Examining Models of Collusion: the Market for Lysine

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Abstract

Economic theory admits a spectrum of predictions of firm behaviour under collusion, depending on the specific modeling assumptions employed. This paper compares the experience with collusion in the market for lysine with the predictions of several classes of collusion models. The lysine market provides an ideal setting for this study following the recent confessions of market participants in anti-trust investigations. Data and information is collected covering periods of successful collusion and price wars. Demand and cost functions are estimated and used to calculate the markup over marginal costs of a major firm in the market. It is found that static models provide little guidance for the behaviour of the markup under collusion. Models of repeated games with imperfect information are roughly descriptive of some of the events in the lysine market. However, to better capture the flavour of collusion in the lysine market, we may need to relax the assumptions, common to much of the literature, that firms are symmetric and operate in a stable environment. This point is highlighted by the dramatic role that entry plays in the experience with collusion in the lysine market.

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1 Introduction

1.1 Motivation and Outline

When examining collusive behaviour among firms, there are many potential models to choose from. In a world of perfect information (and a homogeneous product), the Cournot model is a common reference point. More cooperative models follow from the introduction of a repeated game setting.\(^1\) Introducing imperfect monitoring unleashes a host of other models involving inference and signalling among participating firms. Explicitly dynamic models incorporate the impact of opportunities for investment, entry and exit on incentives to collude. My aim is to concentrate on one market, the market for lysine, in which it is known that collusion took place, and examine the ability of these models to replicate the observed dynamics of this market.

By October 1996, the major participants in the market for lysine had confessed to fixing prices. Some data on lysine prices and quantities covering the period of conspiracy is available from the proceedings of the various anti-trust cases. This makes the market for lysine an ideal test case for models of collusion. In addition, the homogeneous nature of the product greatly simplifies the analysis.

Below, I briefly describe some relevant models of collusion. Section 2 outlines some background information on the market for lysine. This includes a discussion of the salient features of the market and the history of the operation of the lysine cartel. In Section 3, models of lysine demand and costs are discussed. Based on demand and cost estimates, section 4 compares the behaviour of Archer Daniel Midland’s mark-up to that predicted by different models of collusion. A test of the Cournot model is included. Section 5 offers some potential explanations for the major events over the lysine market’s history. Possible modelling assumptions are also discussed. Finally, Section 6 concludes.

1.2 Models of Collusion

The market I am considering is characterised by a homogeneous product and hence the Cournot model is a natural place to start. The Cournot model is an explicitly static model. It predicts as the result of a Nash equilibrium in quantities, a level of competition intermediate between perfect competition and joint profit-maximisation. A firm’s mark-up of price over marginal cost should depend on the elasticity of market demand and the firm’s market share. Allowing repeated interaction between firms can lead to models exhibiting a more cooperative outcome. Such models require a regime of punishments and rewards to maintain sufficient incentive to

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\(^1\)See Pearce (1992) for a survey of cooperation in repeated games of symmetric and asymmetric information.
cooperate. Commonly, rewards for cooperation take the form of more restrictive output and higher attendant profits, while punishments include temporary or permanent reversion to the Cournot-Nash equilibrium or minimaxing deviating firms.²

Once we allow for the possibility that firms cannot perfectly monitor the behaviour of their competitors, the character of cooperative equilibria changes. Green and Porter (1984) develop a model predicting price wars along the equilibrium path. Firms are faced with stochastic demand and unobservable actions of their competitors. Should they encounter an adverse profit realisation, they face an inference problem to distinguish the competing explanations. On the equilibrium path, punishment takes place whenever a negative demand shock occurs, in order to maintain adequate incentives for cooperation. Abreu, Pearce and Stachetti (1986) characterise optimal collusive equilibria for a more general class of game than considered by Green and Porter.

An alternative generalisation is to allow firms to account for dynamic factors. Fershtman and Pakes (2000) develop a model in which heterogeneous firms explicitly consider the impact of their decision of whether to collude on the entry, exit, and investment decisions of incumbents and potential competitors. It is found that collusion is particularly hard to sustain if one of the firms is likely to exit in the near future. The model assumes symmetric information, but could be generalised to allow asymmetric information.

²See Friedman (1971) on the use of Cournot-Nash threats to enforce collusive equilibria, and Abreu (1986) on the use of “stick and carrot” incentive schemes to generate extremal collusive equilibria.

³This section draws heavily on work done by Connor (1998a, 1998b, 2000), where a detailed description of the evolution of the lysine conspiracy can be found.

⁴It is also important for the development of fish, but this can account for only a small fraction of the demand for synthetic lysine in the United States.

2 The Lysine Market³
entry occurred during the life of the cartel, two other firms were planning to enter the market until Archer Daniels Midland’s dramatic entry, and large scale entry occurred after the cartel was dissolved. In addition, the switching of capacity between the production of different amino acids appears possible, although the costs to doing so are not known (Connor, 1998a).

Prices and volumes of lysine suppliers are not directly observable. Manufacturers of animal feeds account for the bulk of lysine demand. Wholesalers of farm supplies and individual farmers also purchase some lysine. Contracts of most large buyers specify annual volumes and contain 30-day price protection clauses.

By the 1960s, Japanese biotechnology firms had discovered a bacterial fermentation technique that transformed the production of lysine. It involves the fermentation of dextrose into lysine and is considerably cheaper than conventional extraction methods. Throughout the 1980s, Asian firms imported large quantities of dextrose from the US and exported lysine back to the US. The first US based lysine plants were built in the mid-1980s. By the end of the 1980s, there were three major players in the lysine market: Ajinomoto and Kyowa Hakko based in Japan; and Sewon based in South Korea. The US market was supplied by Ajinomoto’s and Kyowa’s US plants, their imports from Japan, Mexico and France, and Sewon’s South Korean plant. Testimony by officials at Ajinomoto suggests that the lysine industry fixed prices in its early history (Connor, 2000). Figure 1 depicts the evolution of lysine production capacity in the U.S.
In 1988, Archer Daniels Midland (ADM) acquired a fermentation technique for lysine and began production of the world’s largest lysine factory in 1989. ADM’s plant began production in February 1991, precipitating a severe price war. This can be seen in Figure 2, which depicts the evolution of lysine prices and the ceiling price dating from before ADM’s entry to after the cessation of the cartel. Competing explanations for this price war and other major events will be discussed later.

During the price war, Ajinomoto and Kyowa Hakko tried unsuccessfully to raise prices several times. Subsequently, ADM suggested the formation of a lysine trade association. The first meeting, attended by Ajinomoto, Kyowa Hakko, and ADM, took place in June 1992. Sewon and Cheil Jedang, an Indonesian firm which also began production in 1991, were subsequent participants. Following the meeting, prices rose, but by less than envisaged at the meeting. Alternative, competitive explanations for the price rise include movements in the ceiling price, and demand seasonality (colder temperatures tend to require higher feed use). Movements in the ceiling price do not seem, by themselves, a satisfactory explanation of the lysine price rise because the ceiling price was considerably above the lysine price at the time. The demand results, below, do not suggest a major role for seasonal factors.

A second price war began early in 1993. It was apparently resolved later that year. Prices rose from a trough approaching $0.60 per pound to a plateau of about $1.10-$1.20. This appears

It has been suggested that the technology may have been stolen rather than purchased (Connor, 2000).
to be the most successful phase of the cartel. In June 1995, the FBI simultaneously raided the headquarters of the participating firms. Prices were falling at the time, perhaps in response to a drop in the ceiling price, but actually rose subsequently. In July 1997 Degussa and Cargill, two large biotechnology firms, announced a joint venture with a large scale plant in Nebraska due for production in 1999.

There were two distinct phases of the cartel. The first began with the first meeting of the lysine association and ended with the onset of a price war. During this period, there were regular meetings of the participants. However, no consensus was reached on the operating mechanism of the cartel. Market shares were not allocated. ADM favoured an allocation of global volume quotas with independent auditing of sales volumes. Sewon initially favoured a price agreement. Even once a volume allocation was later agreed to, Ajinomoto and Sewon preferred an allocation of regional monopolies instead of global volume quotas. There was little cooperation in the monitoring of member sales and prices. There appeared to be considerable uncertainty about rivals' costs and capacities during this period. Capacities tended to be overstated and costs understated. ADM conducted tours of its plant in June 1992 for Sewon and April 1993 for Ajinomoto. Even these tours did not appear completely convincing.

By contrast, the second phase of the cartel, beginning in late 1993 and concluding with the FBI raid in June 1995, was characterised by considerably less uncertainty. A system of global volume quotas was agreed to, loosely based on current market shares. There were no regional quotas. Monthly scorecards were prepared and discussed at quarterly meetings, based on reported sales volumes of each firm. A compensation scheme involving intra-cartel sales operated for those firms not achieving their designated quotas. There also seemed less uncertainty about rivals’ costs and capacities.

The different character of the two phases suggests a potential explanation for their relative success in sustaining cooperation among participants. The first phase broke down abruptly into a price war, while the second phase encompassed a sustained period of stable collusive prices, interrupted only by the intervention of the anti-trust authorities. In neither phase is there any publicly available evidence of the repercussions of a systematic breach of the cartel under the agreement.

3 Lysine Demand and Cost

3.1 Specification

Being an essential ingredient in the diets of hogs and poultry, the demand for lysine is necessarily a derived one. Alternative explanatory variables include the ceiling price, determined by the
prices of corn and soybean meal; feed efficiency ratios, which capture the rate at which animals transform feed into muscle development; and seasonal factors.

Log-linear and linear demand specifications are considered:

\[ \ln Q_t = X_t \beta - \alpha \ln P_t + \varepsilon_t \]

\[ Q_t = X_t \beta - \alpha P_t + \varepsilon_t \]

where \( Q_t \) and \( P_t \) denote market quantity and price in period \( t \); \( X_t \) contains a vector of explanatory variables; and \( \varepsilon_t \) captures unobserved demand errors. The vector \( X_t \) includes a constant, a trend, corn prices, soybean meal prices, hog spot and futures prices, hog inventories, broiler prices and broiler slaughter, feed efficiency ratios and monthly dummies. In the log-linear model, logs are taken of all price and quantity variables. The data sources are described in the next section. The parameter \( \alpha \) determines the elasticity of demand.

The ceiling price, described previously, is intended to capture the shadow price of an alternative source of lysine. For both the log-linear and linear models, two alternative specifications involving this shadow price were considered. The first included the prices of lysine, corn, and soybean meal without restriction. The second explicitly recognises that corn and lysine are used together in animal feed.\(^6\) A weighted average of corn and lysine prices is included together with the soybean meal price. This specification has the advantage that the price of corn represents a ready instrument for this weighted price.

Feed efficiency ratios describe the rate at which animals transform feed into weight gain. Feed efficiency ratios have improved over time as the fraction of animals that have been genetically improved to increase lysine absorption increases. The supply of poultry has been saturated by the genetically improved variety for some time, but there was a gradual increase in the ratio of genetically improved hogs over the sample period. Hence, the feed efficiency ratio for hogs is included as a potential explanatory variable. It is suggested that colder temperatures necessitate greater feed use. Therefore, monthly dummies were incorporated to allow for demand seasonality.

Lysine price and quantity are jointly determined by equation (1) and a supply equation dependent on assumptions about the competitive regime. Estimating (1) by ordinary least squares could therefore lead to simultaneity bias. Accordingly, (1) is also estimated by instrumental variables. Instruments considered for lysine prices include the variables contained in \( X_t \), and a vector of cross-country exchange rates between the U.S. and countries holding major lysine plants. Bilateral exchange rates were included for their potential role as cost shifters for firms based overseas.

\(^6\)A third specification was also examined. This included the lysine price and the ceiling price, implicitly restricting soybean meal and corn prices to enter in a fixed ratio. No role was found for the ceiling price.
Some cost data is available for ADM over the period July 1991 to June 1995. ADM experienced some production teething troubles which appear evident on casual inspection of the cost data. Consequently, a cost equation allowing for the possibility of learning by doing is postulated:

\[
MC(k_{i,t}, u_{i,t}) = c k_{i,t}^\gamma \left[1 + A_0 e^{-\alpha \sum_{t=0}^{t} k_{i,t}}\right] + u_{i,t}
\]  

(2)

where MC represents marginal costs, \(k_{i,t}\) is the capacity utilisation of firm \(i\) in period \(t\), and \(u_{i,t}\) is an unobservable, firm-specific error. Note that in (2), \(k_{i,t}\) refers to the production of firm \(i\) divided by capacity, while in (1), \(Q_t\) refers to market sales volume. The parameters \(A_0\) and \(\alpha\) capture the impact of learning by doing. A finding of \(\gamma = 0\) would imply a constant marginal cost once learning has ceased.

### 3.2 Data

A weighted average of the prices charged by the top four firms in the market for lysine is available from the Plaintiff’s report in the lysine criminal trial. This data is available from January 1990 to June 1996. Quantity data is obtained by combining several sources. Annual sales values for the top four firms can be divided by the monthly prices to obtain a monthly quantity series. However, with all the inter-year variation in quantity determined by prices, this will bias any estimates of demand elasticity toward \(-1\). To circumvent this problem, quantity data for ADM, available from July 1991 to June 1995 was integrated into this series. ADM’s annual market share was almost constant for the four years for which data was available. Hence, this data was used in the period August 1991 to June 1995, scaled up to reflect ADM’s market share.\(^8\)

To calculate the ceiling price, it was assumed that 100 lbs of soybean meal was a nutritional substitute for 97 lbs of corn supplemented with 3 lbs of lysine. Therefore, the ceiling price was calculated as follows:

\[
P_c^t = \frac{100P_{SB}^t - 97P_{Corn}^t}{3}
\]

The weighted average corn and lysine price, included in some demand specifications, is calculated as follows:

\[
P_w^t = 0.97P_{Corn}^t + 0.03P_t
\]

Hogs are fed lysine from weaning until they are ready for slaughter, usually at the age of five to six months. To reflect the farmer’s time horizon, quarterly hog inventories and spot and future

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7An alternative formulation using quantity rather than capacity utilisation as a dependent variable was also considered. Results were similar due to the lack of variation in ADM’s capacity.

8It appears that in July 1991, ADM’s production was yet to come fully online. This observation was not thought representative of market sales and was not used.
prices are considered as explanators. Hog inventories were obtained from the Hogs and Pigs publication compiled by the National Agricultural Statistical Service (NASS). The quarterly data was interpolated geometrically to form a monthly series. Hog prices were obtained from the Barrow and Gilt price series in Table 73 of the Agricultural Outlook publication. Hog futures prices with time to maturity between one and six months were obtained by choosing the nearest contract to the desired maturity of the Live Hog futures contract. Poultry are typically slaughtered between the ages of six and eight weeks. Consequently, broiler slaughter data and spot prices are considered as explanators. Broiler slaughter data was obtained from Table 69 of the Poultry Slaughter publication put out by NASS. The 12 city composite wholesale price from Table 93 of Agricultural Outlook was used to capture broiler prices. An annual feed efficiency ratio is obtained from United Feeds, based on trials on approximately 700 hog farms. This is interpolated geometrically to form a monthly series.

Exchange rates were thought to act as cost shifters for importers of lysine and therefore were considered as potential instruments for prices. Monthly bilateral exchange rates (in U.S. dollars) for Japan, South Korea, Italy, France, and Indonesia were obtained from Datastream.

On the cost side, marginal costs, fixed costs, production, and domestic sales are available from ADM production and sales reports over the period July 1991 to June 1995. Marginal costs, expressed per unit of production, are determined primarily by energy costs and raw material costs. They were constructed by summing reported variable costs, raw material costs and a (negligible) “by-product credit”. There is a high probability that this marginal cost series is in fact average variable costs. Therefore, based on the parameter estimates reported below, marginal costs could be slightly overstated. Fixed costs reflect depreciation and an allocation of total overhead costs. Production and domestic sales differ due to exports and the holding of inventories.

3.3 Results

Equation (1) was estimated by ordinary least squares (OLS) and instrumental variables (IV). Insignificant variables were eliminated sequentially and tested for joint significance. Table 1 summarises the results. The ordinary least squares and instrumental variable results are very similar. One interpretation is that most of the variation in price and quantity over the sample results from variation in firm behaviour rather than demand variation. An alternative explanation is that marginal costs are almost invariant to sales, once learning has ceased (see

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9 Similar results were obtained using a restricted sample in which ADM quantity data was available. This suggests that constructing quantity data by dividing annual sales by monthly prices over the remainder of the sample had little effect on the results.
cost results, below). Demand appears relatively inelastic over the sample. This would appear to rule out the possibility of joint profit-maximisation by the participating firms.

The restriction that lysine and corn prices enter together is rejected. Little role can be found for either corn or soybean meal prices if this restriction is not made. Over the sample, the ceiling price never dips below the price of lysine (see Figure 2). This may explain why soybean meal prices fail to play a role. However, given that corn represents a substantial share of the price of feed, we would have expected a role for corn prices.

Coefficient estimates suggest a mild trend rise in demand over the sample. As expected, demand for lysine increases with poultry consumption. However, hog inventories were not found to be a significant determinant of demand. A possible explanation is that lysine demand has risen over the sample, while hog consumption has been stable and poultry consumption has risen markedly. Neither poultry nor hog prices or futures enter significantly. Finally, feed efficiency is found to be a positive determinant of demand in some specifications. The OLS results of Model 1 are used for the purpose of analysis, below.

Equation (2) was estimated by non-linear least squares. The results are summarised in Table 2. Model 2 incorporates the restriction that $\gamma = 0$. Wald and LR tests suggest that we cannot reject this restriction at the 10 per cent level.

4 Explaining ADM’s Markup

Armed with estimates of demand, we are in a position to examine the predictions of some of the competing models of firm behaviour. Equation (1) implicitly defines an inverse demand function, $P(Q, \varepsilon_t)$. Under perfect information, the Cournot model predicts that firm $i$ sets quantity such that its mark-up is given by

$$\frac{P(Q_t, \varepsilon_t)}{MC(k_{i,t}, u_{i,t})} = \frac{1}{1 - \frac{q_{i,t}}{Q_t} \alpha^{-1}}$$  \hspace{1cm} (3)

An alternative assumption is that firms do not observe the demand and cost errors in equations (1) and (2). Firms choose output to maximise expected profits, given the outputs of their competitors. Given the functional forms of (1) and (2), and the realisations of $\varepsilon_t$ and $u_{i,t}$, this leads to an implied mark-up of

$$\frac{P(Q_t, \varepsilon_t)}{MC(k_{i,t}, u_{i,t})} = \left( \frac{\varphi}{E_\varepsilon \left\{ e^{\frac{\varepsilon_t^2}{2}} \right\} } \right) \left( \frac{MC(k_{i,t}, u_{i,t}) - u_{i,t}}{MC(k_{i,t}, u_{i,t})} \right) \left( \frac{1}{1 - \frac{q_{i,t}}{Q_t} \alpha^{-1}} \right)$$  \hspace{1cm} (4)

Expectations are calculated based on the realised distributions of $\varepsilon_t$ and $u_{i,t}$ over the sample. Figure 3 plots ADM’s observed mark-up with the Cournot mark-up implied by equations (3)
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<td>-11.112</td>
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<td>(54.955)</td>
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<td>(0.177)</td>
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\textsuperscript{a} Figures in parentheses () are standard errors. Figures in brackets \{\} are p-values.
Table 2: Cost Results$^a$

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<td>Coef</td>
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<td></td>
<td>0.138</td>
<td></td>
</tr>
<tr>
<td>Wald</td>
<td></td>
<td>1.386</td>
<td>{0.239}</td>
<td></td>
</tr>
<tr>
<td>LR</td>
<td></td>
<td>2.006</td>
<td>{0.157}</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Figures in brackets {} are p-values.

$^b$ Under the assumption of correct specification.

and (4). Note that throughout 1991 and early 1992, ADM was battling production teething troubles, and hence their mark-up may appear artificially low. This is indicated by the shaded region labelled “learning by doing”.

To test the Cournot model given these results, we could test whether the difference between the implied and actual mark-up is a white noise process. This represents a test of whether the two series could have been generated by the same distribution. Alternatively, we could test whether the observed mark-up can be explained by factors implied by a richer model than Cournot. The aim would be to test whether Cournot could be rejected in favour of a model nesting Cournot. This represents a more appealing test as it suggests an explanation should the Cournot model break down.

Consider a relaxation of the assumption of symmetric information. Particularly in the first phase of the cartel, asymmetric information appears to be a prominent feature of the lysine market. In the models of Green and Porter (1984) and Abreu, Pearce, and Stacchetti (1986) (hereafter GP and APS, respectively), firms are homogenous and do not observe the actions of their competitors. GP assume the use of trigger strategies. Firms behave cooperatively while prices remain above a critical level, and revert to Cournot output for a fixed period of time should prices drop below this critical level. In order to maintain incentives for participation in such a scheme, profits in periods of cooperation will in general be lower than monopolistic profits. A firm’s mark-up will follow a step function, given by the Cournot mark-up in non-
cooperative periods, and a higher mark-up, perhaps approaching the monopolistic mark-up, in cooperative periods.

APS relax the assumptions of trigger strategies and reversion to Cournot behaviour. The most collusive equilibrium is found to involve production of only two quantities, corresponding to two regions of price space. Quantities are restricted, resulting in a high mark-up, when prices fall into a "reward" region; and quantities are expanded, resulting in a low mark-up, when prices fall into a "punishment" region. In general, punishment and reward phases will tend to be more extreme than their counterparts in GP.

The lysine market departs from the assumptions of GP and APS in that firms are heterogeneous and face capacity constraints. Nevertheless, the flavour of their results may carry over. To capture time periods falling into the "reward" phase, a dummy variable, $c_{sp_t}$, is constructed based on the results of discussion at the regular lysine association meetings. A value of 1 is assigned to periods in which it is deemed that firms were behaving cooperatively, and a value of 0 is assigned otherwise.\(^\text{10}\) In both GP and APS, we would expect a higher mark-up during periods of cooperation. This is a departure from the Cournot model, which postulates a mark-up depending only on a firm’s market share and market demand elasticity.

\(^{10}\)Choosing the periods characterised by cooperation is a somewhat controversial exercise. See Connor (1998a, Appendix B) and White (1998) for contrary views. The results, below, are robust to alternative choices.
Table 3: Mark-up Equation<sup>a</sup>

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P(Q_t, \varepsilon_t)$</td>
<td>$E{P(Q_t, \varepsilon_t)}$</td>
</tr>
<tr>
<td>Constant</td>
<td>1.350</td>
<td>1.384</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.093)</td>
</tr>
<tr>
<td>$cons p_t$</td>
<td>0.615</td>
<td>0.614</td>
</tr>
<tr>
<td></td>
<td>(0.085)</td>
<td>(0.117)</td>
</tr>
<tr>
<td>Observations</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.533</td>
<td>0.373</td>
</tr>
<tr>
<td>$\bar{R}^2$</td>
<td>0.523</td>
<td>0.360</td>
</tr>
<tr>
<td>Dep Var Sum of Sq</td>
<td>152.4</td>
<td>161.4</td>
</tr>
<tr>
<td>Sum of Sq Errors</td>
<td>3.721</td>
<td>7.119</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>0.634</td>
<td>0.470</td>
</tr>
<tr>
<td>Durbin-Watson</td>
<td>0.801</td>
<td>1.061</td>
</tr>
</tbody>
</table>

<sup>a</sup> Figures in parentheses () are standard errors.

A mark-up equation of the following form is examined:

$$\frac{P(Q_t, \varepsilon_t)}{MC(k_{i,t}, u_{i,t})} = \phi_0 + \phi_1 cons p_t + \upsilon_{i,t} \quad (5)$$

To test the possibility that $cons p_t$ is endogenous to either demand or supply conditions, it was included additionally as an explanatory variable in both equations (1) and (2), and found to be insignificant. The results of (5) are summarised below. In Model 1, the dependent variable is ADM’s realised mark-up. In Model 2, the dependent variable is ADM’s expected mark-up, with expectations based on the realised distribution of errors, $\varepsilon_t$ and $u_{i,t}$.

The results suggest the existence of price wars and are inconsistent with the Cournot model. Figure 4 plots the realised mark-up against the markups implied by models 1 and 2. Comparison of Figures 4 and 3 suggests that under the punishment phase, the mark-up is well below the Cournot mark-up. This suggests that the Green and Porter model based on Cournot reversion is not an appropriate description. Even under the reward phase, the mark-up appears to be below that predicted by the Cournot model. Neither GP nor APS suggest an explanation for this. Several alternative explanations are possible:

1. Perceptions of market demand elasticity may have differed from $\alpha$. Participants in the cartel may have had a different model of demand or may have observed a longer pe-
period of data, implying a different demand elasticity. Mark Whitacre, the head of ADM’s biotechnology division and a major player at the price-fixing discussions, suggests a demand elasticity varying between about -0.95 at a market price of $0.95 and between -2.6 and -3.6 at a price of $1.05, while Kanji Mimoto, an experienced sales officer with Ajinomoto, suggested an elasticity of between -1.1 and -1.4 (Connor, 1999, p. 20). Figure 5 compares the observed mark-up with those predicted by the Cournot model based on the elasticities suggested by Mimoto.

2. Cartel participants were wary of approaching the ceiling price. As can be seen in Figure 2, there were periods in the cartel’s history in which the lysine price became quite close to the ceiling price. The proceedings of the conspiracy meetings reveal that, when setting price targets, the participants were quite wary of the ceiling price and anticipated movements in the ceiling price (Connor, 1999, p. 20-21).

3. The participants were wary of detection by anti-trust authorities, and may have tempered price targets accordingly.

4. The participants were wary of potential entry. For this to influence price-setting behaviour requires that a low price act as a signal of market parameters unknown to potential entrants. Potential parameters could include costs and capacities of incumbents, and the
competitive regime (this assumes the existence of collusion was not known outside the cartel).

5. Target prices were not achieved (Connor, 1999, Table A8). This implies that target markups were higher than realised markups. Figure 6 compares the observed mark-up with the implied target mark-up.

Considered individually, these factors do not seem sufficient to explain the low observed mark-up during cooperative phases, with the possible exception of explanation 1. However, in concert, they may present a satisfactory explanation. Without knowing the extent of any of these explanations, it is difficult to meaningfully test the predictions of GP or APS. Instead, in the next section, some key events will be discussed together with the modelling assumptions we might wish to incorporate into a realistic collusive model of the lysine market.

5 Explaining Major Events

The lysine market has experienced a relatively rich history over the last ten years, with substantial entry, two price wars, and several periods of collusion to its credit. Up until now, concentration has focused on how standard models fare in explaining this history. In this section, I will sketch some alternative ideas on how to model some of the particular events that have taken

Figure 5: Cournot Mark-up Using Perceived Elasticities
place. The aim is to demonstrate that we could potentially account for the observed events of the lysine market by incorporating some additional features into existing collusion models. I will begin by outlining the major events I seek to explain.

As can be seen in Figure 2, following the entry of ADM into the market, a severe price war ensued. This was apparently resolved by the formation of a cartel comprising the five major firms. The cartel broke down temporarily as a second price war erupted. The collusive agreement was later reinstated. Following the FBI raid two years later, prices ebbed briefly, but then actually rose. The challenge is to develop a model or models of firm behaviour to explain these phenomena in the context of the lysine market.

Three potential explanations for the initial price war could be considered.

1. Inertia in production or sales in response to ADM’s entry.

2. ADM and/or the incumbent firms attempted (and failed) to force out their competitors.

3. ADM wished to collude, but wished to signal or gain market share in advance of the striking of a collusive agreement.

The first explanation appears unlikely because the incumbent firms were given advance warning of ADM’s entry and appeared to be actively preparing for it. Signalling could have occurred across many dimensions. Potentially fruitful areas are costs and capacity, or patience.
The idea of ADM wishing to signal it was a low cost operation in advance of collusion is supported by the fact that ADM conducted guided tours of its new plant for the benefit of Ajinimoto and Kyowa Hakko executives in June 1992 and April 1993, respectively (Connor, 2000). The alternative notion that ADM sought market share in advance of collusion is supported by the fact that in the lysine market, market shares under periods of collusion appear to be based on existing market shares (Connor, 1999). In addition, ADM has stated that it’s strategic goal in the lysine market is to achieve a market share in line with the largest competitor in the industry (Connor, 1999). This interpretation requires that it is costly to build market share. In the context of a homogeneous product model one way to achieve this is to include convex adjustment costs. The rationale for this assumption is that it is increasingly costly to expand production due to advertising, searching for customers, costs of establishing a distribution network, etc.

Some combination of explanations 2 and 3 is also possible. ADM may have been unsure about whether to attempt to force its competitors to exit, or to collude, with its decision resolved through learning of its rivals’ cost parameters. The timing of the decision to opt for collusion may have been influenced by a cost/capacity shock to ADM. ADM experienced unexpected (at the time of plant construction) production teething troubles, which temporarily raised costs and restricted available production capacity. This shock appears to have been observed by ADM, but not its rivals.

Potential explanations for the second price war include the following.

1. There were differences in opinion about the form of the cartel. ADM wanted an explicit market share agreement with external production auditing, which the other firms resisted. There was some disagreement about the appropriate market shares.

2. There were reasons for distrust among the participants. Ajinimoto believed ADM had stolen its patented micro-organisms.

3. There was widespread suspicion of cheating.

The first two explanations do not appear particularly appealing as there is no indication of how the environment changed between the time the collusive agreement was first successfully negotiated and the time it apparently broke down. As discussed above, the third explanation could be captured in a price war model, along the lines of GP and APS. To pursue an explanation of this flavour, we may wish to depart slightly from the philosophy of APS and GP. Their models describe incentive compatible mechanisms for enforcing optimal collusion. In both models, only last period’s market price is relevant in deciding whether to collude. By contrast,

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11Klepper (1996) introduces convex adjustment costs in a similar context.
in the lysine market, especially in the first phase of the cartel, the collusive mechanism was, at best, imperfect. Suspicion of cheating was widespread, suggesting that the mechanism was not incentive compatible. The fact that price targets were systematically not met (see Figure 6) is further evidence of cheating, particularly if cartel participants have overestimated the elasticity of demand (see Section 4). In fact, there is no evidence in the public record of a well-defined enforcement mechanism at all, beyond vague allusions to the mobilisation of excess capacity.

In this context, it may be more fruitful to examine the implications of the prevailing cartel mechanism and accept the existence of cheating, rather than imposing an incentive compatible mechanism. We may then expect inferences on the extent of cheating to be based on the entire history of market prices rather than just last period’s price. Fershtman and Pakes (2000) present an alternative solution. In their dynamic model, price wars result from changes in the operating environment which make collusion unattractive. Their model assumes symmetric information, but could be extended to asymmetric information. The history of market prices could then be one element of the state vector determining the viability of collusion. Figure 7 depicts the observed lysine price and mark-up, and the demand errors, $\varepsilon_t$, from equation (1). It can be seen that the most persistent negative demand shock of the sample occurs at the start of the second price war. This provides some hope for an explanation of this ilk.

There are several conceivable explanations for the resumption of the collusive agreement.

1. The cartel participants were able to negotiate a more appropriate form for the cartel after
a lengthy negotiation process.

2. There was a substantial increase in the ceiling price.

3. The end of the punishment phase in a price war model was reached. That is, punishment had ensued for sufficient time to maintain the incentives for collusion.

The first explanation appears the most likely, although the other two may have contributed. There were many apparent problems with the first phase of the cartel. There were no explicit goals set for participants, there was no mechanism for monitoring compliance, suspicion of cheating was widespread, and cartel participants were highly uncertain of their rivals’ costs and capacities. It is highly likely that these problems contributed to the breakdown of the cartel. There was thus potential for future mutually beneficial cooperation, should these problems be ironed out. An increase in the ceiling price would have increased the value of collusion by raising the potential collusive price. The third explanation presupposes an incentive compatible enforcement mechanism. This does not seem to have existed in the lysine market.

There are two potential explanations for the behaviour of prices after the FBI raid.

1. An implicit understanding may have developed between the cartel participants, facilitating the continuation of collusive behaviour, albeit tacitly.

2. Different geographic markets appeared to be characterised by differences in demand elasticities and in other demand determinants. In particular, it appears that higher markups were observed in Europe and Japan than in the United States. Following the breakdown of the cartel, we would expect these markets to be supplied first.

The second explanation is supported by a surge in U.S. exports following the FBI raid, but is unlikely to explain continuing high prices in the U.S.

In order to model the above features, I will take as primitives the demand and cost curves described by equations (1) and (2). This yields the following profit function.

$$\pi_{i,t} = q_{i,t} P_t(Q_t, \varepsilon_t) - FC_i - \int_{k=0}^{k_{i,t}} MC(k, u_{i,t}) \, dk - m(q_{i,t} - q_{i,t-1})$$  \hspace{1cm} (6)$$

where $FC_i$ refer to firm-specific fixed costs, and the function $m(\cdot)$ describes the convex adjustment costs, if applicable. In addition to these primitives, firms face capacity constraints and a ceiling price constraint. The latter constraint, reflecting the ease of substituting between synthetic and natural lysine sources, constrains firms from restricting quantity such that the lysine market price rises above the ceiling price.
Armed with these primitives and assumptions about the mechanism of the collusive agreement, profit functions for each firm under the following circumstances could be calculated: collusion, punishment, defection from the agreement, and competition (that is, absence of collusion). The existence of heterogeneity in costs and capacities and an ill-defined collusive mechanism renders this a challenging task. Models of non-cooperative firm behaviour are typically based on an assumption of identical firms. Such models then predict that firms either have identical output or produce at capacity. However, in the lysine market, firms differ in capacity, yet produce at similar capacity utilisation rates.\textsuperscript{12}

We can then capture each of the features above through assumptions about the information observed by participants and the form of the cartel agreed to. Our description of the lysine market revealed both that market shares under the collusive agreements were loosely based on existing market shares, and that there was a high degree of uncertainty about competitors’ costs and capacities, certainly until the second phase of the cartel. If ADM sought to build market share in advance of the collusive agreement, this can be captured through the convex adjustment cost function, $m(.)$. To examine the signalling explanations of the initial price war, we could introduce uncertainty into competitors’ cost parameters, capacities, or discount factors. This explanation requires that the terms of the collusive agreement depend on (or were expected to depend on) cost parameters, capacities, or patience.

To explain the second price war requires assumptions of demand uncertainty and unobservable production and sales. Both of these assumptions appear plausible given our knowledge of the lysine market. Price war models tend to predict a sharp transition between reward and punishment phases. The gradual nature of this transition observed in the lysine market (see Figure 2) could reflect either the nature of the price-setting contracts (recall contracts with major buyers typically involved specification of annual volumes and price-protection clauses), or wariness of detection by anti-trust authorities.

Finally, if the rise in the ceiling price relative to the lysine price did contribute to the decision to reinstate the collusive agreement, then this requires a mechanism by which the value of collusion is affected by the difference in the two prices. One possibility is simply that sales quotas under the agreement responded to this difference between the ceiling price and the lysine price.

\textsuperscript{12}Compte, Jenny, and Rey (1997) present a stylised model of collusion involving asymmetric capacity constraints.
6 Conclusions

Analysis of the lysine market suggests that static models provide little guidance for firm behavior under collusion. This is demonstrated by establishing that ADM set a significantly higher mark-up during periods of conspiracy, thus ruling out the Cournot model or joint-profit maximisation as behavioural regimes. Given the degree of imprecision in estimates of the mark-up, we are unable to adequately distinguish between alternative price war models. However, it is clear that to more adequately characterise events, we may need to incorporate additional features. Specifically, the crucial role of entry is dramatically demonstrated in the lysine market. Additionally, we may wish to relax the assumption of an incentive compatible enforcement mechanism in the collusive agreement.

References


