
Cartel Behaviour in Commodity Markets*

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Abstract

A theory for the behaviour of cartels is advanced. The theory deviates from the received literature on three main points: Cartel behaviour is derived from literature on human behaviour rather than from principles of profit maximization, the theory focuses on commodity markets rather than being general, and it deals with the timing of formation, break down, expansion and dissolution. The theory is stated formally in a simulation model, which seems to replicate well the qualitative behaviour of cartels. Historical accounts of the timing of cartel events lends support to the theory.

1. INTRODUCTION

Research on cartels in economic literature has been motivated by efficiency losses to society. The starting point has been assumptions about cartels as profit maximizing entities. No doubt, there are numerous historical instances of high prices, high cartel profits and efficiency losses. However, there are also numerous examples of cartels that have broken down, cartel participants that have gone out of business for ever, and participating countries that have inflicted upon themselves unbearable instabilities. In fact, the general conclusion about cartels in commodity markets seems to be that they do not last very long¹. These facts imply that it might be fruitful to view cartels from a new viewpoint: Not only as calculating organizations that control the market, but also as reacting institutions that are at the will of the environment. This viewpoint does not at all rule out the profit motive. However, it introduces additional behavioural factors such as expectation formation, fairness and misperception of feedback. Similarly, Pindyck (1981) expresses the need to consider "myopic behaviour".

"Myopic" behaviour at the *decision making level* is indicated by the following two anecdotes. In 1922 the British Government and the Rubber Growers Association pressed for a cartel, in spite of recommendations not to do so by the Stevenson Committee appointed by the Secretary of State for the Colonies, Winston Churchill. Historians later call the decision a blunder. In 1979 the Oil Minister of Saudi Arabia, Sheikh A. Zaki Yamani, said "this is the beginning of the end" when Opec decided not to counteract the oil price escalations of 1979. The oil price collapse in 1986 probably represents what he was expecting.

This paper is not meant to deal with all types of cartels. Focus is on commodity markets where entry is not restricted and where the returns to scale in production are not increasing. Under these conditions a cartel comprising a given set of producers cannot make pure profits in equilibrium. Thus, equilibrium analysis rules out profit maximization as a valid motive to form a cartel. However, there still remains the possibility that such a cartel could make profits in a dynamic market with randomness or uncertainty. Solutions to this problem are complicated and seems lacking even in economic literature². Consequently, cartels that want to optimize dynamically are faced with a bounded rationality problem. Therefore our focus on commodity markets should give the best chance of finding evidence of practical rules-of-thumb (heuristics) for cartel behaviour, other than those that follow from overall profit maximization. For markets with increasing returns to scale, barriers to entry, and greater concentration, profit maximization seems to be a more likely proposition. However, this does not necessarily rule out the possibility that the behavioural rules discussed in this paper still play some role. To avoid misinterpretations, it is important to be aware that most of the literature on cartels seems to address the latter type of markets. Note also that our assumption about low concentration implies that we will not assume that all producers participate in the cartel, a competitive fringe exists.

The second section of the paper presents behavioural theories that underlay our explanation of the following four cartel acts: Formation, breakdown, expansion, and dissolution. We propose that:



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- Cartels are likely to form when the market price falls below a desired price.
 - Cartels are the more likely to break down the lower capacity utilization gets.
 - A cartel is likely to be expanded after it has broken down.
 - Cartels are likely to be dissolved when capacity utilization returns to a normal level.

It is not straight forward to test these propositions. In section two various sources of prior information are used to develop and discuss the propositions. In section three a formal model is constructed to ensure consistency between relationships and time behaviour. The mathematical model also serves to make explicit all the assumptions that are made. In section four the time behaviour of the model shows qualitative similarities with historical accounts. Simulations demonstrate that the proposed rules for cartel behaviour tend to stretch the length of time between price peaks in cyclical commodity markets. The effects on stability and profitability depends on parameters chosen for the decision rules. Finally, in section five empirical evidence on the timing of formation, breakdown, expansion and dissolution are collected for a few markets. The data are mostly favourable to our propositions.

2. FORMATION, BREAK-DOWN, EXPANSION, AND DISSOLUTION

We split the producers into a cartel core and a competitive fringe. An expansion of the cartel implies that the fringe joins the core. We will not discuss who belongs to the core and who belongs to the fringe. For our purpose it suffices to say that producers are different, and that there are members in both categories. We do not explicitly deal with new substitutes; however they could be thought of as belonging to the production of the fringe.

The propositions below strike a balance between simplicity and realism. Although not reported here, numerous ideas have been tested and discarded or accepted by simulation models similar to the one presented in the next section. The propositions describe probabilistic events.

The question of when cartels are formed is neglected in economic literature³. For markets where cartels are permanent, the question is irrelevant. For commodity markets with coming and going cartels it seems most relevant.

Proposition for the formation of cartels:

Cartels are likely to form when the market price falls below the desired price, where the desired price is influenced by historical prices.

The proposition is based on arguments about problems, opportunity and misperception of feedback. First, what problems could cause a cartel to form when prices fall? For producers, lower prices represent a threat if they have engaged in massive borrowing for new investment. For countries and wage earners, dwindling exports and incomes cause stress⁴. It also seems likely that prices falling below expectations are frustrating to producers, confer literature on mental accounting, see Thaler (1980) and Tversky and Kahneman (1981).

Secondly, the opportunity for cartel formation at falling prices seems to be provided by people's notion of fairness. Kahneman, et al. (1986) and Gorman and Kehr (1992) find through surveys that people seem to accept that transactors have an entitlement to the terms of the reference transaction and that it is fair to cover increasing costs. Another opportunity for cartel formation lies in the mutual desire for stability by producers and consumers, allowing producers to reduce capacity utilization.

Thirdly, since unsuccessful cartels are known to have been formed in spite of advices not to, it seems pertinent to ask if misperceptions influence decisions. There is a growing literature⁵ on misperceptions in dynamic systems indicating that salient cues close in time and space are relied on instead of complete models and uncertain information. In our case, this means that prices above equilibrium are perceived to be sustainable. Long-term supply and demand responses are under-estimated. Evidence of this effect can be seen in forecasts based on adaptive expectations or trend-extrapolation; methods that typically lead to

over-optimistic forecasts for the period after a price peak⁶.

Breakdowns of cartels have been studied as functions of market parameters like concentration, demand and supply elasticities, Eckbo (1976), in the tradition of oligopoly theories based on static equilibrium concepts e.g. Cournot and Stackelberg. While such studies indicate expected efficiency and length of cartels, they do not explicitly deal with behavioural aspects. Much theoretical literature on collusions deals with what Stiegler (1964) calls "secret price cutting" and retaliatory price reductions. Green and Porter (1984) argues, in light of uncertainty, that "price wars" are needed to give cartel participants incentives to cooperate. Our focus is on breakdowns due to external competition (in this paper by the fringe).

Proposition about breakdown of cartels:

Cartels are the more likely to break down the lower capacity utilization gets.

The proposition is that if the cartel breaks down, it is due to unbearable problems, it is not a well planned act following a long-term strategy. Below a certain utilization, the core cartel will find it better to compete on price, hoping that the fringe joins the cartel, than to accept further possible reductions in utilization or market share. Osborne (1976) writes, in a paper mostly on internal cartel problems, that: "I can find no record of a cartel which died of internal problems alone, but plenty which fell to new substitutes." This does not mean that we totally ignore internal competition. Insufficient output reductions are likely to cause prices to erode. The proposition is also meant to explain the breakdown of an expanded cartel.

Proposition about expansion of cartels:

A cartel is likely to be expanded after it has broken down (or after the threat of a breakdown has become overwhelming) and prices have eroded to an acceptable level.

After a breakdown of the cartel with core producers, the fringe faces the choice between fierce price competition due to the existing over-capacity, or cooperation with a certain reduction in utilization. This choice is fairly simple, given the availability of institutions, because competition means low or negative profits while cooperation ensures a positive margin on the commodities sold.

The core members might feel that the fringe has a moral obligation to join the cartel and will accordingly try to put pressure on the fringe to join. Fringe members might also feel that they are responsible, after all the breakdown is due to their expansion, albeit a predictable expansion. That fairness might play a role in these considerations is indicated by Selten (1987) who concludes that equity considerations have a strong influence on observed payoff divisions in coalition bargaining in experimental games. In the light of the findings of Kahneman, et al. (1986), it seems likely that actions to reduce losses would be deemed fair after a breakdown.

Due to the bad experience with high prices causing the core cartel to break down, it is likely that both the fringe and the core will be averse against too high prices in the immediate future. This explains the required price erosion, for expansion to take place, in the proposition above. Finally, cartels might be expanded even though a breakdown of the core does not take place. Low capacity utilization among core members poses a serious threat to the fringe, and might motivate the fringe to join the cartel without a breakdown.

Proposition for the dissolution of cartels:

Cartels are likely to be dissolved when perceived capacity utilization approaches 100 percent after an extended period with lower utilizations.

When utilization returns to a normal level, one might think that a cartel raises prices rather than dis-

solving itself. We argue that the cartel members neither are particularly interested in higher prices nor will a price rise be well perceived by buyers. "Mental accounts", Thaler (1980) and Tversky and Kahneman (1981), which are low on utilization and market shares, imply that cartel members want to compete for market shares. Kahneman, et al. (1986) and Gorman and Kehr (1992) find that it is judged unfair to increase prices, even if there is a demand pull. Thus, overt actions by the cartel to raise prices from a low level are likely to be deemed unfair. Actually, perceived growth in utilization signals better prices anyway.

If the cartel is not overtly causing prices to increase, an act we assign low probability for our type of cartels, why do episodes with high prices occur? First, prices might rise because of covered actions by the potential cartel members. One could ask if a purpose of the Yom Kippur war in 1973 was to escalate oil prices, or if the war was used as an excuse to limit oil supplies and to cover up a price rise⁷. Another covered action could be to delay increases of supplies in periods where demand is perceived to grow faster than expected. Secondly, prices could increase due to exogenous events such as frost damage of agricultural products and unexpected business cycle variations in demand. Thirdly, prices could rise due to cyclical tendencies of commodity markets. This represents the approach taken in the next section where a cartel is put on top of a dynamic commodity market model.

3. CARTEL MODEL

The propositions of the previous section are formalized below. To save space most parameters are not assigned names. The parameter values are chosen roughly to mimic the sugar market.

As mentioned above, we build a cartel on top of a structural commodity market model, which has been used extensively, see e.g. Meadows (1970), Adams and Behrman (1976), and Labys (1973). This model is characterized by a static demand function, a delayed supply response, and price given by the adequacy of inventories. Different from the original model, suppliers are split into core producers, c, and fringe producers, f. These two are supposed to be of equal size initially. Production, q, for each producer, i, is the product of capacity, k, and utilization, u.

$$q_i = k_i u_i \quad (i=c,f) \quad (1)$$

Capacity increases with yearlings, y, and is reduced by scrapping after 3 years on average. Initial production capacity is 100 units for each producer.

$$\frac{dk_i}{dt} = y_i - k_i/3 \quad (2)$$

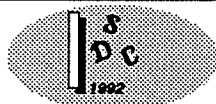
"Yearlings" (mixture of sugar cane and sugar beet) are given by a 0.8 year delay of planting, n:

$$\frac{dy_i}{dt} = (n_i - y_i)/0.8 \quad (3)$$

The basic determinant of planting is the difference between desired capacity and actual capacity, k. Desired capacity is given by current capacity times a price effect with an elasticity of 0.4, set to calibrate cycles in a market without cartels. Planting aims at closing the gap between desired and actual capacity in 2 years. To enable equilibrium when the gap is closed, scrapping, k/3, has to be made up for. A max-function ensures that planting does not turn negative at low prices.

$$n_i = \max(0, (k_i p^{0.4} - k_i)/2 + k_i/3) \cdot (0.5 + 0.5 u_i) \quad (4)$$

The chosen investment function is of a neoclassical type⁸. In addition to the standard function, capacity utilization, u, is allowed to influence planting. Planting is reduced by half the reduction in utilization⁹. Demand or consumption, z, is given by an equilibrium demand of 200 units times a price effect with a price elasticity of -0.2. The price expression is a consumer price including refining, transportation, and distribution costs of 1 currency unit, divided by the initial consumer price (1+1). In addition demand is multiplied by a random variable, v, which might be thought to represent all exogenous randomness in the market.



$$z = 200 \left(\frac{p+1}{1+1} \right)^{-0.2} \cdot v \quad (5)$$

Inventory, s , is given by:

$$\frac{ds}{dt} = q_c + q_f - z \quad (6)$$

Price is given as a function of desired inventory equal to initial inventory of 50 units divided by actual inventory raised to the power of 3. This effect is supposed to work only on a fraction of total costs (1-0.2), somewhat larger than capital costs. The number 0.2 represents a lower limit for prices and is somewhat below operating costs. A min-function ensures that prices never exceed 3 currency units. The parameters chosen make the price equation mimic price development in sugar and rubber markets under influence of cartels, see Moxnes (1990). It might seem a little odd that the adequacy of inventories is assumed to determine prices even when a cartel is operating. However, our focus is on production quotas, and then the adequacy of inventories remains an important indicator of (spot) price. Anecdotal evidence support this view¹⁰.

$$p = \min(3, 0.2 + (1-0.2)\left(\frac{50}{s}\right)^3) \quad (7)$$

This concludes the description of the standard commodity market model. Desired utilization by the cartel, u_i^d , is given by price, p , relative to desired price, p^d raised to the power of α_i , reflecting the strength of the cartel. The core ($\alpha_c=3$) is assumed to react stronger than the fringe ($\alpha_f=1.5$). The reductions only take place if the producers participate in the cartel, $c_i=1$. Otherwise, $c_i=0$, utilization equals one. A min-function ensures that utilization stays below 1. Anecdotal evidence of quotas that are adjusted upwards if prices increase is presented by Stocking and Watkins (1947) for the sugar cartel in the early 1930's (the Chadbourne Plan).

$$u_i^d = \min(1, (1-c_i) + c_i \left(\frac{p}{p^d}\right)^{\alpha_i}) \quad (8)$$

Normally capacity utilizations, u_i^n , are adjusted after a delay of 1.0 year, accounting for inherent delays both in the decision process and in the adjustment of production.

$$\frac{du_i^n}{dt} = (u_i^d - u_i^n)/1.0 \quad (9)$$

However, we assume that a certain fraction of core members ($f_c^s=0.2$) can operate as swing producers and adjust utilization immediately according to desires. The fringe is assumed to have no swing producers ($f_f^s=0$).

$$u_i = f_i^s u_i^d + (1-f_i^s) u_i^n \quad (10)$$

The desired price is assumed to be shared by the two sets of producers (this assumption is only of any importance when they cooperate). It is formed as an adaptive expectation; it follows the actual price after a delay of τ years. A conservative attitude is ensured roughly by a min-function limiting price desires to 2.5 currency units.

$$\frac{dp^d}{dt} = (\min(2.5, p) - p^d)/\tau \quad (11)$$

The price desire is assumed to react asymmetrically to price rises and declines. When the price is higher than the desired price, the adjustment time is 0.5 years. When prices are below desired prices, the time delay is 2 years, unless there has been an episode of cartel breakdown during the last two years. Then the adjustment time is 0.5 years. In equation 12, m_c measures the memory of a breakdown, being 1 at the time of the breakdown and e^{-1} after two years.

$$\tau = \begin{cases} 0.5, & p > p^d \\ 0.5, & p \leq p^d \text{ and } m_c \geq e^{-1} \\ 2.0, & p \leq p^d \text{ and } m_c < e^{-1} \end{cases} \quad (12)$$

Participation in the cartel is denoted by the discrete variable c_i , c_i being either 0 or 1. According to the



discussion in the previous section, participation changes through cartel formation, f_i , breakdown, b_i , or dissolution, d_i . Expansion is represented by cartel formation by the fringe, f_f :

$$\frac{dc_i}{dt} = f_i - b_i - d_i \quad (13)$$

Formation for the core can only take place when there is no cartel ($c_i=0$). With this logical restriction, the core forms a cartel when the difference between desired p^d and perceived price p^p is greater than 0.25 currency units and break down has not taken place over the last two years ($m_c > e^{-1}$), or if the fringe participates ($c_f=1$). The parameter dt represents the time step when the model is simulated using a simple Euler method.

$$f_c = \begin{cases} 1/dt, & c_c=0 \text{ and } ((p^d - p^p) > 0.25 \text{ and } m_c > e^{-1}) \text{ or } c_f=1 \\ 0, & \text{otherwise} \end{cases} \quad (14)$$

Formation, breakdown and dissolution should ideally be viewed as stochastic events rather than deterministic ones. This could have been achieved by using stochastic processes instead of constants such as 0.25 in equation 14. The cartel breaks down if there exists a cartel ($c_i=1$) and capacity utilization u_c is less than 0.65.

$$b_c = \begin{cases} 1/dt, & c_c=1 \text{ and } u_c < 0.65 \\ 0, & \text{otherwise} \end{cases} \quad (15)$$

The cartel can only be dissolved when there exists a cartel ($c_c=1$). Dissolution takes place when utilization, u_c , is greater than 0.95 and u_c is greater than a more distant reference for utilization u_c^r .

$$d_c = \begin{cases} 1/dt, & c_c=1 \text{ and } u_c > 0.95 \text{ and } u_c > u_c^r \\ 0, & \text{otherwise} \end{cases} \quad (16)$$

Perceived price p^p is a 0.3 year delay of actual price, p . This delay represents the time needed to sort out lasting movements in prices and to agree on cartel formation. The reference utilization u_c^r is a 3 year delay of actual utilization.

$$\frac{dp^p}{dt} = (p - p^p)/0.3 \quad (17)$$

$$\frac{du_c^r}{dt} = (u_c - u_c^r)/3 \quad (18)$$

Formation, f_f , for the fringe (expansion) takes place if the fringe does not already take part in the cartel ($c_f=0$), if the price is below an upper limit of 1.4 currency units, and less than 2 years have passed since a breakdown of the core cartel ($m_c > e^{-1}$).

$$f_f = \begin{cases} 1/dt, & c_f=0 \text{ and } p < 1.4 \text{ and } m_c > e^{-1} \\ 0, & \text{otherwise} \end{cases} \quad (19)$$

Breakdown, b_f , of the fringe's participation takes place if the fringe participates ($c_f=1$) and the core participation breaks down, $b_c=1/dt$. Similar assumptions are made for dissolution, d_f .

$$b_f = \begin{cases} 1/dt, & c_f=1 \text{ and } b_c=1/dt \\ 0, & \text{otherwise} \end{cases} \quad (20)$$

$$d_f = \begin{cases} 1/dt, & c_f=1 \text{ and } d_c=1/dt \\ 0, & \text{otherwise} \end{cases} \quad (21)$$

Finally, the memory, m_c , of core cartel breakdown increases to 1 if the core cartel breaks down ($b_c=1/dt$). Otherwise the memory fades away with a time constant of 2 years.

$$\frac{dm_c}{dt} = \begin{cases} (1 - m_c)/dt, & b_c=1/dt \\ -m_c/2, & \text{otherwise} \end{cases} \quad (22)$$

4. MODEL SIMULATIONS

The model is simulated using a time step of 0.1 year. The model starts in initial equilibrium, and the only disturbance is the random variation in demand, see figure 2 (it starts out with a step of 0.12 after half a year). Figure 1 shows an example of typical behaviour produced by the model. After the initial increase in demand, the price increases rapidly, and the price desire follows shortly. When the price drops, the desire stays high causing a cartel with core producers to form. The initial effect is a price increase, followed by an erosion of the price due to insufficient reductions in capacity utilization. After about 5 years the cartel breaks down, and the fringe producers participate in an expansion. The expanded cartel is dissolved when perceived utilization approaches 100 percent. Later in the same simulation the core producers again form a cartel. However, this time the price is fixed at a lower level. The cartel does not break down. Note that the two core cartel formations lead to higher prices in the short run, however lower than the preceding peak prices. This signals an important distinction, cartel formation is motivated by falling prices, while the results of cartel action might be increased and maybe overshooting prices, partly due to complicated dynamic control¹¹.

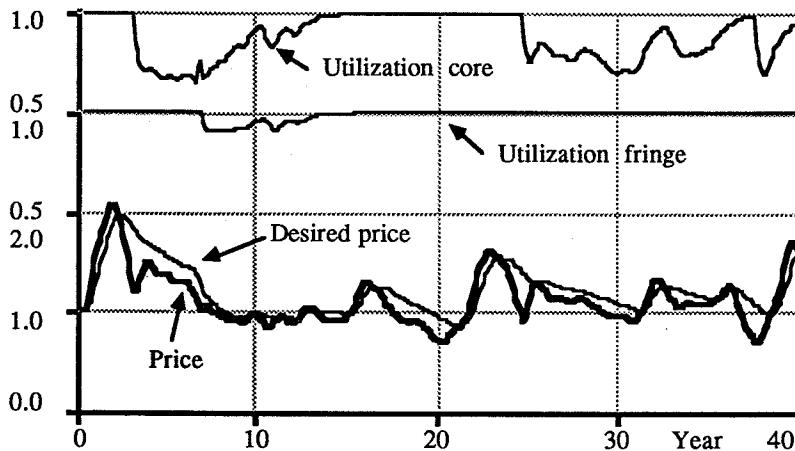


Figure 1: Example of typical cartel behaviour arising from the model.

After 40 years the core has lost 15 percent of its initial market share. The core gets only 15 percent of the total net profits¹² (not discounted). While the core gets only short term benefits from defending a high price, it might be profitable to prevent prices from falling below costs. At this price level the fringe has no incentives to expand capacity.

Figure 2 shows a comparison between the cartel model and the traditional commodity market model, both being driven by the same randomness in demand. The competitive model shows cyclical tendencies of the same shape and duration as observed in the sugar market during the period from 1955 to 1984, see Moxnes (1990). The period length of the cartelized market is clearly much longer than in the competitive market. This is explained by the introduction of a positive feedback loop through price, desired price, utilization and production when the cartel operates, in a model otherwise dominated by negative (equilibrating) feedback. Interesting to note is that while the period of commodity cycles is sensitive to construction delays and lifetimes of capital, simulation experiments indicate that the length of a cartel cycle seems to be less so.

Over the 40 year period cartel producers together make 12 percent higher total net profits than the competitive producers. However, the core producers come out with 66 percent less than what they would have earned under free competition. The cartel leads to more stable prices than the competitive market, with

indices¹³ of stability of respectively 7.8 and 11.4. These numbers depend on model parameters.

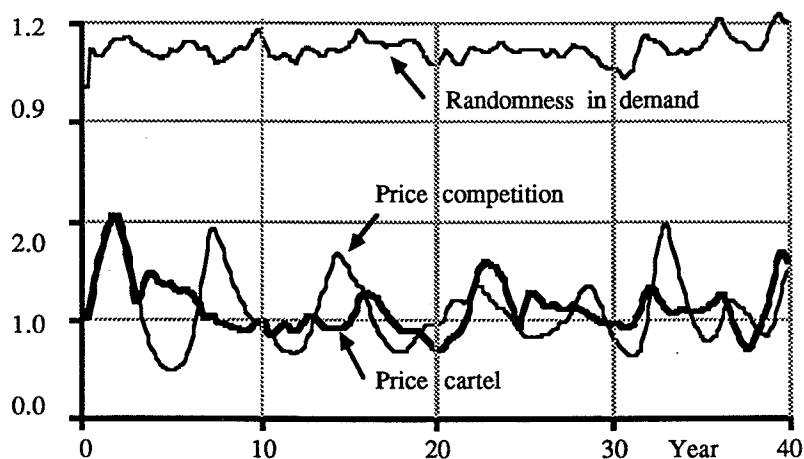


Figure 2: Comparison between price development for a market with cartel formations and a market with competition, the randomness in demand is the same for both markets.

5. TIMING OF HISTORICAL CARTELS

Time-series data available are not sufficient to test all relationships and parameters of the model¹⁴. Here we will see if historical accounts of the conditions for cartel events correspond to the conditions of the propositions. If for instance a formation of a cartel took place in a period with declining prices, this is in accordance with the theory (1 point for the theory). If a cartel was formed in a period with constant or

Table 1: Historical cartel episodes. F-formation, B-breakdown, E-expansion, and D-dissolution. 1 denotes that conditions coincide with propositions, 0 that they do not.

Period	F	B	E	D	Membership	M.Share%
Sugar*						
1926-28/29-30	1	1	1		Cuba	20
1930-37			1		9 countries	45→26
1937-					21 countries	88
Rubber*						
1920	1			1		25
1922-28	1	1			British Colonies	71→54
1933-44	1			1	5 countries	
Nitrate*						
1919-30	1		1		Chile	46→23
1930-31		1	1		Many	
1932-					More	
Aluminium*						
1896-1901	1		0			
1901-08				1		
1923-31	1		1		Not all	
1931-					All important	
Tin+						
1930-	1					
Summary	8/8	3/3	5/6	3/3		

Sources: * Stocking and Watkins (1947), + Hexner (1945).



increasing prices, this data point contradicts the theory (0 point for the theory). For this test we need data both about market conditions and about cartel events.

The condition for core cartel formation is price decline. The condition for break down is low capacity utilization (or data for loss of market share). The conditions for expansion are either break down or low capacity utilization (threat of break down). Finally, the condition for dissolution is recovering utilization. Table 1 summarizes the findings. The historical records do not invalidate the propositions. Only in one event have we found conditions that are contradictory to what the theory predicts. Measurement errors and possible misinterpretations of the data imply that the conclusion is not as certain as the scores indicate.

In addition we note that the model simulations seem to mimic typical cartel behaviour, see e.g. Moxnes (1990) for data on a few commodity markets. The oil market might serve as an illustration. The last 20 years of figure 1 resembles development from 1947 to 1973, and the first 20 years resembles development since 1979. See also Morse (1986).

6. CONCLUSION

We have advanced a theory for cartel behaviour in commodity markets. Based on this theory, it seems that better understanding of market behaviour, acknowledging that cartels might cause both profits and problems, could help prevent the most destabilizing cartel formations.

NOTES

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- * The original research for this paper was supported by Statoil, Norway, see Moxnes (1990).
- 1 See e.g. Eckbo (1976) p.44.
 - 2 Dynamic optimization involves the timing of reactions by competitors and consumers, leads and lags in capital and employment adjustments, inventory adjustments, and even resource dynamics.
 - 3 See e.g. Danielsen and Kim (1988) for the same observation.
 - 4 Stocking and Watkins (1947) write: "The natives [Cuba] danced 'the dance of the millions', as the boom was popularly termed", p. 30. When sugar prices later fell, there was a popular demand for price increases among Cubans.
 - 5 See e.g. Proffitt and Gilden (1989), Sterman (1989a, 1989b), Brehmer (1989), and Dörner (1980).
 - 6 Meadows (1970) refer studies where adaptive expectations are found, Sterman (1987) and Frankel and Froot (1987) find trend-extrapolations with a certain tendency towards equilibrium values.
 - 7 The answer is largely no since reported Opec desires for price increases in the years before 1973 were typically less than five percent of the price escalations that followed the war.
 - 8 See Jorgenson (1963), Jorgenson and Stephenson (1967) and Mass and Senge (1978) on formulation and empirical justification.
 - 9 In case of prorating the effect of utilization would be reduced. We ignore that excess capacity by core members might serve as a deterrence against entry, see e.g. Lieberman (1987).
 - 10 Stocking and Watkins (1947) view stocks as an important factor for price determination in a cartelized sugar market: "Stocks accumulated steadily - and their growth contributed to an almost unbroken decline of prices", p. 28. They also indicate that the Aluminium Alliance of 1931 was aware of the importance of stocks for price development: "With excess stocks thus 'frozen', a similar device for regulating prices in the ordinary course of business came into play", p.264.
 - 11 The feedback loop through inventory, price, utilization, and production produces cycles with periods of a few years and with little dampening.
 - 12 Total net profits are the sum of yearly profits $pq_i - 0.4q_i - (1-0.4)k_i$, where 0.4 is operating costs.
 - 13 The index accumulates $\ln|p-p^f|$ where $dp^f/dt=(p-p^f)/25$.
 - 14 We do not attempt to estimate the probabilities for cartel actions to take place at various conditions. For instance we will not look at all situations with price declines and estimate the probabilities of cartel formation. Without such estimates, the model is lacking with respect to predicting development.



REFERENCES

- Adams, F.G. and Behrman, J.R. (1976). *Econometric Models of World Agricultural Commodity Markets. Cocoa, Coffee, Tea, Wool, Cotton, Sugar, Wheat, Rice*. Ballinger Publishing Company.
- Brehmer, B. (1989). "Feedback Delays and Control in Complex Dynamic Systems." In Milling, P. and Zahn, E., ed. *Computer Based Management of Complex Systems*. Berlin: Springer Verlag.
- Danielsen, A.L. and Kim, S. (1988). "OPEC Stability. An empirical assessment." *Energy Economics*. (July 1988): 174-184.
- Dörner, D. (1980). "On the difficulties people have in dealing with complexity." *Simulation and Games*. 11(1): 87-106.
- Eckbo, P.L. (1976). *The Future of World Oil*. Ballinger Publ. Company.
- Frankel, J.A. and Froot, K.A. (1987). "Using Survey Data to Test Standard Propositions Regarding Exchange Rate Expectations." *The American Economic Review*. 77(1): 133-153.
- Gorman, R.F. and Kehr, J.B. (1992). "Fairness as a Constraint on Profit Seeking: Comment." *The American Economic Review* 82(1): 335-358.
- Green, E.J. and Porter, R.H. (1984). "Noncooperative Collusion under imperfect Price Information." *Econometrica* 52(1): 87-100.
- Hexner, E. (1945). *International Cartels*. Chapel Hill: The University of North Carolina Press.
- Jorgenson, D. (1963). "Capital theory and investment behavior." *American Economic Review* 53.
- Jorgenson, D.W. and Stephenson, J.A. (1967). "The Time Structure of Investment Behavior in United States Manufacturing, 1947-1960." *Review of Economics and Statistics* 49: 16-27.
- Kahneman, D., Knetsch, J.L. and Thaler, R. (1986). "Fairness as a Constraint on Profit Seeking: Entitlements in the Market." *American Economic Review*. 76(4): 728-741.
- Labys, W.C. (1973). "Dynamic Commodity Models: Specification, Estimation, and Simulation." In *Dynamic Commodity Models: Specification, Estimation, and Simulation*. Lexington Books.
- Lieberman, M.B. (1987). "Excess Capacity as a Barrier to Entry: An Empirical Appraisal." *The Journal of Industrial Economics* 35(4): 607-627.
- Mass, N.J. and Senge, P.M. (1978). "Alternative Tests for the Selection of Model Variables." *IEEE Transactions on Systems, Man and Cybernetics*. SMC-8(No 6): 450-480.
- Meadows, D.L. (1970). *Dynamics of commodity production cycles*. Cambridge, Mass.: W.- Allen Press.
- Morse, E.L. (1986). "After the Fall: The Politics of Oil." *Foreign Affairs*. 64(4, Spring 1986): 792-811.
- Moxnes, E. (1990). "Kartell: Når dannes de, og når slutter de å fungere?" CMI-90-F30017, Chr. Michelsen Institute, Bergen.
- Osborne, D.K. (1976). "Cartel Problems." *The American Economic Review* 66(5): 835-844.
- Pindyck, R.S. (1981). "Models of Resource Markets and the Explanation of Resource Price Behaviour." *Energy Economics*. (July 1981): 130-139.
- Proffitt, D.R. and Gilden, D.L. (1989). "Understanding Natural Dynamics." *Human Perception and Performance Journal of Experimental Psychology*. 15(No 2): 384-393.
- Selten, R. (1987). "Equity and coalition bargaining in experimental three-person games." In Roth, A.E., ed. *Laboratory Experimentation in Economics*. Cambridge: Cambridge University Press.
- Sterman, J.D. (1987). "Testing Behavioral Simulation Models by Direct Experiment." *Management Science*. 33(12): 1572-92.
- Sterman, J.D. (1989)a. "Misperceptions of Feedback in Dynamic Decision Making." *Organizational Behavior and Human Decision Processes*. 43(3): 301-335.
- Sterman, J.D. (1989)b. "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment." *Management Science*. 35(3): 321-339.
- Stiegler, G.J. (1964). "A Theory of Oligopoly." *Journal of Political Economy* 72: 44-61.
- Stocking, G.W. and Watkins, M.W. (1947). *Cartels in Action, Case Studies in International Business Diplomacy*. New York: The Twentieth Century Fund.
- Thaler, R. (1980). "Toward a Positive Theory of Consumer Choice." *Journal of Economic Behavior and Organization*. 1(March): 39-60.
- Tversky and Kahneman (1981). "The Framing of Decisions and the Psychology of Choice." *Science*. 211(30 Jan. 1981): 453-458.

