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# COLLUSIVE EQUILIBRIUM IN THE GREAT SALT DUOPOLY*

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This paper sets out to test two interesting lines of recent development in oligopoly theory. The first, arising out of the analysis of infinitely repeated games, suggests conditions under which collusive outcomes can be supported as non-cooperative equilibria by appropriate threat strategies. The second considers the nature of equilibrium in a homogeneous duopoly in which firms set prices subject to fixed capacity constraints. Both these bodies of theory are discussed more fully in the next section.

The data used for the tests are given in a report on the UK Monopolies and Merger Commission (MMC) inquiry into price behaviour in the UK market for white salt.[1] In this market two firms produce an essentially homogeneous commodity with blockaded entry and fixed capacities. The report provides detailed data on prices, outputs and (marginal) costs as well as a great deal of more qualitative information which is valuable in interpreting these data. The information in the report is derived directly from the working of a real-world oligopoly. Its main drawback is that it relates only to five years, and does not allow standard econometric methods to be applied, in particular to the estimation of a demand function.

Nevertheless, this paper hopes to demonstrate that some quite strong conclusions can still be drawn, in particular on the extent to which the various possible equilibrium concepts proposed by the theoretical literature can explain the apparent nature of the equilibrium in this case. The wealth of detail given in the report seems too good to ignore, even if it cannot support a standard econometric investigation.

There is a correspondence between the two types of model with which this paper is concerned and the positions taken by the MMC and the firms that

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[1] 'White salt: A Report on the Supply of White Salt in the United Kingdom by producers of such salt', H.M.S.O. London 1986. This is subsequently referred to as MMC (1986). Though the present author was at the time a member of the MMC he was not involved in this particular inquiry, and all the information used in this paper was derived solely from the published report.

were the subject of the inquiry. The theory of price-setting duopoly under capacity constraints assumes that firms act non-cooperatively, making no attempt, whether tacit or explicit, to agree upon their choice of prices. The firms in the MMC inquiry claimed that they had in fact not colluded, and that the market outcome was fully consistent with 'competitive' behaviour. By examining whether the predictions of the price-setting model match what happened in this market, we have simultaneously a test of the model and also of whether the firms' claims can be accepted.

While skating carefully around the word 'collusion', the MMC concluded that the firms had 'severely restrained price competition'.[2] The basis for this judgement appears to have been some evidence on communication between the firms, the fact that over a long period prices had been virtually identical and changed more or less simultaneously, and finally a view of what the outcome should have been had the firms in fact competed. This view was not based on the predictions of the models considered here, and it is indeed questionable that it could be supported by any generally accepted positive model of the market, but later in this paper we argue that the MMC's judgement was essentially correct.

Given then that the behaviour of the firms can be taken to be collusive, the question arises of whether this can be explained by recent developments in the analysis of repeated games. In the next section we present brief outlines of the relevant theories and identify the sense in which they will be tested in this paper.

## I. THEORETICAL BACKGROUND

Consider a market with two firms producing homogeneous outputs in a single time period, and independently choosing prices subject to equal, constant marginal costs and exogenously given capacity constraints. Edgeworth (1897) showed that if each firm's capacity is less than market demand at a price equal to the given marginal cost, the Bertrand result that equilibrium price equals marginal cost no longer holds. If the market situation is repeated over a sequence of periods, price will vary cyclically between well-defined upper and lower limits, $p_h$ and $p_l$. The upper limit $p_h$ is the price which maximises a firm's profit *given* that it is undercut by its competitor. The firm with the lower price produces at capacity, the higher-priced firm is then faced with a residual demand with respect to which it finds the most profitable price $p_h$. The lower limit $p_l$ is the price which yields a firm the same profit $\pi^*$ when it is the lower-priced firm and produces to capacity, as when it is the higher priced firm and sets $p_h$. In general $p_l$ exceeds marginal cost. If, however, we insist that the analysis must relate to only one time period, i.e. to a 'one-shot game', then Edgeworth essentially shows that no equilibrium price exists in this model.

Shubik (1959) gave this result a game-theoretic reinterpretation: in this game there is no equilibrium in pure price strategies, but there is an

[2] Para. 9.10, MMC (1986).

equilibrium in mixed strategies. Beckman (1965) and Levitan and Shubik (1972) derived these equilibrium mixed strategies for specific examples of the model, the main difference between them being in the assumptions made about the rationing process. When the firms set different prices, some assumption must be made as to how the residual demand facing the higher-priced firm is determined, or equivalently, how buyers wishing to be supplied by the lower-priced firm are rationed. Beckman assumed a form of random rationing. Levitan and Shubik assumed *efficient rationing*: the lower-priced firm supplies those buyers with higher willingness to pay.[3] For concreteness, we focus here on this latter case. Then the equilibrium outcome in this type of market is predicted to be as follows: there is a given interval of prices which is defined by the Edgeworth upper and lower bounds $p_h$ and $p_l$. Firms choose prices randomly from this interval, and the equilibrium probability distributions regulating these choices are such that each firm has the same expected profit $\pi^*$ whatever the price pair chosen. It follows that there is a zero probability that the firms will choose equal prices, and that if the market situation is repeated after a period, each firm's price changes randomly (within the given interval) over time.[4]

An interesting extension of these results with particular relevance to the market studied in this paper has recently been made by Deneckere and Kovenock (1992). They allow the (still exogenously given) capacity levels of the firms, as well as their (constant) marginal costs, to differ, and consider the question of the endogenous non-cooperative determination of the identity of a price leader in this model. That is, firms engage in a game of timing of price announcements, and the equilibrium of the game determines which firm is the price leader and which the follower. Their result is that the firm with larger capacity will be the price leader, while the smaller firm will follow with a price just below that of the leader, and will produce at full capacity. Thus the price set by the leader is $p_h$, the upper bound of the Edgeworth interval, and it earns the same profit $\pi^*$ as in the mixed strategy equilibrium. On the other hand the smaller firm earns higher profit under price leadership than under simultaneous choice of (mixed strategy) prices, since it is producing to capacity at a price greater than $p_l$.

The theories then give quite definite testable predictions about the kind of price behaviour we should observe in this type of market. It is argued in the next section that the market for white salt is the type of market for which these models can apply, and therefore can be used to test these theories.

[3] For a thorough discussion of the economics of these rationing schemes see Dixon (1987).

[4] Capacity is here taken to be exogenous. Kreps and Scheinkman (1983) allow capacity levels to be chosen endogenously, in a two stage game. At the second stage firms play a price-setting game with fixed capacities. At the first stage they choose capacities in the light of their effects on the equilibrium at the second stage. The interesting result is that capacities are chosen to be such that outputs and price are precisely those given by the Cournot equilibrium of the model. This result is further generalised by Osborne and Pitchik (1986). Unfortunately, as Davidson and Deneckere (1986) show, this striking reconciliation of the results of quantity-setting and price-setting duopoly models is not robust to relaxation of the 'efficient rationing' assumption. Moreover, as we show below, its prediction that both firms will produce at capacity is not confirmed in the market being considered. However, this is probably not a fair test of the theory, since capacity in this market is best taken as exogenous over the period to which the observations relate.

The models just discussed are essentially 'one-shot games': they are concerned with deriving a Nash equilibrium in a single play of the price-setting game. However, if we move to the empirically more relevant view of the market as an infinitely repeated game, then it is well-known that repeated plays of the one-shot Nash equilibrium also represent a Nash equilibrium of the repeated game. However, the important point is that other Nash equilibria are possible, and in particular those that yield the firms more profitable outcomes than those in the one-shot non-cooperative equilibrium. The basic idea underlying the work of Friedman (1971), Abreu (1986, 1988) and Fudenberg and Maskin (1986) among others, is that these more profitable outcomes in the one-shot game may be sustained as non-cooperative Nash equilibria of the repeated game by threats of appropriate punishments for deviation. The intuition is clear. If a firm deviates from an agreement to collude in one period, it could be punished in later periods, and the threat of this *ex ante* may be enough to sustain collusion. However, going beyond intuition, a number of issues have to be considered. What form can or should punishment take and will it be sufficient in fact to offset these gains since it causes future losses which have to be discounted to be comparable with immediate gains from deviating? Moreover, since punishment will often hurt the punishers, for example a punitive price war reduces profits to all firms, will threats to carry out such punishment in fact be credible?

A formal answer to these questions is given by Abreu's theory of 'simple penal codes', which has been applied to the case of price-setting capacity-constrained oligopoly by Lambson (1987, 1991). Suppose that firms agree, tacitly or explicitly, on a particular price and allocation of outputs for each period. They also agree on a time path of prices that will be applied as a punishment for a deviation from the agreed price by a firm, where this punishment path may depend on exactly which firm deviates. A punishment path is credible if it is in each firm's interest not to deviate from it in the event that it has to be imposed. An agreed price and output allocation is sustainable if it would not pay any firm to deviate from it given the credible punishment path that would then be imposed. An interesting aspect of the punishment path is its 'stick and carrot' nature. In the first stage of punishment, price is cut to inflict loss of profit, but this is followed by a second stage of reversion to the more profitable price and output allocation. It then pays a firm that has just deviated to accept its punishment, since failure to do so leads to reimposition of the punitive phase of the punishment path and postponement of the return to the more profitable cooperative phase. If a firm that did not deviate originally refused to participate in punishing the firm that did, then it itself would become a deviant and have the appropriate punishment path inflicted on it. In this theory the requirement of credibility is formally embodied in the concept of subgame perfect equilibrium. The strategy of adhering to the agreed price and output allocation as long as no firm deviates, and adhering to the prescribed punishment path immediately following any deviation, is shown to induce a Nash equilibrium for every possible subgame of the infinitely repeated game. Of course, if the cooperative agreement *is* sustainable, we would not actually observe implementation of the punishment strategies – the observed market equilibrium would be the agreed price and output allocation.

Any particular price and output allocation may or may not be sustainable by Abreu's punishment strategies or simple penal code. This depends on the firms' discount factors and the structure of the market – the demand and cost functions the firms face. Those determine the extent of the gains from deviation, the losses of profit that can be inflicted through punishment, and the present value of future losses relative to immediate gains from deviation. For our present purposes, we are interested in the question: if we were to accept that firms in the white salt market behaved collusively, whether tacitly or explicitly, is this consistent with the models of Abreu and Lambson? We would conclude that it was, if the actual allocation turned out to be sustainable by Abreu-type punishment strategies, while if the actual allocation turned out to be not sustainable (at reasonable discount rates), we would have to reject the theory and look for some alternative explanation of collusion. Note that this is a one-sided test of the theory. It would also be interesting to find a market in which collusion did not take place, and to examine whether more profitable allocations than the actual one would be sustainable, in which case we could again reject the theory.[5] This will however have to be left for further work.

## II. THE MARKET FOR WHITE SALT

This section sets out briefly some salient facts about the salt market.[6]

*Production.* Salt production in the United Kingdom consists essentially of the extraction and processing of a non-renewable natural resource. However, reserves are so large relative to consumption that the resource rent is effectively zero and we can regard salt as a manufactured commodity. Water is pumped down into salt strata lying underground, this dissolves the salt to form brine, which is then pumped to the surface and transported through a pipeline to, initially, a purification plant. Here chemicals are added to remove unwanted minerals, then the purified brine is pumped to an evaporation plant. Six large boilers, known as effects, are arranged in sequence, brine is pumped into the first, the water is boiled off and the salt precipitated, and the waste steam is passed into the second effect where it is used to heat more brine, and so on. After the evaporation process 'undried salt' is produced, with the consistency of wet sand. Part of this output is shipped immediately to chemical plants, mainly for use in production of caustic soda and chlorine. The remainder is dried, and then shipped, in bulk or in bags, again to chemical plants for use in

[5] To put this more precisely, consider the set of all markets, and the subsets of markets (*a*) which satisfy Abreu's conditions for the sustainability of an agreed allocation by credible threats, and (*b*) in which collusion is observed. I interpret Abreu's theory to say that these subsets are equal. All that this paper can do, in considering just one market, is to show that their intersection is not empty, if Abreu's conditions are satisfied; or that the sets are not equal, if the conditions are not satisfied. In this latter case the set in (*a*) could still be a subset of that in (*b*), in which case Abreu's conditions would be sufficient but not necessary for collusion.

[6] A fuller description, together with a complete set of the data on which the later discussion is based, is given in Rees (1991).

production of sodium and chloride, but also to food manufacturing and animal feed preparation plants, and tanning and dyeing works. Less than 10% of total salt output is sold for cooking or table use.

*Concentration.* There are effectively just two producers: British Salt, (BS), a self contained but wholly-owned subsidiary of an industrial engineering and contracting group, Stavely Industries; and ICI Weston Point, (WP), a small part of the Mond division of the large chemicals conglomerate ICI. Fortunately for this study WP is a self-contained accounting unit selling less than 5% of its output to other ICI plants. Imports and a number of very small salt works account for around 3% of the market and so in the rest of this study will be ignored. We treat BS and WP as single-plant profit maximising firms. BS takes on average about 55% of the UK market and WP the remainder.

*Capacity.* Each firm is subject to a maximum capacity constraint, which is 824 kilotonnes (kte) pa for BS and 1095 kte pa for WP. Over the years 1980–4 there was considerable excess capacity: BS averaged less than 75% capacity utilisation, while WP's UK sales alone amounted only to 45% of capacity, on average, though its export sales, made at a much lower profit, brought its capacity utilisation rate up to around 65%. The degree of excess capacity appears to have been caused by an unanticipated decline in demand since the capacity was first installed in the early 1970s.

*Entry.* Though salt strata suitable for extraction are common in the United Kingdom, a combination of planning controls and high transport costs seems to rule out production outside the Cheshire area in which both BS and ICI's plants are located. The main users are located quite closely to the salt plants, while at the prevailing prices imports were not regarded as a threat because of the high cost of transport and transshipment relative to value. The major salt strata in Cheshire are owned by the incumbent firms. Moreover, there are significant economies of scale and as we have just seen significant excess capacity in the market. In the rest of this study therefore we assume that the market behaviour of the incumbents has been influenced by the threat of new entry only to the extent that the possibility of imports places an upper bound on the price that can be set.

*Costs.* The MMC report suggested that variations in output by BS can be achieved without significantly affecting energy usage per unit of output (para 4·10, MMC (1986)) and, since this is the main variable input, we translate this into the assumption that over the relevant range of outputs average variable cost of production (*avc*) is constant as output varies and so equals marginal production cost. WP, which has a somewhat different technology than BS, has a more complex cost structure. Reductions in output below capacity are most efficiently coped with by reducing the number of effects in operation, and this raises *avc* in a stepwise way.[7] See Fig. 1. The MMC report gives an indication

[7] As Fig. 1 shows, fixed production costs are assumed not to depend on the number of effects in operation. The total cost function jumps discontinuously at an output level (here 400 kte pa and 800 kte pa are chosen for purposes of illustration) at which it becomes efficient to change the number of effects in operation. Essentially, however, we are interested only in the middle step, which corresponds to the actual operations, and costs in the neighbourhood of WP's capacity output.

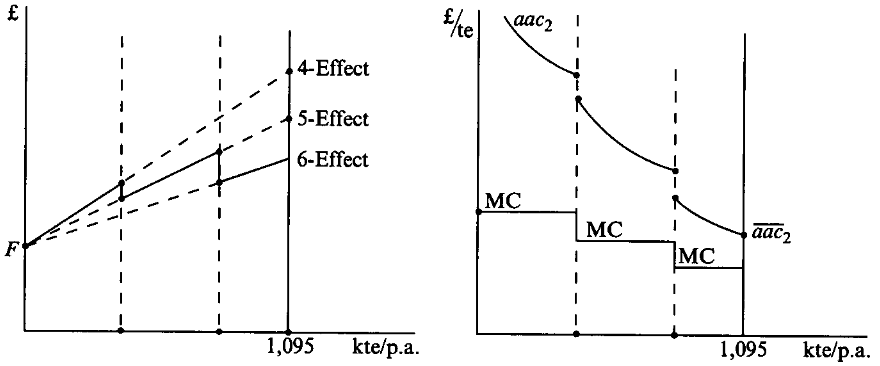


Fig. 1. Cost Structure for WP.

of the heights of these steps but does not give the precise output levels at which the steps occur. In the period under study WP operated along the middle step.

In addition to production cost, the other component of variable cost is distribution cost, consisting mainly of transport costs. We assume these are constant per unit of output. Marginal cost *MC* is then the sum of *avc* and average distribution cost. Finally, we define as average avoidable cost (*aac*) a firm's *MC* plus 'fixed production costs' per unit of output. The latter, consisting mainly of labour, management and maintenance costs, do not vary with output, but are incurred if and only if the plant is operating: *aac* is therefore zero if output is zero and the plant is shut down. $\overline{aac}_1$ denotes BS's *aac* at its capacity output, and similarly $\overline{aac}_2$ is WP's capacity *aac* and takes into account WP's lower average variable production cost at capacity, due to six-effect operation. Since all these costs play an important role in what follows, it is useful to summarise the full range of information in Table 1.

Table 1
*Firms' Marginal and Average Avoidable Costs*

| | | Year | | | (£/te) | |
|---|---|---|---|---|---|---|
| | | 1980 | 1981 | 1982 | 1983 | 1984 |
| *avc* | *BS* | 6·30 | 8·07 | 8·12 | 9·21 | 9·07 |
| | *WP* | 6·02 | 7·39 | 9·49 | 10·82 | 11·47 |
| *mc* | *BS* | 9·81 | 12·11 | 12·03 | 13·67 | 13·36 |
| | *WP* | 12·77 | 14·22 | 14·74 | 16·77 | 16·14 |
| $\overline{aac}$ | *BS* | 12·61 | 15·07 | 14·72 | 17·07 | 17·01 |
| | *WP* | 14·46 | 15·68 | 16·28 | 18·49 | 17·72 |

*Source:* MMC (1986).

The data in Table 1, interpreted here as the actual values of marginal and average avoidable costs firms would have used in their decision-taking, are one of the most valuable contributions of the MMC report, given the concerns of this paper. We should at this point therefore enter a qualification. We shall throughout conduct the analysis as if there is only one output. However, there are at least three: undried and dried salt sold in bulk, and dried salt sold in bags. The last two outputs must be somewhat costlier to produce because of the additional drying and/or bagging costs. It is impossible to disaggregate the cost data among these three outputs (for example no separate figures are given on bulk and bagged dried salt sales). However, for each firm the proportions of total output accounted for by each type of salt remained fairly stable over this period. For WP, undried salt varied apparently randomly between 35 % and 41 % of total output and for BS between 30 % and 37 %. Thus we assume that no significant systematic bias results from treating output as homogeneous. This is helped by the fact that, as we see below, the two firms made identical percentage increases in the prices of all types of salt over this period.

*Prices.* In a fascinating section of the report (paras 5·25–5·41, MMC (1986)), the MMC lists the dates and amounts of the seventeen changes to list prices made by the two firms between January 1974 and January 1984. The increases are always either exactly or virtually identical. From 1980 each firm made the same percentage increases across all grades of salt, prior to this increases varied across grades. In each case one firm announced its price increases and the second firm followed within a month and usually within two weeks. Of the 13 price increases announced from 1974–80, BS led 8 times and WP led 5 times. In each of the years 1981–4, WP was the leader. Typically the leader would inform the follower of its planned price increase a month before it came into effect, and the latter would then inform the leader of its proposed (identical) price change within that period (Table 5·8 of MMC (1986)).

In their evidence to the MMC on this matter, the firms denied collusion[8] and the exchange of any information other than of proposed price changes[9] (paras 8·8–8·17, 8·56–8·74, MMC (1986)). They made the point that in a competitive market prices would be identical and would move closely together. They also argued that it is not enough to consider only list prices, since there is widespread discounting to buyers and so actual prices paid could well have moved differently. To test this latter point the MMC examined the discount structure of each seller. Until 1980 the rebate scales of the firms had been identical. Furthermore, for the majority of buyers discounts have been insignificant, amounting to less than 1 % of the list price. For a few very large buyers, BS's discount structure after 1980 implied a price per tonne of roughly 0·25 % below that of WP. Moreover, the MMC sampled a group of buyers to identify the values of differences in prices they had been quoted by the two sellers. These differences average about 0·5 % of the price, with the highest at

[8] Prior to the Restrictive Practices Act, 1956, a formal agreement to set common ex works and delivered prices for producers and common resale prices for merchants had been in force for more than twenty years. There was also an aggregated rebate scheme under which buyers received a discount based on aggregate purchases from all sellers. The Act required such agreements to be registered with the Registrar of Restrictive Practices, following which they could be challenged in the Restrictive Practices Court. The salt agreement was discontinued and not registered.

[9] The firms explained that this was done because each bought salt from the other and it was usual to notify buyers in advance of price increases.

Table 2
*Capacity Utilisation, Market Share, Prices and Profits*

| | Year | | | | |
|---|---|---|---|---|---|
| | 1980 | 1981 | 1982 | 1983 | 1984 |
| I. Capacity utilisation (%) | | | | | |
| BS | 85 | 71 | 79 | 69 | 67 |
| WP (U.K. output/capacity) | 54 | 47 | 43 | 40 | 41 |
| WP (total output/capacity) | 75 | 60 | 65 | 59 | 64 |
| II Shares of U.K. market (%) | | | | | |
| BS | 54 | 53 | 58 | 57 | 55 |
| WP | 46 | 47 | 42 | 43 | 45 |
| III. ROC (%) | | | | | |
| BS | 46 | 45 | 53 | 52 | 53 |
| WP | 33 | 32 | 30 | 24 | 24 |
| IV. Rate of Price Increase (%) | 19·4 | 7·5 | 14 | 8 | 5 |
| Firm initiating | BS | WP | WP | WP | WP |

*Source:* MMC (1986).

2·2% and the modal value close to zero (Table 5·14, MMC (1986)). The proposition that buyers perceived price uniformity is supported by the fact that around 78% of buyers had not changed their sources of supply over the five years previous to the enquiry (para 5·13, MMC (1986)).

*Profits.* The accounting rates of return on capital employed (ROC), net of depreciation, and at historic cost, are shown for the two firms in Table 2, which also gives some other important market information. Over the same period, the comparable rate of return for all large quoted companies varied between 9% and 13%, and of companies in the chemicals and man-made fibres industries between 7% and 16%. However, in the remainder of this paper we consider only profits defined as revenues less variable and fixed production and distribution costs. The reason is of course that the capital costs were essentially sunk and did not vary either with the level of output or the shutdown decision. Profits are the short run quasi-rents which the firms are assumed to maximise.

## III. COMPETITION, PRICE LEADERSHIP, COLLUSION AND JOINT PROFIT MAXIMISATION

The data on costs, capacities and prices given by the report we take to be 'hard data'. Though they are subject to interpretation, the numbers themselves are those the firms themselves would have had to work with. We can give reasonably firm answers, on the basis only of these data and, in some cases, general assumptions on demand, to the three questions with which we are concerned. Did the firms behave non-cooperatively as in the Edgeworth–Levitan–Shubik (ELS) or Deneckere–Kovenock models? If not, does an Abreu-Lambson type of explanation of collusion hold? Did they maximise joint profits? We consider these in turn.

From the results summarised in Section I, we know that the one-shot non-cooperative equilibrium involves firms operating at below capacity and choosing mixed strategies in prices.[10] Clearly, both firms were producing at less than capacity. If they had been choosing prices according to mixed strategies, then the probability that every time they chose prices those prices would be identical, is zero. Yet on each of the 17 times prices were set in the period 1974–84 prices were in fact identical. Thus we could reject the ELS model, even if we had no knowledge of the extent to which the firms actually exchanged information on proposed price changes, and thus could be said to be correlating strategies.

A somewhat stronger case could be made for the Deneckere–Kovenock theory of price leadership. The theory predicts that the larger firm would be the price leader. This was true in each year 1981–4. In the seven years previous to that, leadership varied between the two firms, but we have cost data only for 1980–4. In the Deneckere–Kovenock model, the smaller firm could be price leader if its marginal cost is sufficiently higher than that of the larger firm, and only in 1980 can we certainly say that this was not true, so that BS's price leadership in that year contradicts the theory. The theory also predicts that the follower will price 'just below' the leader, and, though this is not consistent with the data on list prices, the evidence on discounts given by the MMC could perhaps be interpreted as just consistent with this. However, the crucial mismatch is in respect of capacity utilisation. In the Deneckere–Kovenock price leadership equilibrium, the follower sells at full capacity. This was clearly not the case in the white salt market.

Thus, in this market at least, the predictions of the ELS and Deneckere–Kovenock theories are not confirmed. The main reason, we would claim, is that they are derived from one-shot non-cooperative equilibria.

In its evidence to the MMC, BS stated that 'if it raised prices by a lesser amount than [WP], and [WP] failed to lower its own price to the same level, there would be an immediate transfer of business to itself... This would lead to a long-term retaliation by [WP] who would seek to take customers from British Salt'. (MMC (1986), para 28·11). This statement shows that the firms clearly share the intuition underlying the idea of collusive equilibrium supported by the threat of retaliation, which is hardly surprising, simple as it is.

We now have to see if the outcome in this market is consistent with the more formal theory. We assume that the actual prices and profits in each of the years 1980–4 correspond to collusive allocations, and we wish to test whether these can be sustained by credible threats. Following Lambson (1987), we have the criteria for:

(i) *Sustainability:* Let $\pi_i^C$ denote the one-period profit firm $i = 1, 2$ earns under the agreement, $\pi_i^R$ the maximum profit it can earn by reneging on this agreement, $\tau_i$ a punishment path of prices that will be imposed in the period

[10] In fact there are two other equilibrium possibilities, each of which can be ruled out in the salt market. Where firms' capacities are sufficiently large, we would have the Bertrand equilibrium with price equal to marginal cost. This was clearly not the case here. Alternatively, if each firm's capacity is less than or equal to its Cournot output in this market each would produce at capacity and price would clear the market. Since both firms produced below capacity we can also rule out this as a possible equilibrium.

following a violation of the agreement by firm $i$, $V_i(\tau_i)$ the present value at the date punishment begins of profits to firm $i$ along this path, $r > 0$ the per-period interest rate and $\delta = (1+r)^{-1}$ the discount factor. Then the agreed allocation is sustainable if at each time $t$

$$\pi_i^R - \pi_i^C \leqslant \pi_i^C/r - \delta V_i(\tau_i) \quad i = 1, 2. \tag{1}$$

This says that the one-period gain from deviating at time $t$ is less than the present value at $t$ of the future loss of profit from having the punishment path inflicted next period rather than enjoying the collusive profit forever. Provided the punishment path is credible, satisfaction of (1) ensures that the threat of future punishment will deter a one-shot violation of the agreement.[11]

(ii) *Credibility*: Let $\pi_i^P$ denote the profit in some given period $t$ that firm $i$ will make on a prescribed punishment path[12], $\pi_i^{RP}$ the maximum profit it could make at $t$ if it reneged on the punishment path in that period, and $V_i^L$ the present value at $t+1$ of profit the firm would earn from adhering to that prescribed punishment path from $t+1$ onward. Then that punishment path is credible if

$$\pi_i^{RP} - \pi_i^P \leqslant \delta [V_i^L - V_i(\tau_i)] \quad i = 1, 2. \tag{2}$$

The right-hand side of (2) gives the present value at $t$ of the difference in profits between continuing along the prescribed punishment path from $t+1$ on, and having a punishment path for a deviation imposed at $t+1$ from its beginning. The left-hand side gives the one-shot gain from deviating from the prescribed punishment path. If this inequality is satisfied, it does not pay firm $i$ to deviate from the prescribed punishment path and so the threat of imposing that path is credible.[13]

To test whether these conditions can be satisfied in the market under study we first need to specify a time period and associated interest rate. We take 3 months and 10% respectively as reasonable assumptions.[14] Next we need to specify the exact nature of the punishment price paths. In general, a path which can satisfy (1) and (2) for some set of interest rates is not unique, but the following specification has some intuitive appeal:

If either firm deviates, in the following three periods both firms set price at $aac_2$ and then they revert to the initial allocation.

Since on this (symmetric) punishment path price falls to WP's actual *aac*, it makes no profit in the punishment phase, while BS makes a small profit because its *aac* is somewhat lower. The punishment strategy corresponds to a 'price

[11] Abreu (1988) shows that if deviation is unprofitable for one period it will never be profitable.

[12] Strictly we should write $\pi_{itj}^P$, $t = 1, \ldots, j = 1, 2$ since profits may well vary along a punishment path, and the path may depend on which firm deviated, but no confusion should result from keeping the notation uncluttered here.

[13] Simply rearranging the condition as $\pi_i^{RP} + \delta V_i(\tau_i) \leqslant \pi_i^P + \delta V_i^L$ shows that we could equivalently interpret the condition as saying it is better to continue along the given punishment path than to deviate this period and have punishment begin anew next period.

[14] The longer the time period, the more profitable does reneging become, since the longer the period for which additional profit is earned and the further into the future retaliation takes place. Assuming a period of one year does not change the conclusion that for reasonable interest rates the cooperative allocations in this market were sustainable by credible threats, though to assume that one firm would take an entire year to react to open price-cutting by the other is extreme. A quarterly interest rate of 10% is equivalent to an annual rate of 46%, which again seems to be a reasonable upper bound.

war' in which prices are slashed to the break-even level (at actual output) for the higher cost firm.

To quantify the effects of punishment on the firms' profits as well as the gains from one-shot deviations from the punishment path we require some assumption about market demand. As a first approximation, we assume zero elasticity of demand at any prices below the agreed price. Since, if this were true at prices above the agreed price, the latter could not be profit maximising, we are implicitly assuming a kink in demand at the actual price, possibly due to the threat of imports.

Finally, we need to assume how total market demand will be shared between the firms along a punishment path. Since they set the same prices, it seems reasonable to assume that their market shares are as in the actual allocation. Thus, effectively we assume that along a punishment path the firms would produce the same outputs as those they actually produced, but at much lower prices and profits. For each of the years 1980–4, we then calculate the values of the quantities entering into conditions (1) and (2), given the punishment strategies just described. The results[15] are given in Table 3, and show that the specified punishment path was credible in each year, and could sustain the actual allocation.

Table 3

*Gains and Losses from Deviation and Punishment*

(£000)

| | $\pi_i^R-\pi_i^C$ | | $(\pi_i^C/r)-\delta V_i$ | | $\pi_i^{RP}-\pi_i^P$ | | $\delta(V_i^L-V_i)$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | BS | WP | BS | WP | BS | WP | BS | WP | |
| 1980 | 367 | 2,015 | 3,347 | 3,759 | 256 | 1,068 | 1,012 | 1,136 | (17%) |
| 1981 | 964 | 2,901 | 4,172 | 4,148 | 376 | 636 | 1,260 | 1,254 | (116%) |
| 1982 | 800 | 3,340 | 5,143 | 4,006 | 276 | 735 | 1,554 | 1,211 | (80%) |
| 1983 | 1,377 | 3,397 | 5,041 | 3,621 | 494 | 948 | 1,524 | 1,094 | (26%) |
| 1984 | 1,631 | 3,633 | 6,035 | 3,645 | 468 | 819 | 1,824 | 1,101 | (49%) |

Thus for example if in the first quarter of 1984 BS (WP) had undercut the agreed price slightly,[16] it would have gained just over £1·6 m. (£3·63 m.) in additional profit in that quarter, but would have lost just over £6 m. (£3·65 m.) in present value of profit from the ensuing three quarter long price war, relative to the agreed allocation.[17] On the credibility of the punishment path, if BS reneged on the first quarter's punishment, by setting price slightly below the agreed level of WP's *aac* and producing to capacity, then it would have made a net gain of close to £½ m., but would have lost over £1·8 m. in present value of profit from postponing the time of reversion to the agreed

[15] Space limitations preclude presentation of the detailed calculations here. An appendix presenting these was supplied to the referees and is available from the author upon request.

[16] The numerical calculations assume a price cut resulting in a 1% fall in 'net sales value', i.e. revenue minus distribution cost per unit.

[17] In fact a punishment phase lasting only one quarter would have been sufficient to deter BS from reneging on the agreed allocation. However this would not have been sufficient to deter BS from reneging on the first period of a punishment path following a deviation by WP.

allocation by one period. In WP's case, in 1980 and 1982 it was more profitable to renege on the punishment path by setting price at the actual level and allowing itself to be undercut by BS. Market demand in those years was sufficiently high that its residual output was large enough to give it more profit than if it undercut the punishment price slightly and produced at capacity. In the other years market demand was so low that the latter was the better means of reneging. In no year however did it pay WP to renege on punishment. The figures in brackets are the quarterly interest rates at which condition (2) for WP is just satisfied as an equality. Condition (2) for BS, (as well as condition (1)), could be satisfied at far higher interest rates even than these. Thus we conclude that on our assumptions conditions (1) and (2) were satisfied and cooperation in this market was consistent with the Abreu–Lambson theory.

This then raises the question of how to explain the collusive allocation. The solution most usually considered in the literature is that of joint profit maximisation. On the face of it, this would immediately be rejected as an explanation of the actual equilibrium in this market, since we would expect it to imply that the firm with the lower marginal cost, in this case BS, would produce to capacity, leaving the higher marginal cost firm to meet residual demand. The fact that both firms produced well below capacity is then not consistent with this. However, some care must be taken in drawing this conclusion in the present instance, because two important non-convexities in the cost functions complicate the analysis. First, as Fig 1 showed, at low levels of output WP has to switch to 4-effect operation, resulting in a significant increase in unit production cost (MMC(1986) para. 4·37). It may actually minimise total production costs to keep WP's output high enough for it to maintain 5-effect working, therefore. Secondly, for each firm there is a large fixed production cost which is avoidable if the plant shuts down. In order to identify the output allocation which minimises total avoidable costs, therefore, we consider four sets of costs:

A. the variable and fixed production costs actually incurred in producing total market output;
B. the cost resulting when BS produces to capacity in each year, with WP meeting residual demand, on the assumption that 5-effect working could be maintained and WP operates at the corresponding (actual) marginal cost;
C. the costs resulting when BS produces to capacity and WP meets residual demand with 4-effect working;
D. the costs resulting when WP produces to capacity and BS meets residual demand[18] at its actual marginal cost.

Table 4 gives the results. The figures in brackets show the percentage deviation of the given cost figure from the actual cost figure for that year.

Thus we see that total costs could have been around 2% to 5% lower if BS had always produced to capacity, but only if WP would have been able to

[18] Only in 1980 was total market output significantly greater than WP's capacity of 1095 kte pa. In 1983 and 1984 total output was less than this, and in 1981 and 1982 was greater by 4 kte and 30 kte respectively. In neither of these two latter cases would it have been worth incurring the fixed production cost to open up the BS plant.

Table 4
*Total Cost Comparisons*

| | Output (kte) | A | (£000) B | C | D |
|---|---|---|---|---|---|
| 1980 | 1,294 | 19,455 | 19,095 (−1·9) | 19,884 (+2·2) | 20,103 (+3·3) |
| 1981 | 1,099 | 19,479 | 18,399 (−5·5) | 19,546 (+0·3) | 17,170 (−11·8)† |
| 1982 | 1,125 | 20,074 | 19,598 (−2·4) | 20,393 (+1·6) | 17,827 (−11·2)‡ |
| 1983 | 1,007 | 21,352 | 20,567 (−3·7) | 21,117 (−1·1) | 18,730 (−12·3) |
| 1984 | 1,003 | 21,031 | 20,281 (−3·6) | 20,852 (−0·8) | 18,054 (−14·2) |

† The market would have been undersupplied by 4 kte.
‡ The market would have been undersupplied by 30 kte.
Figures in parentheses are % deviation of cost of B, C and D from A. A, B, C and D are defined above in the text.

maintain 5-effect working. If this had not been the case then overall there would have been no cost advantage in doing this. The interesting result however is that in every year except 1980, because market output was close to or below WP's capacity, the cost-minimising policy was clearly to close BS's plant and meet market demand only from WP. Although, even at full capacity (6-effect) working WP's marginal cost was above that of BS, the latter's capacity was too small to meet market demand, and the saving in fixed production costs from shutting down BS more than offsets the higher variable production costs from switching production to WP. Thus we can conclude that the actual production allocation between BS and WP did not minimise total costs, and therefore did not maximise joint profit. An explanation for the non-maximisation of joint profit is of course that side-payments would have been required, and these would have been clear evidence of collusion.

## IV. CONCLUSIONS

The first conclusion of this paper is that the type of market behaviour predicted by the non-cooperative one-shot game models of Edgeworth, Levitan and Shubik, and Deneckere and Kovenock was not observed in the white salt market. The predictions of these models call into question the standard defence of oligopolists (also used by the salt producers) that identical prices which change (virtually) simultaneously by identical amounts is evidence of 'competitive' behaviour. Of course we cannot expect 'perfectly competitive' outcomes in these markets, and the only feasible requirement for 'competitive' behaviour is that it be non-cooperative. But in a market for which these models are appropriate, namely a homogeneous, price-setting duopoly with exogenous capacity constraints, non-cooperative behaviour does not result in identical prices.[19] For this reason, we would support the MMC's conclusion that the salt duopolists 'acted to restrain competition'.

[19] This is not to say that there are no non-cooperative duopoly models which predict identical prices – homogeneous quantity-setting duopoly is obviously one. The point is rather that non-cooperative behaviour may well not result in identical prices.

The second conclusion is that the intuitive idea, apparently shared by the firms, that deviation from the (possibly tacitly) agreed prices could not pay, is fully borne out by application of the more formal analysis of Abreu and Lambson. Taking a time period and interest rate which err on the side of favouring deviation, we show that the gains from deviating from the actual prices were easily outweighed by the losses from credible, relatively short-lived punishments. Because of its lower degree of capacity utilisation, the higher cost firm WP had the greater incentive to deviate, but a short price war in which price was cut to its average avoidable cost was a credible deterrent to this deviation. On the one hand this tells us that it is not difficult to explain collusion in this market, and on the other that behaviour in the market was consistent with the theory of Abreu and its extension by Lambson.

Finally, we conclude that the actual allocation did not correspond to joint profit maximisation, because the output allocation did not minimise the (avoidable) production costs of total output. The apparent cost minimising allocation would have BS, the firm with lower marginal cost, producing to capacity. However, given the fairly small residual output, this may well have caused a jump in WP's marginal production cost and, our calculations show, total cost may not have been lower as a result. In fact, given that aggregate output was about or below WP's capacity, the cost minimising allocation would involve shutting down BS, thus saving its fixed production costs, and meeting total output requirements from WP. The general point is that the non-convexities in the cost structures of the two firms make marginal cost-based comparisons potentially misleading.

If side-payments between the firms are ruled out then there is no compelling reason to expect the agreed allocation to be joint profit maximising. This is reinforced in the present case by the extreme nature of the joint profit maximising solution. This still leaves open the question of how to explain the observed prices and outputs in this market. That appears to be a fruitful subject for further study.

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