5b)$$

where $\hat{p}=\alpha/\beta-(s_{a0}+s_{b0})/3\beta$ and $\theta=1/6\beta>0$.

2.2. The futures market in t=2

In t=2, the futures market reopens. (We are at step 8 of the game.) To determine the payoffs of players A, B and S, we must incorporate the extraction rates found in (4) and the spot prices p_2 and p_3 in the certainty equivalent levels of profit

$$W_i = E(\pi_i) - \frac{K_i}{2\beta^2}\left(q_{i2}+q_{i3}-N_i\right)^2 = E(\pi_i) - \frac{K_i}{2\beta^2}\left(s_{i0}-q_{i1}-N_i\right)^2$$

where

$$\pi_i = q_{i2}p_2(q_{i2}+q_{j2}) + (q_{i3}-N_i)\,p_3(q_{a3}+q_{b3}) + p_{ab}f_{ab} + p_{as}f_{as}$$

and

$$W_s = (p_3 - p_{as})\,f_{as} + (p_3 - p_{bs})\,f_{bs}\,,$$

the speculator being risk-neutral while the duopolists are risk-averse.[6] The futures position f_{ab}, f_{as} and f_{bs} are net total positions for each contracting pair across t=1 and t=2 trades. The futures prices p_{ab}, p_{as} and p_{bs} are average prices over the t=1 and t=2 trades. Positions are indicated by sign: $f_{ab}>0$ indicates that A sold futures to B ("A went short"), and similarly f_{bs} would be negative if, across t=1 and t=2, B bought more futures contracts from S than he sold to S. Thus, $f_{sb}=-f_{bs}$ (the alphabetized order for subscripts is used throughout), so $N_a=f_{ab}+f_{ns}$, $N_b=f_{bs}-f_{ab}$, $N_s=-f_{as}-f_{bs}$. We obtain

$$W_a = \hat{p}_a'(s_{a0} - q_{a1}) + V_a \qquad (6a)$$

$$W_b = \hat{p}_b'(s_{b0} - q_{b1}) + V_b \qquad (6b)$$

$$W_s = (\hat{p}_s'-p_{as})\,f_{as} + (\hat{p}_s'-p_{bs})\,f_{bs} - \theta(f_{as}+f_{bs})^2 \qquad (6c)$$

where

$$V_a = (p_{ab}-\hat{p}_a')f_{ab}+(p_{as}-\hat{p}_a')f_{as}+\frac{\theta}{3}(f_{as}+f_{bs})^2 - \frac{K_a}{2\beta^2}(s_{a0}-q_{a1}-f_{ab}-f_{as})^2$$

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6. The producers must be risk-averse since the sum of the pay-offs V_a and V_b, defined in (6), is linear in f_{ab}.

$$V_b = (\hat{p}'_b - p_{ab})f_{ab} + (p_{bs} - \hat{p}'_b)f_{bs} + \frac{\theta}{3}(f_{as}+f_{bs})^2 - \frac{K_b}{2\beta^2}(s_{b0}-q_{b1}+f_{ab}-f_{bs})^2.$$

Note that $\hat{p}'_i$ represents i's expectation of $\hat{p}$ after observing t=1 demand. Similarly $\hat{p}'_s$ denotes S's expectation of $\hat{p}$. Beliefs are thus expressed as expectations about $\hat{p}$ rather than α.

With full knowledge of equations (6) and the expectations appearing in these, players now go through steps 8 to 11 of the game. Given the announcements of the two other players, each player announces a contract which he considers to be acceptable to a particular other player, because it would give the latter at least a minimum acceptable profit.[7] Once it is clear to all which contracts will be rejected, each player wishes to gain as much as possible in an acceptable contract. Thus, the f_{ij} to announce result from simultaneous solution of max (W_a+W_b), max (W_a+W_s) and max (W_b+W_s). Manipulating the first-order conditions in these maximizations, the net short positions become:

$$N_a = \sigma^{-1}\left(3K_b(\hat{p}'_s-\hat{p}'_a)+4\theta(\hat{p}'_b-\hat{p}'_a)+(\sigma-\sigma_b)(s_{a0}-q_{a1})-\sigma_b(s_{b0}-q_{b1})\right) \quad (7a)$$

$$N_b = \sigma^{-1}\left(3K_a(\hat{p}'_s-\hat{p}'_b)-4\theta(\hat{p}'_b-\hat{p}'_a)+(\sigma-\sigma_a)(s_{b0}-q_{b1})-\sigma_a(s_{a0}-q_{a1})\right) \quad (7b)$$

$$N_s = \sigma^{-1}\left(3K_a(\hat{p}'_b-\hat{p}'_s)-3K_b(\hat{p}'_s-\hat{p}'_a)-(\sigma-\sigma_a-\sigma_b)(s_{a0}-q_{a1}+s_{b0}-q_{b1})\right) \quad (7c)$$

where $N_s=-f_{as}-f_{bs}$, $\sigma_i=4\theta K_i$, $\sigma=\sigma_a+\sigma_b+3K_aK_b$ and

$$\hat{p}'_i = \frac{E_i(\alpha)}{\beta} - \frac{s_{a0}-q_{a1}+s_{b0}-q_{b1}}{2\beta}.$$

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7. We simplify presentation by assuming that a player who is indifferent between accepting and rejecting a contract always accepts. This simplification is rather harmless, in that an appeal to a smallest money unit would justify the conclusions reached with only notational complications. All financial exchanges have smallest money units, which serve the purpose of identifying a smallest feasible increment above an indifference curve.

The first two terms inside the brackets are the speculative component of each net position. It is based on differences in beliefs, and independent of stocks. A natural comparative static result: greater divergences in beliefs lead to larger speculative positions. The remaining terms represent the hedging component. They relate the futures positions to the available stocks of resources, and are independent of differences in beliefs. Note that futures prices do not appear in equations (7): contract curves in futures are vertical.

While the net short positions are uniquely determined by the requirements of subgame-perfect equilibrium, the prices at which individual futures contracts are signed are not uniquely determined. However, the prices accepted can be described by a set of inequalities, derived from the simple idea that the player who accepts a particular offer will do so if it provides a nonnegative contribution to profit. For example, A accepts the offer f_{ab} and the associated price p_{ab} if $V_a - V_a|_{f_{ab}=0} \geq 0$. Let capitalized subscripts indicate players accepting. Then

$$p_{Ab} \gtrless \hat{p}_a' - K_a(s_{a0} - q_{a1} - f_{as} - \frac{f_{ab}}{2}) \quad \text{as} \quad f_{ab} \gtrless 0 \qquad (8a)$$

$$p_{aB} \lesseqgtr \hat{p}_b' - K_b(s_{b0} - q_{b1} - f_{bs} + \frac{f_{ab}}{2}) \quad \text{as} \quad f_{ab} \gtrless 0 \qquad (8b)$$

$$p_{As} \gtrless \hat{p}_a' - K_a(s_{a0} - q_{a1} - f_{ab} - \frac{f_{as}}{2}) \quad \text{as} \quad f_{as} \gtrless 0 \qquad (8c)$$

$$p_{aS} \lesseqgtr \hat{p}_s' - \theta(f_{as} - 2f_{bs}) \quad \text{as} \quad f_{as} \gtrless 0 \qquad (8d)$$

$$p_{Bs} \gtrless \hat{p}_b' - K_b(s_{b0} - q_{b1} + f_{ab} - \frac{f_{bs}}{2}) \quad \text{as} \quad f_{bs} \gtrless 0 \qquad (8e)$$

$$p_{bS} \lesseqgtr \hat{p}_s' - \theta(f_{bs} + 2f_{as}) \quad \text{as} \quad f_{bs} \gtrless 0 . \qquad (8f)$$

The direction of inequalities is that a seller prefers a higher, and a buyer a lower, price.

Of course, a player also has the option of foregoing futures trading entirely. For futures trading in t=2 to be of interest, additional profit must be possible given the positions taken in the t=1 futures market. Equilibrium must therefore satisfy

$$V_a \geq (\tilde{p}_{ab}-\hat{p}'_a)\,\tilde{f}_{ab}+(\tilde{p}_{as}-\hat{p}'_a)\,\tilde{f}_{as}+\frac{\theta}{3}(\tilde{f}_{as}+f_{bs})^2-\frac{K_a}{2}(s_{a0}-q_{a1}-\tilde{N}_a)^2 \quad (9a)$$

$$V_b \geq (\hat{p}'_b-\tilde{p}_{ab})\,\tilde{f}_{ab}+(\tilde{p}_{bs}-\hat{p}'_b)\,\tilde{f}_{bs}+\frac{\theta}{3}(f_{as}+\tilde{f}_{bs})^2-\frac{K_b}{2}(s_{b0}-q_{b1}-\tilde{N}_b)^2 \quad (9b)$$

$$W_s \geq (\hat{p}'_s-\tilde{p}_{as})\,\tilde{f}_{as}+(\hat{p}'_s-\tilde{p}_{bs})\,\tilde{f}_{bs} - \theta(\tilde{N}_s)^2 \quad (9c)$$

where ~'s indicate variables evaluated as of the close of the t=1 futures market. It thus appears that gains in period 1 cannot be removed. This may prevent going all the way to the end of a contract curve.

3. Anticipations of updating of beliefs after t=1 spot market

We now move to step 7, at which $\omega=\alpha+\gamma_1$ is revealed. To get notation in hand, let prior beliefs be distributed as normals with means and standard deviations (α_a^0,ξ), (α_b^0,ξ) and (α_s^0,ξ) and with likelihood functions proportional to normals $(\alpha_a^0+\gamma_1,1)$, $(\alpha_b^0+\gamma_1,1)$ and $(\alpha_s^0+\gamma_1,1)$. Then[8] the posteriors are normal with mean

$$\frac{\alpha_i^0\xi^{-2} + \omega}{1 + \xi^{-2}} = \frac{\alpha_i^0 + \xi^2 \omega}{1 + \xi^2} \qquad (i = a, b, s)$$

and standard deviation

$$\frac{1}{1 + \xi^{-2}} = \frac{\xi^2}{1 + \xi^2} .$$

Our key interest in step 7, however, is in how it relates to a player's decision whether to contract in the futures market

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8. See Box and Tiao (1973, Appendix A1.1).

before or after the information from the first spot market is revealed. Before $\omega=\alpha+\gamma_1$ is revealed, each player believes in his own beliefs and expects the other players to have to update. So player i with prior α_i^0 expects to update to $E_i(\alpha_i)=\alpha_i^0$, that is, to stick to his beliefs on average, but expects the others to update to

$$E_i(\alpha_j) = \frac{\alpha_j^0 + \xi^2 \alpha_i^0}{1 + \xi^2},$$

that is, adjusting their beliefs toward his. In other words, the other players are expected to update α_j^0 on average to $E_i(\alpha_j)$. It is on the basis of these expectations as to how beliefs will change that players evaluate the relative profitability of reaching agreements in the t=1 futures market (discussed below in Section 4.2). After all, whenever differences in beliefs are based upon fundamental differences in opinion, there is also (naturally) a difference in opinion as to who can be expected to be forced to revise his belief in the presence of new information.

4. Subgame-perfect equilibrium in t=1

4.1. The extraction subgame in t=1

It will be shown below that, if futures contracts are signed between each pair of players in t=1, then no activity will occur in the t=2 futures market because net positions extract all gains from trade. In this case extraction policy in step 6 is straightforward, as in equations (11) below. However, if some futures contracts remain to be signed during t=2, then player i=A,B who expects to still be active in t=2 futures has the possibility to alter q_{i1} in hopes of influencing the t=2 spot market. This possibility arises because q_{i1} changes the amount of hedgeable stock, which shows up in V_i, in the net short positions (7) and in the acceptable price equations (8). We claim that in subgame-perfect equilibrium, player i will not alter q_{ij} for these purposes. The argument proceeds in four steps.

First, if q_{i1} is set as in (11) below (which is the "unaltered" benchmark), then, given unaltered behavior by the other producer, $p_1=p_2$. So any altering by producer i will shift extraction from a higher-priced to a lower-priced spot market. Thus, it strictly decreases spot market profits (in proportion to $(\Delta q_{i1})^2$ if Δq_{i1} is the alteration), and will only be done if the added futures market profit exceeds the loss in spot market revenues.

Second, consider the t=2 futures market. Equations (7) for net positions separate into speculative and hedging components, as do the acceptable price equations (8). Speculative components are unaffected by Δq_{i1}, so any futures market profit from Δq_{i1} results in the hedging components and is independent of beliefs and belief updatings.

Third, if a contract between i and j is anticipated in t=2 and it is anticipated that j will dictate terms to i, which is determinable, then i expects to gain just a minimum acceptable payoff increase by signing this contract. Hence, any gains from trade increase due to Δq_{i1} will accrue to j, not to i. Thus $\Delta q_{i1} \neq 0$ cannot help when j dictates to i (and it costs in the spot market).

Fourth, if i anticipates dictating terms to j, the resulting price and futures position will both be altered, and j's payoff will not be affected. However, the net short position equations and the q_{i1} equations below already incorporate maximizing gains from trade between i and j, and with this maximizing the gains from i dictating terms to j. Thus, here $\Delta q_{i1} \neq 0$ cannot gain in the futures market, and loses in the cash market.

The conclusion is that the t=1 extraction equilibrium equations to be derived presently, with given futures contracts signed in t=1 between each pair of players, also apply to any subgame-perfect equilibrium, whether trading is in t=1 or not.

Equilibrium extraction for t=1 is obtained by maximizing

$$q_{i1}p_1(q_{i1}+q_{j1}) + q_{i2}p_2(q_{i2}+q_{j2}) + (q_{i3}-N_i)\ p_3(q_{i3}+q_{j3}) \quad (10)$$

for i=A,B subject to constraint (1). Although q_{i2} and q_{i3} here are just plans, subject to change in t=2, they are in fact not changed in subgame-perfect equilibrium. Note also that N_i is the expected net short position at the end of t=2. Simultaneously satisfying first-order conditions requires

$$q_{i1} = q_{i2} = \frac{s_{i0}}{3} - \frac{2N_i}{9} + \frac{N_j}{9} \quad (11a)$$

$$q_{i3} = \frac{s_{i0}}{3} + \frac{4N_i}{9} - \frac{2N_j}{9}\ . \quad (11b)$$

Substituting this value of q_{i1} into equations (4) gives consistent answers.

4.2. The futures market in t=1

We finally consider steps 2 to 5 of the game, during which the t=1 futures market is open.

To determine the payoffs, we must substitute in the results of t=1 and t=2 extraction activity as defined in equations (11). Each payoff function is as viewed by the relevant player at step 2. (In particular, on average he expects not to have to update his own belief about α, and expects the others to update their beliefs.) While W_s remains as defined in (6c), V_a and V_b, which appear in (6a) and (6b), have to be reduced to take account of the risk of trading before $\alpha+\gamma_1$ is revealed. Hence

$$V_a^0 = V_a - \frac{K_a\ \xi^2}{2}\ (\tilde{f}_{ab} + \tilde{f}_{as})^2 \quad (12a)$$

$$V_b^0 = V_b - \frac{K_b \xi^2}{2} (\tilde{f}_{bs} + \tilde{f}_{ab})^2 , \qquad (12b)$$

where $\tilde{f}_{ij}$ is again a futures position evaluated as of the close of the t=1 futures market and the values of q_{a1} and q_{b1} given in (11a) are used. Thus, if A is considering whether to trade in t=1 or wait until the t=2 futures market opens, he considers how much hedgeable stock he expects to have when t=2 starts. The new risk-reduction terms in (12a) and (12b) reflect the fact that prices in t=2 futures will be higher if $\omega=\alpha+\gamma_1$ is higher.

Ignoring risk premia, additional gains from trading in t=1 over trading in t=2 are

$$|f_{ij}| \left(\frac{\xi^2}{1+\xi^2}\right) \left|\hat{p}_j^0 - \hat{p}_i^0\right| > 0 , \qquad (13)$$

where $\hat{p}_i^0$ is i's expectation of $\hat{p}$ when no observation on ω, that is, on t=1 demand, is available yet.

However, both A and B expect to be compensated for the risk of trading before ω is revealed. What prices are they willing to accept, taking risk premia into account? To equations (8) now correspond

$$\tilde{p}_{Ab} \gtrless E_a^0(p_{ab}) + K_a \xi^2 (\tilde{f}_{as} + \frac{f_{ab}}{2}) \quad \text{as} \quad f_{ab} \gtrless 0 \qquad (14a)$$

$$\tilde{p}_{aB} \lessgtr E_b^0(p_{ab}) + K_b \xi^2 (\tilde{f}_{bs} - \frac{f_{ab}}{2}) \quad \text{as} \quad f_{ab} \gtrless 0 \qquad (14b)$$

$$\tilde{p}_{As} \gtrless E_a^0(p_{as}) + K_a \xi^2 (\tilde{f}_{ab} + \frac{f_{as}}{2}) \quad \text{as} \quad f_{as} \gtrless 0 \qquad (14c)$$

$$\tilde{p}_{aS} \lessgtr E_s^0(p_{as}) \quad \text{as} \quad f_{as} \gtrless 0 \qquad (14d)$$

$$\tilde{p}_{Bs} \gtrless E_b^0(p_{bs}) + K_b \xi^2 (\frac{f_{bs}}{2} - \tilde{f}_{ab}) \quad \text{as} \quad f_{bs} \gtrless 0 \qquad (14e)$$

$$\tilde{p}_{bS} \lessgtr E_s^0(p_{bs}) \quad \text{as} \quad f_{bs} \gtrless 0 . \qquad (14f)$$

In these equations, p_{ij} is the price that will result if trade happens in t=2 (from the relevant equation in (8) above). The capital subscript again indicates the player to whom acceptability applies. (Since there is the possibility of trading in t=2, constraints reflecting the option of foregoing futures activity such as (9) are never binding at this step of the game.)

The interpretation of equations (14) is facilitated if we refer to Figure 1. It illustrates (14a) and (14b) for the case where A dictates to and sells to a more optimistic B (so that $f_{ab}>0$). The upper triangle in Figure 1 contains the set of contracts that would be mutually acceptable in t=1 if B's beliefs were used to forecast the t=1 spot market price. (Thus, the upward-sloping line that forms the base of the upper triangle is a strange hybrid, giving minimally acceptable prices for A under the assumption, which A would not accept, that B's forecast of period 1 spot prices is unbiased.) The lower triangle, an exact translation, contains the set of contracts that would be mutually acceptable if p_1 were forecast in accordance with A's beliefs. The vertical line at position f_{ab} is halfway across both triangles, and contains the contract curve.

The distance from Y to Z in this diagram is

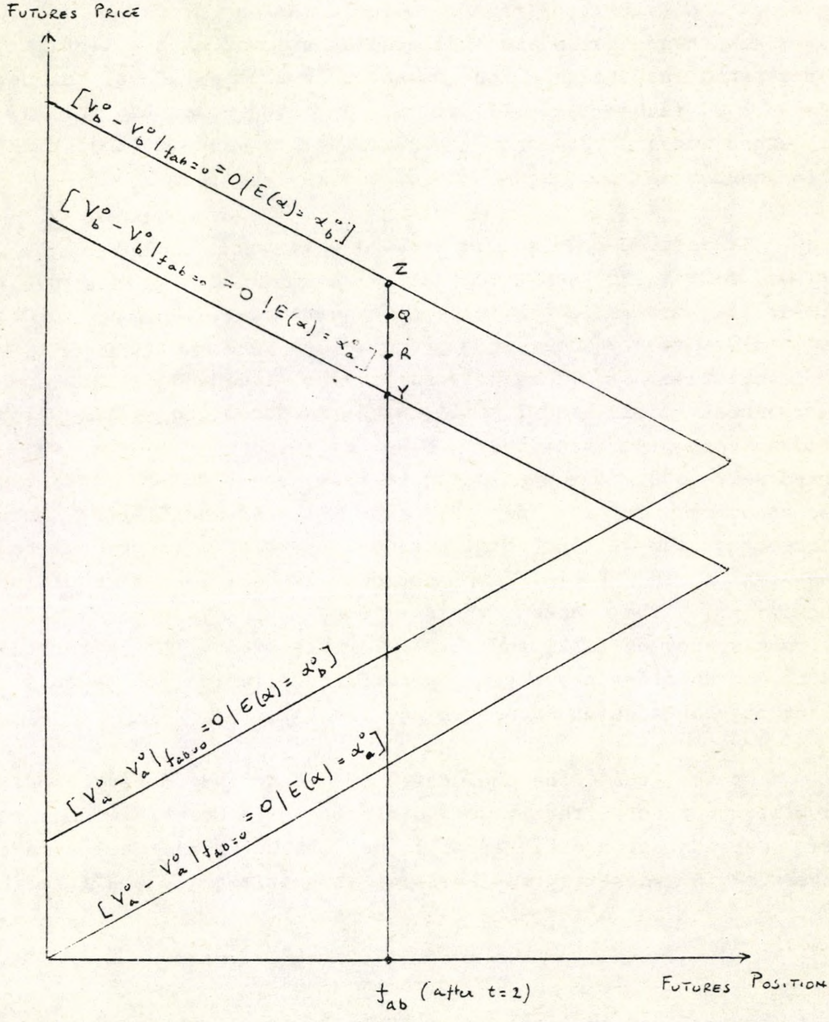
$$\frac{1}{\beta}\left(\frac{\xi^2}{1+\xi^2}\right)\left|\alpha_b^0 - \alpha_a^0\right|$$

which corresponds to

$$\left(\frac{\xi^2}{1+\xi^2}\right)\left|\hat{p}_b^0 - \hat{p}_a^0\right| .$$

Point Z represents the maximum price acceptable to (buyer) B if risk aversion is ignored, that is, $E_b^0(p_{ab})$. Point Y is the average price which A expects he can attain in t=2, namely $E_a^0(p_{ab})$. The expressions after the plus sign in equations (14a) and (14b) give the vertical distances between points Y and R and between points Z and Q, respectively.

Figure 1



Both players realize that higher observations of the spot price p_1 will lead to higher prices in the t=2 futures market, and inversely for lower observations [cf. (8)]. Thus, relative to the average expectations encoded in Z and Y, higher p_1 observations will lead to gains for a seller of t=2 futures, lower p_1's to a loss for a t=2 futures seller, relative to his expectation (vice versa for a buyer). As a producer is risk-averse, these gains are evaluated at a lower marginal utility of incremental payoff than the losses are evaluated. Thus, a better price, Q rather than Z for B, R rather than Y for A, is required for a producer to be willing to accept the risk of signing futures contracts before p_1 is revealed.

It must be commonly understood that the p_{ab} in (14a) and (14b) refers to the price that A will dictate to B in t=2 if no trading occurs in t=1 (with nonetheless different expectations of this commonly understood price). Then Q>R corresponds to the possibility of simultaneously satisfying (14a) and (14b), and A announces Q in step 2 (t=1), with B accepting; after which no trade takes place in t=2. Q=R corresponds to the case of precisely one common solution to (14a) and (14b); in this event, A announces Q in step 2, and B is indifferent between accepting and waiting until period 2 to trade.[9] (However, trading between A and B in both periods is still not equilibrium behavior.) The case where Q<R, then, corresponds to inconsistency of (14a) and (14b); in this event, A is careful to announce an offer above the upper triangle (which B rejects), so that A saves gains from exchange for t=2.

Notice that the heights ZQ and RY depend upon risk aversion but not directly upon differences in beliefs. The height ZY depends upon differences in beliefs but not at all upon risk aversion. So whenever risk aversion is sufficiently small relative

9. This is the one case of indifference which would not be resolved by the introduction of a smallest money unit. In a space of belief profiles, it is a razor's edge event.

to differences in beliefs, trading occurs exclusively in the t=1 futures market.[10]

Let us briefly reintroduce the speculator. A diagram corresponding to Figure 1 for the case where A dictates to and sells to a more optimistic S has Q rising to coincide with Z (as S is risk-neutral), so all trade occurs in t=1 whenever R<Z. If S dictates to and sells to a more optimistic B, R coincides with Y. Two risk-neutral players always transact only in t=1.

It is possible to have (14c) and (14d) consistent, (14e) and (14c) consistent, and (14a) and (14b) inconsistent (or similar pairings). Then A and B each trade with S only in t=1, but with each other only in t=2.

5. Characteristics of subgame-perfect equilibria

5.1. Spot prices and thin markets

Having finished looking backwards, we can look forwards. In subgame-perfect equilibrium, regardless of the extent of activity in the first-period futures market, expected spot prices progress as follows:

$$p_1 = \hat{p} + \frac{2\theta}{3} (N_a + N_b) \tag{15a}$$

$$p_2 = \hat{p} + \frac{2\theta}{3} (N_a + N_b) \tag{15b}$$

$$p_3 = \hat{p} - \frac{4\theta}{3} (N_a + N_b) . \tag{15c}$$

In our model, oligopolistic manipulation thus proceeds in the following way. If producers have taken a net <u>short</u> position over t=1

10. Sufficiently strongly held beliefs - small ξ - also makes risk aversion appear less of an obstacle to t=1 trading.

and t=2, they have substituted known futures prices for uncertain spot market prices, and are willing to let the futures price be low at maturity. For that purpose, they make sure the spot price is low at maturity, since at t=3 futures and spot prices have to be equal. Their equilibrium extraction policy is then to extract less in t=1 and t=2 and to extract more in t=3. As a result, the spot price will be higher than in the absence of manipulation (i.e., than $\hat{p}$) in t=1 and t=2, and lower in t=3. If producers have accumulated a net long position, they will do the reverse and the spot price will decrease relatively more in the beginning of the life of a contract and increase relatively more at the end.

The empirical inference is that detrended spot prices in thin markets are likely to exhibit more volatility, whether producers are going long or short, than when no producers with market power in spot markets are active in futures markets. Oligopolistic manipulation, of the type analyzed here, is likely to occur in thin futures markets in which it is possible to surmise the identity of participants in many transactions. The crude oil futures contract at the London International Petroleum Exchange (IPE) might be a case in point, as suggested by the following quotation from the Oil Buyers Guide of 5 September 1988:

> "Though prices are called out on the exchange, experts say that the IPE Brent is functioning more like a formalized cash brokerage system than a dynamic NY-style futures market. The lack of "locals" on the floor means that most bids or offerings will not elicit the instant open-market response typical of the Nymex.[11] In this slower moving environment it is often possible for observers to surmise the identity of participants in many transactions."

5.2. Manipulation and closing out contracts

For arbitrary choices of beliefs, stocks, and demand responsiveness, there are nontrivial ranges of the parameters governing risk aversion (K_a, K_b) for which the speculator signs futures contracts in t=1. No fruitful opportunity to manipulate

11. The New York Mercantile Exchange.

the t=2 futures market is available to producers (cf. Section 4.1). Thus the speculator has an opportunity in the model to engage in "canceling" futures transactions, which would effectively close out his futures position before the manipulation by producers, that he is aware will happen at maturity.

At the prices satisfying equations (14), the opportunity to obtain positions in t=1 which are then closed out prior to maturity is viewed by any one of the three players (due to differences in opinion) as an opportunity with expected positive profit.

The speculator knowingly and wilfully does not (in equilibrium) close out positions prior to maturity, aware that manipulation is coming. In fact, if both K_a and K_b are sufficiently small, the speculator does not trade at all in equilibrium in t=2, leaving both contracts open to maturity.[12] Positions are not closed out for the simple reason that perceived gains from trade remain in positions kept open to maturity. By predicting the extent of manipulation that would result from signing a contract [via (4)], the speculator can determine what futures price will induce him to keep open positions [cf. (8)].

An even more striking rational tolerance for being manipulated arises in the equilibrium described above. For a variety of parameters, in some commitment orders, the speculator is able to dictate terms to a producer who requires a sufficiently large risk premium that the relevant equations in (14) have no common solution. When this happens, the speculator is choosing to forego a short-term unmanipulable profit that he fully expects to be positive, in order to improve the terms of trade he can

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12. For parameter classes with $\hat{p}_s$ much larger than $\hat{p}_a$, $\hat{p}_b$, K_a sizeable, K_b small, s_{a0} small, s_{b0} larger, S may buy futures from B in period 1, and then go on to take a longer position by buying from A (at a higher or a lower present price) in period 2.

dictate. Then this short-term profit is rationally foregone, and the only trade the speculator makes with this producer is a "last-minute" position held open to maturity. Only substantial notational complexity would be added by extending the characterization of open positions at maturity to a model with several speculators.

When gains from trade are available, there is nothing necessarily irrational about deliberately exposing oneself to manipulation. For some readers, inconsistent incomplete information would appear to leave too wide a breach open to be a first choice for modelling markets. But the alternative is surely less palatable: a model with consistent prior beliefs and informational bases for rational trading responds to the slightest transaction cost by uniquely predicting a zero volume of futures market activity (Kreps (1977), Milgrom and Stokey (1982)). The predictions of significant activity arising from this model are robust to small commissions on trades.

5.3. The law of one price and the informational content of futures prices

Significant violence is done to the data from a single trading day on the IPE, the Nymex, the London Metal Exchange or the Chicago Board of Trade by pretending that a Law of One Price applies. In contrast, our model predicts that different trading pairs simultaneously transact futures contracts at different prices. The question of whether "the" futures price is an unbiased predictor of the spot price to arise at maturity cannot even be well-posed in such a model. Nor is it a question of any concern: traders who transact futures contracts solely on the basis of differences in opinion are not looking to futures prices to aggregate any information.

Notice that multiple simultaneous prices is in the interest of the traders. Averaging across commitment orders, all traders would benefit from the abolition of an artificial constraint that all futures contracts in a given period had to occur at a single price.

5.4. On the distribution of gains from trading, and take-it-or-leave-it contracts

Interestingly, a producer in a concentrated resource extraction industry can benefit from the existence of a futures market even if he does not take part: if A opts out by setting $f_{ab}=f_{as}=0$, his payoff still includes a positive quadratic term in f_{bs} [see (6)]. This is because another producer active in the futures market will predictably manipulate the spot market by shifting extraction into or out of the maturity date. A producer who opts out rationally responds by shifting some of his resource extraction in the opposite direction, to a higher-priced spot market [see (4)].

As the counter-shift just described is optimally a smaller shift, some of the benefit is passed on to final demanders: in aggregate, producers shift extraction from a spot market with a higher present price to a lower-priced spot market. Because of this feature, the full game among the two producers and the speculator will be ex post negative sum, but it is ex ante viewed as positive sum, inconsistently, by all three.

In the equilibrium described above, any futures contract signed distributes all but a minimal share of gains from exchange to one party. This is clearly due to the simplification of requiring take-it-or-leave-it contracts. "Open outcry" markets typically operate under an alternative in which, if an offer to sell 200 contracts at 45 has standing, it is allowable to accept partially, e.g., to cry "I'll take 100 of that". This alternative is analyzed in a model where the futures market is open only once [Harstad and Phlips (1990)]; it proves much more complicated than take-it-or-leave-it contracts. Without introducing all the complications, some of the changes that would result if this partial acceptance alternative were introduced in the model of this paper are clear.[13] Some features are also clearly robust with respect to this aspect of the trading rules.

Partial acceptance rules would yield an equilibrium in which the commitment order would allow one player in a trading pair to dictate the price at which they trade, with the other determining the quantity. The contract-by-contract distribution of the gains from trade would then be less one-sided. The same contract-by-contract temporary monopoly aspect would also lead to reduced positions on contracts, and an overall sub-optimal volume of futures market opportunity, in contrast to take-it-or-leave-it contracts.

The general pattern of timing of futures activity found above is robust to this sort of change in the trading rules. To wit, under partial acceptance rules, larger gains from trade would be available in the first futures market than in the second; surely only substantial levels of risk aversion would prevent an emphasis upon futures trading in t=1. Necessarily, however, gains from trade will remain when the t=2 futures market opens. It may be possible to see further trading in t=2 even when all trading pairs reached agreement in t=1, but this possibility will have been foreseen and may have been foreclosed; only a complete and extremely complex analysis can tell.

A major conclusion can be proven robust to this change. If he signs contracts in t=1, the speculator will have the opportunity to close out positions in t=2, but he will choose not to do so. Any positions satisfying (14d), (14f) are positions that S will prefer to hold open, and the additional options he has with more flexible trading rules do not change this preference.

13. Harstad and Phlips (1990) also change the game by having the commitment order revealed after offers are announced. The current discussion is not contemplating that change.

6. Insights into futures markets with simultaneous trading of multiple maturities

To avoid the prediction of an inactive futures market, we have based evaluation of potential trades on inconsistent beliefs. "Opening the door" in this fashion has not served to obtain arbitrary behavior. A specific pattern emerges in subgame-perfect equilibrium which accords acceptably with some stylized facts of markets: Early futures contracting arises when risk aversion is not too severe; The speculator does not close out positions prior to maturity.

Emphasis on these results points to the simplification of a single maturity date as a key limitation of the analysis. Existing futures markets involve simultaneous trading of futures contracts for multiple maturity dates. We close by indicating the sort of generalization which seems likely.

Consider a repeated game in which "stage games" having the form outlined in Section 1 recur in an overlapping fashion, perhaps with stage T proceeding through steps 2-5 while stage T-1 proceeds through steps 8-11 and stage T-2 reaches maturity. Technical complications presented by such a game are chilling. Two principal complications merit discussion here. First, the repeated game aspects create the possibility of a plethora of qualitatively different equilibria supported by history-dependent strategies. For this discussion, we limit attention to subgame-perfect equilibria in strategies that depend upon history only through current state variables.

Second, with the sort of Bayesian updating incorporated here, infinitely lived players would come to have nearly identical beliefs, as accumulated information overwhelmed any inconsistency in priors. This would lead to a prediction of vanishing futures market speculation over time.

Adjustments of the following sort could overcome this problem while adding realism. Suppose the players were finitely lived, with overlapping generations stepping into the roles of producers and speculators. Suppose further that a newly arriving role player shows up, perhaps at a random time, with an ad hoc inconsistent prior belief, in no way influenced by the observations of spot prices during his predecessor's lifetime.[14] Then continued speculative trading based upon nonvanishing belief inconsistencies would be possible.

The analysis presented in this paper clearly suggests a carryover of key aspects to such a repeated game model. Whenever inconsistent beliefs are present, a "rush to trade" may continually be observed, as beliefs are known to become less disparate with new information (which could be interpreted more broadly than just spot market clearing prices), and gains from trade are known to diminish correspondingly. Thus, futures market volume and volatility in excess of that justified by underlying fundamentals may be explicable.

Moreover, equilibria involving a willingness on a speculator's part to hold open positions to maturity seem in no way to depend on a single maturity date.[15] The gains from trade which encouraged opening the position early remain, and the manipulation which could repeatedly occur at maturity dates need not prevent market functioning. Speculators would simply anticipate the appropriate terms in which to share in the gains from trade on positions open to maturity.

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14. An alternative scenario would be to have each player employ an ad hoc test of his current beliefs, and discard them in favor of another ad hoc inconsistent prior whenever the extent of updating failed the test.

15. An observed tendency for the aggregate volume of open positions to fall sharply shortly before maturity dates does not seem incompatible with this story. Perceived gains from trade are more substantial further from maturity, so near maturity, a switch by speculators to futures contracts with later maturity dates (including dates for which no market has previously existed) is an expected occurrence.

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