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Cartel price announcements: The vitamins industry ☆

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Abstract

The primary manufacturers of vitamins admitted to participating in international market-share-agreement cartels for several years during the 1990s. Their announced price increases appeared in leading trade journals. We show that price announcements during the cartel period, and the lead times before these prices took effect, were fundamentally different in character from price announcements when explicit collusion was less likely. These differences are consistent with our model of price announcements where we account for the importance to the cartel of buyer acceptance of, or resistance to, a price increase. Acceptance avoids costly market-share reallocations among members of an explicit cartel. Logit estimates show that after 1985, the likelihood of a price announcement is largely driven by the length of time between announcements, rather than cost or demand factors, suggesting that the price announcements after 1985 stem from cartel meetings.

JEL classification: K21; L41; L65

Keywords: Collusion; Antitrust; Buyer acceptance; Purchasing

1. Introduction

Cartels commonly coordinate public price announcements by the member firms. For example, international cartels in the vitamins industry coordinated announcements of price increases, including the designation of which company would lead the price increase.[1] As another example, in the Rubber Chemicals Cartel, one of the components of the conspiracy was "issuing price announcements and price quotations in accordance with the agreements reached."[2] Similar charges have been

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[1] United States v. F. Hoffmann-La Roche Ltd., Crim. No. 3:99-CR-184-R, May 20, 1999, Transcript of Plea of Guilty and Sentencing at 10–11.

[2] U.S. Department of Justice Press Release, "Crompton Corporation Agrees to Plead Guilty for Participating in Rubber Chemicals Cartel," March 15, 2004. Available at: http://www.usdoj.gov/opa/pr/2004/March/04_at_160.htm.

made against firms in sorbates,[3] monochloroacetic acid and organic peroxides,[4] polyester staple,[5] high pressure laminates,[6] amino acids,[7] carbonless paper,[8] cartonboard,[9] and graphite electrodes.[10] In this paper, we explore the role of public price announcements in supporting collusive behavior and examine the data on public price announcements in the vitamins industry.

The primary manufacturers of vitamins, which admitted to participating in explicit international cartels for several years during the 1990s,[11] publicly announced their price increases in leading trade journals.[12] The public price announcements during the admitted cartel period are fundamentally different in character from the price announcements prior to 1985, when explicit collusion was less likely. First, there are far more price announcements after 1985 than before 1985. Second, in contrast to the announcements prior to 1985, the majority of announcements made after 1985 are joint with one firm leading and then others matching within ninety days (we refer to these as joint announcements). Third, prior to 1985, firms other than the market leader for a given vitamin product, typically Hoffmann-LaRoche Ltd. (Roche),[13] rarely led joint announcements, but after 1985, firms other than Roche frequently led joint announcements.[14] Fourth, after 1985 public price announcements often had long lead times before the new price became effective. Fifth, after 1985 price announcements occurred in somewhat regular intervals and increases were incremental in nature. Explanations for these observed phenomena are offered in this paper.

To the best of our knowledge, there is no other study that analyzes price announcements during a period of admitted explicit collusion.[15] In all other empirical studies of which we are aware, it is unknown whether the firms in the industry were acting non-collusively or functioning as an explicit cartel. Thus, this paper provides a unique window into how explicit cartels use price announcements, which are an important aspect of cartel behavior because they are observable, in real time, by both customers and law enforcement.

In Section 4, we develop a model of public price announcement behavior for an industry with homogeneous products and capacity constraints, similar to those in the vitamins industry, by adapting the duopoly model of Deneckere and Kovenock (1992) to allow firms to have positive sales even if they do not publicly announce a price. We show that in the absence of explicit collusion, (*i*) there are equilibria in which no firm makes a price announcement, (*ii*) there are equilibria in which the larger firm makes a singleton announcement or leads a joint announcement, and (*iii*) there are no equilibria in which the smaller firm makes a singleton announcement or leads a joint announcement. This model provides a way for us to understand the behavior in the vitamins

[3] U.S. Department of Justice Press Release, "Top Japanese Executives Indicted in Price-Fixing Conspiracy," July 25, 2000. Available at: http://www.usdoj.gov/opa/pr/2000/July/423at.htm.

[4] U.S. Department of Justice Press Release, "International Chemical Corp. Agrees to Plead Guilty, Pay Fines for Participating in Multiple Criminal Antitrust Conspiracies," March 14, 2002. Available at: http://www.usdoj.gov/atr/public/press_releases/2002/10835.wpd.

[5] See Hollinee LLC versus Nan Ya Plastics Corp., et al., U.S. District Court, Western District of North Carolina, Charlotte Division, October 2002.

[6] "In Re: High Pressure Laminates Antitrust Litigation," Master File No.:00 MD 1368 (CLB), U.S. District Court for the Southern District of New York, June 18, 2003.

[7] European Commission Decision of June 7, 2000, Case COMP/36.545/F3—Amino Acids, at paragraphs 53 and 164. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2001/l_152/l_15220010607en00240072.pdf.

[8] European Commission Decision of December 20, 2001, Case COMP/E-1/36.212—Carbonless paper, at paragraphs 233 and 236. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2004/l_115/l_11520040421en00010088.pdf.

[9] European Commission Decision of July 13, 1994, IV/C/33.833—Cartonboard, at paragraphs 20 and 76. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994D0601:EN:HTML.

[10] U.S. Department of Justice Press Release, "German Company and Chief Executive Officer Each Agree to Pay Record Fines for International Conspiracy," May 4, 1999. Available at: http://www.usdoj.gov/atr/public/press_releases/1999/2411.htm.

[11] An "explicit" cartel in this paper refers to one in which a subset of firms in the industry directly communicate with one another and agree to take actions to increase their profits above what they would have been otherwise.

[12] Although the Vitamins Cartel was international in breadth, our empirical analysis relies only on public price announcement data for the U.S.

[13] According to Connor (2001, Table 10.2), in 1995 no firm had a larger global market share than Roche in any of the vitamins considered in this paper.

[14] The EC decision in Vitamins at 203–204 states: "The parties normally agreed that one producer should first 'announce' the increase, either in a trade journal or in direct communication with major customers. Once the price was announced by one cartel member, the others would generally follow suit. In this way the concerted price increases could be passed off, if challenged, as the result of price leadership in an oligopolistic market." European Commission Decision of November 21, 2001, Case COMP/E-1/37.512—Vitamins. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_006/l_00620030110en00010089.pdf.

[15] Stigler (1947) provides a brief comparison of the number of price changes during periods with and without explicit collusion for several industries. Wilcox (1940) provides descriptions of price leadership in a number of industries, some of which are known or believed to have been engaged in explicit collusion.

industry prior to 1985, but is inconsistent with the observed behavior after 1985, suggesting collusive behavior after 1985.

To understand public price announcements during the period of admitted explicit collusion, our model accounts for the buyer side of the market. In practice, industrial buyers do not passively accept list or posted prices. Invariably, they conduct competitive procurements. However, the bid scoring functions for any given competitive procurement can be structured to be accepting of, or resistant to, a price increase by an incumbent supplier. Resistance to a price increase by incumbent buyers is contrary to the interests of a cartel, especially one that relies on market-share allocations where ex-post reallocations to attain year-end cartel share-agreements are costly. Public price announcements produce greater acceptance whereas private notifications lead to resistance. Lead times for the effective dates of public price announcements allow the cartel to monitor acceptance of the price increase and retract an announced increase that is being heavily resisted by buyers before incurring disruptions in cartel market shares. Our model captures these essential features and thus provides an explanation for the observed lead times in cartel price announcements.

Although firms did not plead guilty to price fixing prior to the late 1980s or 1990, depending on the vitamin, there are characteristics of price announcements between 1985 and the beginning of the period for which firms pled guilty that are essentially indistinguishable from the characteristics of price announcements during the period when the firms admitted to explicit collusion. Thus, the price announcement data tends to point to explicit collusion in the vitamins industry, at least among a subset of firms, as early as 1985, which is many years prior to the periods for which the Department of Justice (DoJ) obtained guilty pleas and the European Commission (EC) issued findings.[16]

This paper provides insight into how one might structure an empirical investigation to determine the existence of explicit collusion based on price announcement data. Of course, as with any investigation of collusion or cartel behavior by firms in an industry, the analysis is tailored to a specific industry. Nevertheless, our analysis can be helpful in studying industries with the same general characteristics as the vitamins industry: high concentration, high entry barriers, homogeneous products, and inelastic demand.

In terms of public policy, it is noteworthy that the cartel chooses substantial lead times for making newly announced prices effective. These are observable and can be enjoined by enforcement authorities.

Finally, to analyze whether the price announcements we observe might be related to market phenomena (and not necessarily collusion by firms), we estimate a logit model for the probability that firms announce a price change in a given month as a function of the time elapsed from the previous announced price change, as well as potential cost and demand triggers for a price change. We find that prior to 1985, the time elapsed from the previous announced price change is not a significant driver of new price announcements; however, after 1985, the probability of a new price announcement is positively related to the amount of time elapsed from the previous announced price change. We interpret these results as implying that the timing of price announcements after 1985 is driven by explicit communication between firms and is tied to the timing of cartel meetings.

The paper is organized as follows. Section 2 contains a description of the vitamins industry, including the cartel behavior of the 1990s. Section 3 reviews the relevant economic literature. Section 4 presents a model of price announcements. Section 5 describes the price announcement data. Section 6 contains our empirical analysis. Section 7 provides a discussion.

Readers interested primarily in the price announcement data from the vitamins industry can skip directly to Section 5.

2. The vitamins industry

2.1. Overview

Vitamins are purchased for both human and animal consumption. Each vitamin has a specific set of beneficial effects. Table A.1 in Appendix A provides a list of known and potential benefits of the six vitamins that are the focus of this paper.[17] The rapid advances in meat and poultry production in the past 40 years have largely come from a better understanding of the role of vitamins and amino acids in facilitating the growth of animals. For example, in 1925 it took 112 days for a broiler chicken to reach maturity for slaughter while in 2000 the same weight bird could be produced in 46 days.[18]

[16] To our knowledge, this is the first discussion in the literature of the time period during which the Vitamins Cartel affected prices; however, there is debate in the literature over the appropriate time period for the Lysine Cartel. See, e.g., Connor (1997) and White (2001).

[17] Vitamins are sometimes referred to by both a chemical name and an alphanumeric sequence. For example, "Calpan" is Vitamin B5. See Table A.1.

[18] Delmarva Poultry Industry, Inc.: http://www.dpichicken.org/download/U.S.%2520Broiler%2520Performance.doc.

Appendix A provides a more detailed discussion of the vitamins industry, but the salient features of the industry are as follows: 1. Vitamins are largely produced through processes of chemical synthesis, with petroleum as a primary factor input, although fermentation technologies can be used for some vitamins. 2. The vitamins industry is highly concentrated. 3. The large capital investments and production experience required for the manufacture of vitamins are a barrier to entry. 4. When considering the cost of producing animal feed or human food, the incremental cost of vitamin additives is small. 5. A given vitamin product made by one firm is chemically identical to the same product made by another firm. 6. With the possible exception of the Chinese manufacturers, most sizable producers of vitamins were involved in explicit collusion throughout much of the 1990s.

2.2. The vitamins cartel

In the late 1990s, the DoJ obtained guilty pleas from several major vitamin manufacturers for participating in an international price fixing cartel that extended back to at least January 1990.[19] In this report, we refer to the interval of the plea dates as the "plea period." Detailed descriptions of the vitamins conspiracy can be found in the EC's decision in *Vitamins*. The following excerpt from the DoJ's Sentencing Statement of Roche also provides important characterizations of the cartel's organization and behavior.

> "On a quarterly basis, regional and world marketing managers from the conspirator companies would meet to exchange pricing and sales information in order to have an accurate picture of the overall global demand and price for the vitamins. Once a year, the global marketing directors for each of the conspirator companies, in concert with the various product managers for the companies, would conduct a 'budget' meeting. During this meeting, the overall global sales volume for the vitamins would be determined for the current year, and … the global sales volume for the coming year would be determined. Next, each company would be allocated a percentage of this projected global market demand…. Finally, vitamin pricing would be reviewed and, if price increases were needed to either account for currency discrepancies or to raise profit levels, new pricing would be agreed upon, to include the timing of the price increases and designation of which company would lead the price increase."[20]

An explanation for this complex apparatus is provided by Stigler in his seminal 1964 paper. Stigler notes in his paper that the central problem of a cartel is to thwart the incentive to secretly cut prices. A secret price cut by a cartel member benefits the member in the short run but undermines the overall profitability of the cartel in the long run. Stigler characterized a solution that a cartel might employ as follows:

1. Allocate fixed market shares to each cartel participant.[21]
2. Monitor output of each cartel participant.
3. Reallocate resources within the cartel to adjust for issues that may arise.[22]

Stigler (1964) does not mention the need for public price announcements by the colluding firms, but our earlier discussion of cartels that explicitly coordinated public price announcements suggests they have value to a cartel. These announcements are the focus of this paper.

3. Literature review

The early literature on price leadership, particularly Stigler (1947), Markham (1951), and Bain (1960), attempts to create a taxonomy within which to view price announcements.[23] It identifies several types of price leadership, including "dominant firm price leadership", "competitive barometric price leadership", and "collusive price leadership" (also called "monopolistic barometric price leadership"). However, this work does not explicitly distinguish between public price announcements and all

[19] In addition, the European Community and Canada found that several of the vitamin producers had violated antitrust laws within their jurisdictions. Table A.3 in Appendix A identifies the firms and plea dates for each of the vitamins. Table A.4 in Appendix A provides the criminal penalties levied against each firm by the DoJ for their participation in the conspiracies.

[20] U.S. v. F. Hoffmann-La Roche Ltd., Crim. No. 3:99-CR-184-R, May 20, 1999, Transcript of Plea of Guilty and Sentencing at 10–11.

[21] These shares would be fixed within the cartel, not fixed with respect to the industry as a whole.

[22] Although not explicitly described in the Sentencing Statement, the EC decision in *Vitamins* indicates that the cartel used interfirm transactions as a mechanism for rectifying any internal issues that arose (see paragraphs 225 and 590). For example, "Any company that sold more than its allotted share was required in the following year to purchase the excess from another conspirator that had not reached its volume allocation target" (U.S. Department of Justice, 2000, p.172).

[23] The literature also contains a number of industry studies that examine the role of price announcements. For a summary of many of these, see Scherer (1980).

other ways of notifying buyers of a price increase.[24] Our work is unique in this regard.

In "dominant firm price leadership", one large producer sets prices, and competitive fringe firms act as price takers.[25] In "competitive barometric price leadership", changes in prices merely reflect changes in market conditions.[26] In "collusive price leadership", as described by Markham (1951), there need not be an explicit agreement among firms, but the process of price announcements itself serves to coordinate firms' prices at the collusive level. Distinguishing among the various types of price leadership requires an analysis of the industry and of the price announcement behavior.

Rotemberg and Saloner (1990) provide a theoretical model of "collusive price leadership" in which firms have private information and in which price announcements allow firms to maintain prices above the competitive level without an explicit collusive agreement (although prices are lower than with explicit collusion). In another theoretical model of "collusive price leadership", Deneckere and Kovenock (1992) consider a capacity-constrained duopoly with one large firm and one small firm and show that the large firm emerges as the price leader.[27] The intuition for their result is that when the large firm acts as a price leader, it provides a price umbrella, allowing the small firm to undercut and sell all of its capacity. However, when the small firm, which loses more from being undercut, leads, it acts aggressively to discourage matching or undercutting. Thus, the small firm prefers to follow; and in the equilibrium of a timing game, the large firm acts as the price leader and the small firm follows.[28]

The aforementioned models of price leadership are non-collusive (including models of "collusive price leadership") in the sense that they can be sustained as a non-cooperative equilibrium in a game with repeated interaction among firms. We are not aware of prior theoretical models of price leadership in an environment with explicit collusion.

Empirical studies of price leadership have been conducted for a number of industries, including cigarettes, steel, automobiles, ready-to-eat cereals, turbogenerators, gasoline, newsprint, and cheese.[29] For each of these industries, for the period in which the price leadership behavior is studied, there is no claim that the firms were explicitly colluding.[30]

4. Modeling price announcements

In this section, we consider a model of announcements and derive empirical implications that allow us to examine the hypothesis of non-collusive behavior in the vitamins industry for time periods other than the plea period. In addition, the model has implications for the price announcement behavior we would expect to observe by an explicit cartel with the means to enforce non-equilibrium behavior, particularly one using a market-share-agreement. Specifically, our model will account for how such announcements facilitate collusion by increasing the likelihood that a cartel price increase is "accepted" by buyers. Acceptance of or resistance to a price increase is of concern in many industries. Procurement personnel are required to explain to superiors their efforts in resisting price increases or the reasons for acquiescing. Procurement personnel have scarce resources to allocate to the buying process and cannot resist all increases for all products. Sellers try to determine the largest increase that will not be resisted. The topic of price acceptance has not received much attention in the economics literature for a number of reasons, including the association of the phenomenon with psychological factors rather than being part of an allocation mechanism.

Despite a lack of attention in the economics literature, the notion of price acceptance and resistance has received attention in EC decisions in cartel cases. In the EC decision in *Vitamins*, resistance to price increases is described as follows: "When BASF's customers resisted the increase, Roche supported the rise by also announcing an increase to DEM 46/kg …. According to Daiichi, the concerted increase was unsuccessful because of customer resistance and the huge differential

[24] A firm could notify only its incumbent customers of a price increase. Or a firm could offer no formal notification at a point in time and just let its new pricing become clear as it "does deals."

[25] See also D'Aspremont et al. (1983) for price leadership with a dominant cartel and competitive fringe.

[26] For example, one firm that has become better informed than the others about new market conditions might announce a change in price, and the others follow rather than engaging in costly information acquisition themselves (see Cooper, 1997).

[27] Holt and Scheffman (1987) also provide a model of price announcements, focusing on the role of best-price guarantees and most-favored-customer clauses. Kovenock and Widdows (1998) provide a dynamic model of duopoly price adjustments in response to demand shocks and show behavior may differ depending on which shocks are positive or negative.

[28] Similar results hold in a model without capacity constraints, but with customer loyalty (see Deneckere et al., 1992) and in a model in which products are imperfect substitutes (see Furth and Kovenock, 1993).

[29] See the references in Scherer (1980, pp.176–184), Booth et al. (1991), and Mueller et al. (1997).

[30] Bain (1959, p.277) and Markham (1951, p.904) suggest that explicit agreements among firms may enhance the effectiveness of price leadership.

between D-calpan and the equivalent in DL-calpan."[31] In the EC decision in *Cartonboard*, cartonboard producers sometimes faced resistance from converters to whom they sold their products: "There is on the other hand an upper limit in practical terms on the amount of any price increase that could be imposed unilaterally by the cartonboard producers on the converters. The converters have on some occasions resisted a proposed price increase for cartonboard on the ground that their own customers would in their turn refuse to accept a price increase for packaging...."[32] The notion of acceptance of price increases by buyers appears in the EC decision in *Amino Acids*: "The five companies... exchanged information on the acceptance of the price increases in the different regions."[33] In *Industrial and Medical Gases*, some price increases were implemented without problems: "the report on the first quarter of 1995 states that price increases were implemented without major difficulties as of 1 January 1995."[34] This was not always the case in *Electrical and Mechanical Carbon and Graphite Products*:

> "That not all customers simply accepted the announced price increases, is evidenced by a fax of 30 April 1996 from the London Underground Ltd. (LUL) to Morgan, stating: 'Unfortunately your price increases are well above the current rate of inflation (i.e. 2.7%) and a full explanation is required. I also note from our files that at a meeting here on 21st September (when LUL again expressed dissatisfaction with your pricing and stockholding policy) Morganite agreed to respond within 3 weeks with a full breakdown of costs. This did not happen and we find ourselves no further forward in our relationship than we were this time last year. I would be pleased if you will now provide the information requested together with the factors underlying this year's increase, i.e. increased costs of materials, wages, etc. supported by relevant indices or letters from suppliers'."[35]

By explicitly modeling buyer acceptance of or opposition to price increases, we are able to implicitly identify a difference between public price announcements and private notification by sellers to buyers.[36] A buyer that receives private notification of a price increase may resist because it does not know if it is being disadvantaged relative to other buyers. A public announcement mitigates this concern. In addition, public announcements allow suppliers to monitor actions of their rivals.

In practice, publicly announced prices are sometimes effective immediately and sometime effective at some future date. When announced prices have a future effective date, suppliers may choose to withdraw or alter their announced prices. After defining our benchmark game, we first consider a game in which announced prices are effective immediately in the sense that they cannot be withdrawn or altered, and second we consider a game in which announced prices have a future effective date in the sense that they can be withdrawn and altered prior to becoming effective.

In our model, non-strategic buyers hold first-price procurements in which each of two sellers participates. A price announcement in our model is a commitment by a seller to bid its announced price at every procurement.[37] If a seller does not announce a price, it is not bound by any announcement, but of course must ultimately set some price to bid at procurements.[38] In what follows, when we describe a seller as "setting" rather than "announcing" a price, we mean that they have not committed to a price through an announcement, or have announced a price but then withdrawn their commitment to that announced price. They then enter the procurements without having committed themselves to a price beforehand.

We use subgame-perfect equilibrium as our equilibrium concept. Although our model does not involve repeated play, we are able to capture many of the most important features of observed behavior.

[31] EC decision in *Vitamins* at 325.

[32] EC decision in *Cartonboard* at 19.

[33] EC decision in *Amino Acids* at 81.

[34] European Commission Decision of July 24, 2002, Case COMP/E-3/36.700—Industrial and medical gases, at paragraph 147. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_084/l_08420030401en00010055.pdf.

[35] European Commission Decision of December 3, 2003, Case C.38.359 – Electrical and mechanical carbon and graphite products, at paragraph 109. Available at http://ec.europa.eu/comm/competition/antitrust/cases/decisions/38359/en.pdf.

[36] In any industry with a sufficiently active trade press there will be no distinction because the trade press will unearth private announcements and report them.

[37] Although manufacturers may offer discounts off of their announced price, there is evidence that cartel price announcements do reflect actual prices. For example, in *Cartonboard* announced and actual prices were similar: "The net price increases achieved closely tracked the price announcements albeit with some time lag... in many cases the producers succeeded in making the customer pay the full amount of the announced increase." (EC decision in *Cartonboard* at 115).

[38] For recent work on collusion at auctions and procurements in a first-price setting see Marshall and Marx (2007).

4.1. Notation and Benchmark

We consider a model with two sellers, 1 and 2, that produce homogeneous products and have identical variable costs (normalized to zero), where seller 1 has greater capacity. Letting k_i denote the capacity of seller i, we assume $k_1 > k_2$. We consider a price-setting game similar to that considered in Deneckere and Kovenock (1992), hereafter DK. In contrast to the model of DK, to account for the features of the vitamins industry, we allow the possibility that sellers can have positive sales even if they do not make a public price announcement. We retain the DK assumption of efficient rationing and the assumptions that there exists a choke price for demand,[39] and that demand, $d(p)$, is twice continuously differentiable, decreasing, and concave. In DK, if the sellers simultaneously announce the same price, then demand is allocated proportionally to capacity, and if the sellers sequentially announce the same price, then the follower sells to capacity first. Momentarily we retain this tie-breaking assumption to specify a benchmark game and payoffs.

The three periods in the benchmark game are identified as either an announcement period or a price-setting period.

Benchmark game

1a. (announcement) Firms can announce prices.
1b. (announcement) Firms that did not announce in period 1a can announce prices.
2. (price setting) Firms with no price commitment simultaneously set prices.

Payoffs are a function of the firms' prices, and in the case of identical prices for the two sellers, payoffs also depend upon whether price commitments (either through announcements or the setting of pricing in period 2) were made simultaneously or sequentially. If the sellers' prices differ, payoffs for the benchmark game are

$$\tilde{\pi}_i(p_i, p_{-i}) \equiv \begin{cases} p_i \min\{k_i, d(p_i)\}, & \text{if } p_i < p_{-i} \\ p_i \min\{k_i, \max\{0, d(p_i) - k_{-i}\}\}, & \text{if } p_i > p_j. \end{cases}$$

If the prices are the same and price commitments were made simultaneously, seller i's payoff is $p \min\{k_i, k_i d(p)/(k_1+k_2)\}$. If prices are the same and price commitments were made sequentially, seller i's payoff is $p \min\{k_i, \max\{0, d(p)-k_{-i}\}\}$ if it was the leader and $p \min\{k_i, \max\{0, d(p)\}\}$ if it was the follower.

[39] Formally, assume that there exists a $p_0 > 0$ such that for all $p \geq p_0$, $d(p)=0$ and for all $p < p_0$, $d(p) > 0$.

To be precise, in the benchmark game, a pure strategy for player i is $\sigma_i = (p_i^{1a}, p_i^{1b}(\cdot), p_i^2(\cdot,\cdot))$, where $p_i^{1a} \in \mathbb{R}_+ \cup \varnothing$, $p_i^{2a} : \mathbb{R}_+ \cup \varnothing \to \mathbb{R}_+ \cup \varnothing$, and: $p_i^2 : \mathbb{R}_+ \cup \varnothing \times \mathbb{R}_+ \cup \varnothing \to \mathbb{R}_+$. In words, p_i^{1a} is player i's price announcement in period 1a, where an announcement of $\varnothing$ signifies no announcement; p_i^{1b} (p_{3-i}^{1a}) is player i's price announcement in period 1b, given that player $3-i$ made announcement p_{3-i}^{1a} in period 1a; $p_i^2(p_{3-i}^{1a}, p_{3-i}^{1b})$ is player i's price choice in period 2, given that player $3-i$ made announcement p_{3-i}^{1a} in period 1a and announcement p_{3-i}^{1b} in period 1b. Given both players' strategies, σ_1 and σ_2, define player i's price by

$$p_i(\sigma_1, \sigma_2) = \begin{cases} p_i^{1a}, & \text{if } p_i^{1a} \neq \varnothing \\ p_i^{1b}(p_{3-i}^{1a}), & \text{if } p_i^{1a} = \varnothing \text{ and } p_i^{1b}(p_{3-i}^{1a}) \neq \varnothing \\ p_i^2(p_{3-i}^{1a}, p_{3-i}^{1b}(\varnothing)), & \text{if } p_i^{1a} = \varnothing \text{ and } p_i^{1b}(p_{3-i}^{1a}) = \varnothing. \end{cases}$$

Then, given strategies, σ_1 and σ_2, player i's payoff is $\tilde{\pi}_i(p_1(\sigma_1, \sigma_2), p_2(\sigma_1, \sigma_2))$. Mixed strategies would be defined in the usual way.

As in DK, if total capacity is large relative to demand, but neither seller has sufficient capacity to serve the whole market,[40] which we assume to be the case, then the unique equilibrium of the simultaneous-move price-setting subgame (i.e., the subgame of period 2 when there are no announcements in 1a or 1b) is in mixed strategies. We let $\tilde{\pi}_i^S$ denote seller i's payoff in the equilibrium of this subgame. Fixing one seller to be the leader and announce in period 1a and the other to be the follower and either announce in period 1b or simply set its price in period 2, we denote seller i's equilibrium payoff by $\tilde{\pi}_i^L$ and $\tilde{\pi}_i^F$ when it is the leader or follower, respectively. For the larger seller, $\tilde{\pi}_1^L = \tilde{\pi}_1^F = \tilde{\pi}_1^S$, but for the smaller seller, $\tilde{\pi}_2^L = \tilde{\pi}_2^S < \tilde{\pi}_2^F$. As mentioned in the previous section, the intuition for this is that when the larger seller acts as the price leader, it provides a price umbrella, allowing the smaller seller to undercut it slightly and sell all of its capacity. Because the smaller seller loses more from being undercut, when the smaller seller acts as the leader, it prices aggressively. Thus, the smaller seller prefers to act as a follower. The larger seller is indifferent between acting as leader or follower or having prices set simultaneously.

There is an equilibrium of the benchmark game in which the larger seller leads by announcing a price in period 1a and the smaller seller follows, either announcing a price in period 1b or choosing its price in period 2. In this

[40] Specifically, it must be that the price that maximizes $p_2 \min\{k_2, \max\{0, d(p_2)-k_1\}\}$, denoted $p_2^H(k_1, k_2)$, satisfies $p_2^H(k_1, k_2) > d^{-1}(k_1+k_2)$. The price $p_2^H(k_1, k_2)$ is unique given our assumptions and can be interpreted as a capacity-constrained monopoly price on the residual demand curve $d(p)-k_1$.

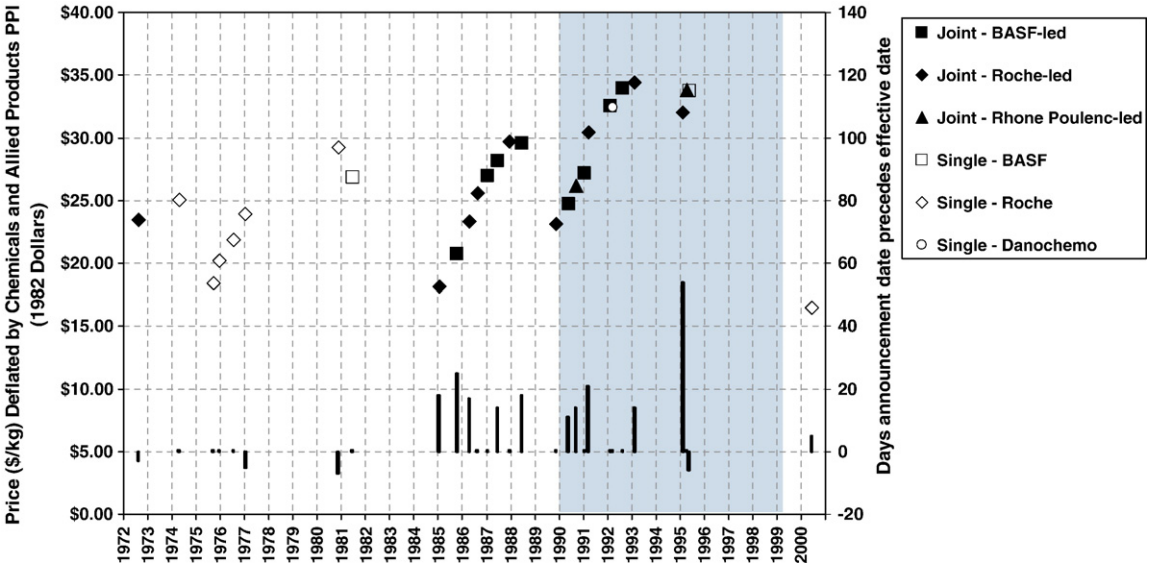

Fig. 1. Vitamin A Acetate 650 Feed Grade.[41]

equilibrium, the sellers' prices are identical, the smaller seller sells to capacity, and payoffs are $(\tilde{\pi}_1^L, \tilde{\pi}_2^F)$. We refer to this equilibrium as the *leader–follower equilibrium of the benchmark game*. Although there are other equilibria (for example, if one seller uses the strategy of making no commitment waiting until period 2 to set a price, then the other seller can do no better than to wait until period 2 to set a price), DK show that the leader–follower equilibrium with the larger seller leading is the unique equilibrium of several games of timing. We let $(\tilde{s}_1, \tilde{s}_2, \tilde{p}_0)$ denote the market shares and price in the leader–follower equilibrium of the benchmark game.

Before developing the model further, it may be useful to consider the price announcement data for a representative vitamin product, Vitamin A Acetate 650 Feed Grade, which is shown in Fig. 1. We describe the data in greater detail in Section 5, but we introduce this figure here to provide a reference point when describing the model. The figure shows the dates and amounts of price announcements, with the date on the horizontal axis and the amount on the left vertical axis. If at least one other seller announces the same price within ninety days, we label the announcement a *joint* announcement (we use the date of the leader's announcement as the date). If no other seller announces the same price within ninety days, we label the announcement a *singleton* announcement. If two or more sellers announce the same price on the same date, we label the announcement a *tie* announcement, but no tie announcements were observed in Vitamin A Acetate 650 Feed Grade. The shape of the symbol on the graph identifies the leader of a joint announcement or the author of a singleton announcement. The number of days that the announcement date precedes the effective date of the price change is indicated by the vertical bars at the bottom of the graph and measured on the right vertical axis. The plea period for the vitamin is shaded on the graph.

Fig. 1 shows that after 1985 most announcements are joint announcements, with a leader and at least one follower, but prior to 1985, most announcements are singleton announcements.

For Vitamin A Acetate 650 Feed Grade, the cartel members are Roche, BASF, and Rhone-Poulenc. The period prior to 1985 is characterized mainly by singleton announcements by Roche and BASF, where the price increases are effective immediately or had already been implemented at the time of the announcement. The period after 1985 is characterized mainly by joint announcements

[41] The *Chemical Marketing Reporter* reported a price increase from Danochemo of $14.70 per kilogram in December 1987. This appears to be a typographical error since $14.70 per pound equals $32.41 per kilogram, the same price as BASF and Roche announced during the same period. We have classified this announcement as $14.70 per pound. Also, BASF's November 1989 announcement in Feedstuffs is listed as $122.70 per pound, when a price of $12.70 per pound maps to $28 per kilogram, a price announced by others at the time. We have classified this announcement as $12.70 per pound. The price announcement by Danochemo on July 20, 1987 did not include an explicit effective date. We assume the effective date is the same as the announcement date.

led by one of the three cartel members and often made well in advance of the effective date. There are two singleton announcements after 1985, one in 1992 and one in 1995. In early 1992, three firms jointly announce a price of $40.55, and then Danochemo undercuts with a singleton announcement of $40.35. In April 1995, Rhone-Poulenc announces a price of $48.70, which is matched shortly thereafter by Roche (a joint announcement). But in between these announcements, BASF makes a slightly higher singleton announcement of $48.75.

4.2. Price announcements with immediate effective date

We now extend the benchmark game to incorporate the buyers' reactions to price changes. To begin, we restate the model in terms of announcements of price changes relative to a status-quo price rather than price levels. When our results require that we specify a particular status-quo price, we use the price in the leader–follower equilibrium of the benchmark game described above.

In addition to a status-quo price, it will also be useful to define status-quo market shares, which we denote by (s_1, s_2). We have in mind that these market shares are defined by each buyer having an incumbent seller, either seller 1 or seller 2.

In what follows, we drop DK's tie-breaking assumption and instead allow the outcome in the event of identical prices to depend on a variable $\theta \in \{A, R\}$, where A represents acceptance and R represents resistance. If $\theta = A$, a buyer facing identical prices purchases from its incumbent, and if $\theta = R$, a buyer facing identical prices purchases from the non-incumbent.[42] In practice, resistance can take many forms. For example, a buyer may threaten to use a substitute product. Or, the buyer may procure from an overseas supplier. Or, the buyer may seek out brokers. The central theme of all of these forms of "resistance" is the potential abandonment of the incumbent supplier for an alternative supplier. This is the motivation behind our introduction of θ.

To guarantee existence of best replies, we restrict prices to a discrete grid with vanishingly small increments.[43]

We assume that the realization of the variable θ depends on a state variable $\omega \in \Omega$ and on how much prices have increased relative to the status quo. Specifically, we let $\Omega_\Delta \subset \Omega$ be the set of states that "justify" a price increase of Δ. Thus, if the state is $\omega \in \Omega_\Delta$ and the sellers announce or set identical prices that constitute an increase Δ relative to the status-quo price p_0, then $\theta = A$ with probability one. However, if $\omega \notin \Omega_\Delta$, then we assume that the value of θ depends stochastically on the size of the price increase, with buyers more likely to resist larger price increases. In particular, in this case we assume $\theta = A$ with probability $\rho(\Delta)$ and $\theta = R$ with probability $1-\rho(\Delta)$, where ρ is decreasing in Δ. This assumption embodies the idea that buyers are less likely to "accept" larger price increases by their incumbent supplier.[44] We also assume that for $\Delta > 0$, $\rho(\Delta) \in [0,1)$, so that for all positive price increases not justified by the state, i.e., $\omega \notin \Omega_\Delta$, there is some probability that buyers will not accept the price increase.

Given prices, status-quo market shares (s_i, s_{-i}), and regime $\theta \in \{A, R\}$, firm i's payoff is

$$\pi_i(p_i, p_{-i}; s_i, s_{-i}, \theta) \equiv \begin{cases} p_i \min\{k_i, d(p_i)\}, & \text{if } p_i < p_{-i} \\ p_i \min\{k_i, s_i d(p_i)\}, & \text{if } p_i = p_{-i} \text{ and } \theta = A \\ p_i \min\{k_i, s_{-i} d(p_i)\} & \text{if } p_i = p_{-i} \text{ and } \theta = R \\ p_i \min\{k_i, \max\{0, d(p_i) - k_{-i}\}\}, & \text{if } p_i > p_j. \end{cases}$$

These payoffs are consistent with the view that the demand curve embodies a large number of identical buyers, each with a downward sloping demand curve.

We begin by considering the following game, where each of the four periods is identified as an announcement period, a price-setting period, or a period in which buyer acceptance or resistance is realized:

Game with immediate effective date
$\Gamma^{\text{immediate}}(s_1, s_2, p_0, \omega)$

Fix status-quo market shares (s_1, s_2), price p_0, and state ω.

1a. (announcement) Firms can announce price changes.
1b. (announcement) Firms that did not announce in period 1a can announce price changes.
2. (price setting) Firms with no price commitment set prices simultaneously.
3. (acceptance/resistance) The value of θ is realized and profits are given by π.

In the context of our game with immediate effective date, a *joint* announcement occurs when sellers sequentially announce, with one seller announcing in period 1a (the leader) and the other announcing in period

[42] In this aspect, we now differ from DK—as noted earlier, in DK if the firms simultaneously announce the same price, then demand is allocated proportionally to capacity, and if the sellers sequentially announce the same price, then the follower sells to capacity first.

[43] In DK, with sequential announcements, the follower sells to capacity first when prices are the same, so the follower has no need to undercut. In our model, the follower might want to undercut the leader's price slightly. Thus, to guarantee existence of best replies, we assume discrete prices.

[44] This is consistent with the observation in Harrington (2006) that cartels may increase prices gradually to avoid buyer resistance.

1b (the follower). A *singleton* announcement occurs when one seller announces in either period 1a or period 1b and the other seller does not announce, but rather sets its price in period 2. A *simultaneous* announcement occurs when both sellers announce in period 1a or both sellers announce in period 1b.

We can now characterize the subgame-perfect equilibria of this game. To begin, we take as the status quo the price and market shares from the leader–follower equilibrium of the benchmark game. With this status quo, there is an equilibrium of our game in which seller 1 leads in period 1a with an announcement of a price change of zero and seller 2 follows in period 1b with an announcement of an infinitesimally small price cut—a joint announcement. To support this equilibrium, specify that if no seller announces in period 1a, then seller 1 announces a price change of zero in period 1b and seller 2 does not announce. There is also an equilibrium in which seller 1 announces a price change of zero in period 1a and seller 2 does not announce—a singleton announcement by seller 1. Finally, there is an equilibrium in which neither seller announces. In this case, sellers simultaneously set prices in period 2.

Thus, there are equilibria involving joint announcements, singleton announcements, and no announcements. Referring back to Fig. 1, we observe both joint and singleton announcements, as well as long periods in which there are no announcements (presumably the price is not constant during these periods even though the price changes are not announced).

Despite the multiplicity of equilibria, it is noteworthy that there is no equilibrium in which seller 2 makes a singleton announcement or leads a joint announcement. There is also no equilibrium in which sellers simultaneously announce.

Proposition 1. *For all $\omega \in \Omega$, there is no equilibrium of $\Gamma^{immediate}(\tilde{s}_1, \tilde{s}_2, \tilde{p}_0, \omega)$ in which the smaller seller leads a joint announcement or makes a singleton announcement, and there is no equilibrium in which sellers simultaneously announce.*

Proof. See Appendix B. □

The empirical implications of this result for the vitamins industry are that in a period without explicit collusion, we would expect to see either no announcements, singleton announcements by the main producer, or joint announcements led by the main producer, and we would not expect the identity of the seller leading joint announcements to change. Referring to Fig. 1, the announcement behavior prior to 1985 is largely consistent with these implications since the announcements we see in that period are, with one exception, singleton announcements by Roche or joint announcements led by Roche.

Another implication is that the observation of a sequence of joint announcements where the leader is changing would be inconsistent with the predictions of our non-collusive model. As Fig. 1 shows, after 1985, BASF, Roche, and sometimes Rhone-Poulenc (the cartel members) alternate in leading joint price announcements. This behavior is not consistent with non-collusive behavior in our model.

Furthermore, given the leader–follower equilibrium of the benchmark game as the status quo, it is clear that sellers cannot use their announcement strategies to increase prices above the status-quo level.

Proposition 2. *For all $\omega \in \Omega$, there is no equilibrium of $\Gamma^{immediate}(\tilde{s}_1, \tilde{s}_2, \tilde{p}_0, \omega)$ in which sellers' profits are greater than $(\tilde{\pi}_1^L, \tilde{\pi}_2^F)$.*

An empirical implication of Proposition 2 is that with immediate effective dates, since price announcements do not accomplish anything incremental for the seller, if announcing is at all costly, we should see no announcements. Thus, during periods of non-collusive play, we would expect to see long periods where no announcements are made. As Fig. 1 shows, we see large gaps in announcements in the late 1970s and early 1980s.

Now consider the behavior of an explicit cartel with the ability to control the strategies of the two sellers. In particular, we assume an explicit cartel can sustain non-equilibrium strategies by the cartel members.

Definition 1. An *explicitly collusive strategy profile* is a strategy profile that is not necessarily an equilibrium strategy profile.

If the cartel is organized around a market-share agreement, as was the case in the Vitamins Cartel, then in order to maintain the agreement, any deviations from agreed-to market shares must be dealt with through transfers of either product or cash. Such redistributions are costly to a cartel in terms of effort and increased probability of detection, and so a market-share-agreement cartel would prefer that the market shares of its members remain constant. However, as the next proposition shows, in the game with immediate effective date there are no strategies for the two sellers such that market shares are guaranteed to remain constant. Thus, in the game with immediate effective date, a market-share-agreement cartel cannot avoid costly redistributions.

Proposition 3. *For all $\Delta > 0$ and $\omega \notin \Omega_\Delta$, unless $s_1 = s_2$, there is no explicitly collusive strategy profile for the game*

$\Gamma^{immediate}(s_1, s_2, p_0, \omega)$ that results in a price of $p_0+\Delta$ and that leaves the sellers' market shares constant at (s_1, s_2); if $\omega \in \Omega_\Delta$, there exists an explicitly collusive strategy profile that results in a price of $p_0+\Delta$ and that leaves the sellers' market shares constant.

Proof. Clearly market shares do not remain constant if the sellers either announce or set different prices. If the status-quo market shares are unequal and if sellers announce or set the same price, then with probability $1-\rho(\Delta)$, the price increase is not "accepted," i.e., $\theta=R$, and the market shares of the sellers reverse. Since for prices above the status-quo price, $\rho(\Delta)<1$, we have the result. □

An empirical implication of this is that in a world with immediate effective dates, an explicit cartel can only increase prices and keep market shares constant when the state variable allows such increases without buyer resistance. Note that even with repeated play there would be no benefit from announcing—firms would just "set" prices (per period 2).

However, as shown in Fig. 1, after 1985, price announcements tended to be made well in advance of the effective date of the price increase. So we adapt our model to incorporate the possibility of future effective dates for price increases.

4.3. Price announcements with future effective dates

Proposition 3 suggests that a cartel with asymmetric sellers and a market-share agreement that is trying to increase its profits faces potentially large redistribution costs since there are no pricing strategies that guarantee constant asymmetric market shares. To study how a cartel with a market-share agreement might overcome this problem, we now add an additional level of complexity to the sellers' announcement strategies. Specifically, we allow them to pre-announce price changes, which potentially gives them the opportunity to observe the other seller's announcement and the realization of θ while there is still time to reverse the announcement and return to the status-quo price. As noted in Clark (1983): "Announcing changes in prices before they are to become effective may also facilitate cooperative pricing strategies. By announcing a price change in this fashion, a seller can initiate an increase in prices without risking any loss of business because if other sellers fail to announce comparable increases, the initiator can simply withdraw or limit its prospective increase before it becomes effective."

As with announcements, we assume pre-announcements of price changes are a commitment to those price changes, with the exception that the commitment can be retracted prior to a final round of announcements. The final round of announcements reflects announcements that are sufficiently close to the date of procurements that the commitment can no longer be retracted.

Adding the possibility for pre-announcement of price changes, we have the following game, where each of the eight periods is identified as a pre-announcement period, a period in which pre-announcements can be retracted, an announcement period, a price-setting period, or a period in which buyer acceptance or resistance is realized:

Game with future effective date $\Gamma^{future}(s_1, s_2, p_0, \omega)$

Fix status-quo market shares (s_1, s_2), price p_0, and state ω.

1a. (pre-announcement) Firms can pre-announce price changes.
1b. (pre-announcement) Firms that did not pre-announce in period 1a can pre-announce price changes.
2. (acceptance/resistance) If both sellers pre-announce, the value of θ is realized and observed.
3. (retraction) Firms that pre-announced can retract their announcements, in which case a seller is viewed as having no commitment to a price change.
4a. (announcement) Firms with no price commitment can announce price changes.
4b. (announcement) Firms with no price commitment (and that did not announce in period 4a) can announce price changes.
5. (price setting) Firms with no price commitment set prices simultaneously.
6. (acceptance/resistance) The value of θ is realized (θ is the same as in period 2 if both sellers pre-announced and did not retract their pre-announcement). Profits are given by π.

As with the game with immediate effective date, there are multiple subgame-perfect equilibria. For example, there are equilibria in which neither firm pre-announces, and then the game is played as in the game with immediate effective date, with the possible equilibria as described in Section 4.2. But the question remains whether the ability to pre-announce generates equilibria with higher profits for the firms than the equilibria in which no pre-announcements are made.

The ability to pre-announce gives sellers an opportunity to come to a type of agreement on prices. For example, the larger seller could use the strategy of pre-announcing a price increase in period 1a, and then if the

smaller seller does not pre-announce the same price increase in period 1b, the larger seller could retract its price increase. However, as the following proposition shows, it is not an equilibrium for the smaller seller to participate in this type of price increase.

Proposition 4. *For all $\omega \in \Omega$, there is no equilibrium of $\Gamma^{future}(\tilde{s}_1, \tilde{s}_2, \tilde{p}_0, \omega)$ in which sellers' profits are greater than $(\tilde{\pi}_1^L, \tilde{\pi}_2^F)$.*

Proof. See Appendix B. □

To see the intuition for Proposition 4, note that the only possible use of pre-announcements to raise prices above the status-quo level is for one or both sellers to use the strategy of pre-announcing a price increase and then, if the other seller does not also pre-announce the same increase, retract the announcement. But if both sellers pre-announce a price increase $\Delta > 0$, then, unless the smaller seller expects to sell its capacity, the smaller seller will retract its pre-announcement in period 3, and then in period 4 announce a price that slightly undercuts the larger seller's price. Using this strategy, the smaller seller either captures all of demand $d(\tilde{p}_0 + \Delta)$ or sells its capacity k_2 at price $\tilde{p}_0 + \Delta$. When the smaller seller captures all of demand, the larger seller's payoff is zero. When the smaller seller sells its capacity at a price $\tilde{p}_0 + \Delta$, the larger seller's payoff is less than its status-quo payoff since the status-quo price $\tilde{p}_0$ maximizes the larger seller's payoff conditional on the smaller seller's selling its capacity. Since the larger seller can ensure a payoff at least equal to its status-quo payoff by not pre-announcing and then announcing a price increase of zero in period 4a, there is no equilibrium in which non-cooperative sellers use pre-announcements to increase the price above the non-cooperative level.

An empirical implication of Proposition 4 is that if there are any costs of pre-announcing, then we will not see pre-announcements in a non-collusive environment. Referring to Fig. 1, there are no pre-announcements prior to 1985, so the data for this period is consistent with this implication. After 1985, pre-announcements are common, something that is not consistent with non-collusive play in our model. But, as we now show, these pre-announcements are consistent with collusive play.

Proposition 4 shows that the pre-announcement of price increases plays no role in a non-cooperative equilibrium of this pricing game. In particular, pre-announcement does not eliminate the incentives for undercutting that are present in a non-cooperative environment. However, since pre-announcement allows sellers to observe θ, they can determine whether a price increase will be accepted or not before implementing that increase. This can be valuable for a cartel that would like to keep the market shares of its members constant. In particular, price increases can be implemented without market-share disruptions if both sellers pre-announce a price increase, either simultaneously or sequentially, and then both retract the price increase if $\theta = R$. This proves the following result.

Proposition 5. *For all $\omega \in \Omega$, there exists an explicitly collusive strategy profile for $\Gamma^{future}(s_1, s_2, p_0, \omega)$ that results in a price greater than p_0 and market shares equal to (s_1, s_2).*

The explicitly collusive strategy of Proposition 5 that allows a price increase without affecting market shares relies on the use of pre-announcements. As in Proposition 3, pre-announcements are not required to achieve a price increase of Δ without affecting market shares when $\omega \in \Omega_\Delta$. Thus, an explicit cartel may need to use pre-announcements in some cases, but not in others, to achieve their desired price increases.

Referring to Fig. 1, after 1985, pre-announcements are common. They are often made two or three weeks before the effective date of the price increase. However, in the two major price run-ups after 1985, there are also some price increases that were implemented without pre-announcement. In the context of the model, if we view the period after 1985 as a collusive period, the price increases with no pre-announcement may correspond to periods in which changes in costs and/or exchange rates could be used as justification for the price increase ($\omega \in \Omega_\Delta$), allowing the cartel to avoid resistance by buyers.

It is clear from various EC decisions, including *Amino Acids*,[45] *Electrical and Mechanical Carbon and Graphite Products*, and *Cartonboard* that the cartels were attentive to possible external justifications for their coordinated price increases. For example, in *Electrical and Mechanical Carbon and Graphite Products*, a detailed justification was agreed upon by the cartel members: "With regard to justifications for price increases, a local meeting in the Netherlands on 19 December 1995 came up with the following agreed explanations to 'justify' an impending price increase: 'Explanation for 4% price increase 1. Environmental requirements cost extra. 2. Increase [in price] of raw materials 3. Wages [increased by] 3%'."[46] In *Cartonboard*, the EC decision states: "Producers of cartonboard

[45] According to the EC decision in *Amino Acids* at 164, "The participants agreed on the explanation to be given to buyers."

[46] EC decision in *Electrical and mechanical carbon and graphite products* at 108.

have usually attempted to justify a proposed price increase to their customers by reference to increases in the costs of raw material, energy, transport, etc."[47]

Proposition 5 shows that the pre-announcement of price increases can be valuable to a market-share-agreement cartel because sellers can use pre-announcements to avoid having to make redistributions to correct deviations in realized market shares from their agreed-to values. A cartel using this strategy could ask each of its members to pre-announce a price increase, either sequentially in periods 1a and 1b or simultaneously in one of the periods 1a or 1b (simultaneous announcement of the same price change might increase the probability that the cartel is detected, and so sequential announcements may be preferable from the perspective of the cartel). If $\theta = A$, sellers proceed to implement the collusive price, and if $\theta = R$, sellers retract their announcements and continue with the status-quo price. By repeating this procedure, colluding sellers can increase the price in stages, with each increase leading to an increase of the status-quo price used in the next repetition, without disrupting the market shares.

Proposition 5 does not specify a collusive mechanism. Specifically, in the background of Proposition 5 is some unspecified set of enforcement and monitoring devices to ensure that cartel members comply with the collusive agreement. However, the cartel cannot directly control the buying decisions of customers. A cartel can preclude customers from switching away from incumbent suppliers by having non-incumbent members not bid for business, but this is an obviously non-competitive action and is likely to draw unwanted scrutiny. Proposition 5 only provides a characterization of how an explicit cartel would implement price announcements so as to achieve higher prices while maintaining market shares.

Empirical implications of Propositions 4 and 5 for the vitamins industry are that in collusive periods we would expect to see price increases announced in advance of their effective dates, and in non-collusive periods, we would not expect to see the pre-announcement of price increases. Referring to Fig. 1, the price announcement behavior in Vitamin A Acetate 650 Feed Grade corresponds well to this empirical implication if we view the collusive period as beginning in 1985.

Proposition 5, together with Proposition 3, suggests that allowing pre-announcement of price increases may be pro-collusive since pre-announcements may allow a market-share-agreement cartel to avoid redistribution costs that it would not be able to avoid otherwise. However, as noted by Clark (1983), "the precise conditions under which advance announcements of price changes may be unlawful have not yet been settled."[48]

Overall, a market-share-agreement cartel could potentially function without public price announcements, but in the absence of these announcements, the cost of enforcing the cartel agreement would be higher, the threat of instability and breakdowns would be higher, and the chance of drawing the attention of enforcement authorities would be higher.

4.3.1. Public versus private price announcements

The probability with which buyers accept a price increase may also be affected by whether price announcements are made publicly, for example through trade a publication, or privately through direct communication between a seller and buyer. Because a buyer that learns of a price increase only through private notification does not know whether its rivals, the other buyers, have been offered a better price, the buyer may resist the price increase. In this case, a market-share-agreement cartel following the strategy of pre-announcing in order to avoid market-share disruptions strictly prefers that all its members make their pre-announcements publicly rather than privately.[49]

4.3.2. Size of price increases

There is one final empirical implication from the preceding discussion that deserves to be highlighted. In practice, when a cartel forms, it typically implements price changes incrementally.[50] Standard economic models would have the cartel move from a non-collusive price to a cartel price in one step. This would be a single large change in the price. However, when a market-share-agreement cartel chooses the extent to which it should increase price, it must consider that a higher price is less likely to be accepted by buyers. A market-share cartel would face immediate disruptions in the shares of members, and consequently costly ex-post redistributions

[47] EC decision in *Cartonboard* at 19.

[48] See, e.g., US v. Sugar Inst., 15 F. Supp. 817, 830, 908 (S.D.N.Y. 1934); Sugar Inst. v. US, 297 U.S. 553, 603 (1936); US v. Pennsalt Chem. Corp., 1967 Trade Cas. (CCH) P71,982, at 83,475 (E.D. Pa. 1967); Wall Products Co. v. National Gypsum Co. 326 F. Supp. 295, 316 (N.D. Cal. 1971); and In re Ethyl Corp., 3 Trade Reg. Rep. (CCH) at 22,546 (F.T.C. Mar. 22, 1983).

[49] One could easily incorporate this into the model by having $\theta = R$ whenever a firm receives private communication of a price increase that is not substantiated by public announcements of that firm or of rivals.

[50] Harrington (2006) identifies several possible reasons for gradual price increases by cartels, including: 1. to avoid buyer resistance, 2. to avoid increasing price beyond the point that would be stable, and 3. to avoid discovery of collusion by buyers.

among members, if it attempted to implement a dramatic price increase in one shot. Thus, the concept of price acceptance allows us to gain a foothold in understanding why cartel price increases are incremental in nature.[51]

We can appeal to our model for a prediction on the size of price increases introduced by a cartel. If we view ρ, the probability that buyers purchase from their incumbents given equal prices, as a function that is decreasing in the amount of the price increase, with $\lim_{\Delta\to\infty}\ \rho(\Delta)=0$, then a cartel attempting to avoid disruptions in market shares may have an incentive to increase the price in small increments rather than jumping immediately to the optimal cartel price since large price increases increase the probability that $\theta=R$, in which case incumbent price increases are not accepted by buyers. The cartel might choose a sufficiently slow rate of increase for its price that cartel members are forced to retract their price increases only with small probability.

Finally, as noted by Harrington (2006), gradual price increases may reduce the probability that an illegal conspiracy to increase prices is detected.

4.3.3. Mimicking non-collusive announcements

The EC decision in *Vitamins* states that,

> "The parties normally agreed that one producer should first 'announce' the increase, either in a trade journal or in direct communication with major customers. Once the price increase was announced by one cartel member, the others would generally follow suit. In this way the concerted price increases could be passed off, if challenged, as the result of price leadership in an oligopolistic market."[52]

Despite the cartel's attempts to mimic non-collusive price leadership, there are features of the cartel's price announcements (for example during the plea period) that differ from the predictions of the economics literature on price leadership. For example, the use of pre-announcements, with effective dates two or three weeks or more after the announcement is not explained in the literature. And the literature cannot explain why the firm leading the price announcements would alternate. For example, in Vitamin A Acetate 650 Feed Grade shown in Fig. 1, starting in late 1989, the first six announcements are joint announcements led by first Roche, then BASF, then Rhone-Poulenc, then BASF, then Roche, then BASF. This type of rotation among firms leading the joint price announcements is not a feature of any models of price leadership in the literature. One might conjecture that none of the participants in the cartel wanted to lead all the price announcements because that might put one of them in the position of appearing to be the ringleader of the illegal activity, increasing its culpability in the eyes of enforcement authorities if caught.

5. Data

We focus on the six vitamins for which both Roche and BASF were part of the U.S. plea agreement (see Table A.3 in Appendix A)[53]: Vitamin A, Vitamin E, Vitamin C, Beta Carotene, Riboflavin (B2), and Calpan (B5). For each vitamin, we focus on a major human and a major feed grade vitamin product, with the exceptions that there is no feed grade Vitamin C product and there is no feed grade Beta Carotene product, giving us the following set of vitamin products (any product with the qualifier "USP" is a human product):

- Vitamin A Acetate 650 Feed Grade
- Vitamin A Acetate 500 USP
- Vitamin E Acetate 50% Spray Dried Feed Grade
- Vitamin E Acetate Oil USP
- Vitamin C Ascorbic Acid 100% USP
- Beta Carotene FS 30%[54]
- Riboflavin (B2) 96% Feed Grade
- Riboflavin (B2) USP
- Calpan (B5) Feed Grade
- Calpan (B5) USP.

In the United States, vitamins manufacturers typically announce price increases in two weekly trade journals—*Feedstuffs* and the *Chemical Marketing Reporter*. Our data come from an exhaustive review of

[51] Additional reasons for a cartel to use small price increases are that large price increases may generate attention from antitrust authorities and that cartel members may not initially know the reliability of their co-conspirators. Incremental steps in price reduce incentives for cheating and give the cartel time to gain confidence in the quality of its monitoring and its members' willingness to engage in redistributions when realized shares differ from agreed shares. In establishing reliability, price announcements that are public rather than private may be useful to the cartel.

[52] EC decision in *Vitamins* at 203–204.

[53] As can be seen in Table A.4, approximately 80% of the criminal fines for the vitamins conspiracy in the U.S., Canada, and Europe were levied against Roche and BASF. Thus, it is reasonable to view Roche and BASF as the two major players in the conspiracy. As stated in the EC decision in *Vitamins* at 75, "The main common denominator of the different vitamin cartels is the presence of Roche and BASF, the two leading producers of vitamins worldwide, in all vitamin cartels to eliminate all effective competition between them in the Community and EEA across almost the whole range of important vitamins."

[54] Beta Carotene is a human product.

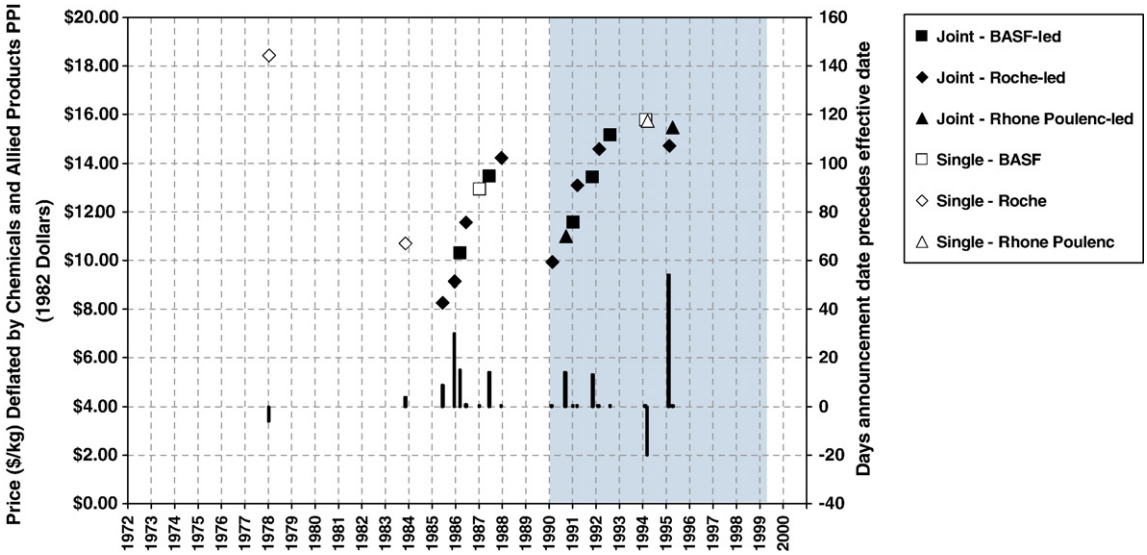

Fig. 2. Vitamin E 50% SD Feed Grade.

these journals from 1970 to 2001. We believe we have been able to construct a complete set of the public price announcements in the United States during this time period for the ten vitamin products listed above.

5.1. Description of the data

Figs. 1–10 depict for each vitamin product the dates and amounts of price announcements, the identity of the price leader (first firm to announce a given price), whether other sellers announced the same price within ninety days of the leader's announcement, and the number of days that the announcement preceded the effective date of the price change. The date of the leader's announcement is given on the horizontal axis, and the amount of the announced price, in 1982 U.S. dollars per kilogram,[55] is given on the left vertical axis. The number of days that the announcement date preceded the effective date is denoted by vertical bars at the bottom of the graph and measured on the right vertical axis (negative values indicate that the announcement was published in the trade journal after the effective date of the price change). The relevant plea period, as defined in Table A.3, is shaded in each graph.

The shape of a symbol marking a price announcement indicates the identity of the price leader. A symbol (e.g., a square or triangle) that is filled-in indicates a *joint announcement*, where that at least one other firm announces the same price within ninety days of the leader's announcement. If multiple sellers announce the same price in the same issue of a trade journal, we label the announcement a *tie announcement*. A symbol that is not filled-in indicates a *singleton announcement*, where no other firm announces the same price within ninety days.

5.2. Feed grade vitamin products

See Section 4.1 for a description of Fig. 1 showing Vitamin A Acetate 650 Feed Grade. The remaining feed grade vitamin products in our data are described below.

Some specific comments about each of the figures are warranted.

Fig. 2 shows the price announcement data for Vitamin E 50% SD Feed Grade. The cartel members are Roche, BASF, Rhone-Poulenc, and Eisai. As the figure shows, there were few announcements in this vitamin product prior to 1985, and the ones there were in that time period were singleton announcements by Roche. The period after 1985 is characterized mainly by joint price announcements led by different cartel members. There are a few singleton price announcements after 1985. Most notably there is a singleton announcements in early 1994 in which Rhone-Poulenc, a member of the cartel, undercuts BASF's singleton price announcement by $0.05.

Fig. 3 shows the data for Riboflavin (B2) 96% Feed Grade. The cartel members are Roche, BASF, and Takeda. In this vitamin product there are no price

[55] We deflate the prices using series the U.S. Department of Labor, Bureau of Labor Statistics, PPI for "Chemicals and Allied Products," which is series WPU06 available at http://data.bls.gov/cgi-bin/srgate.

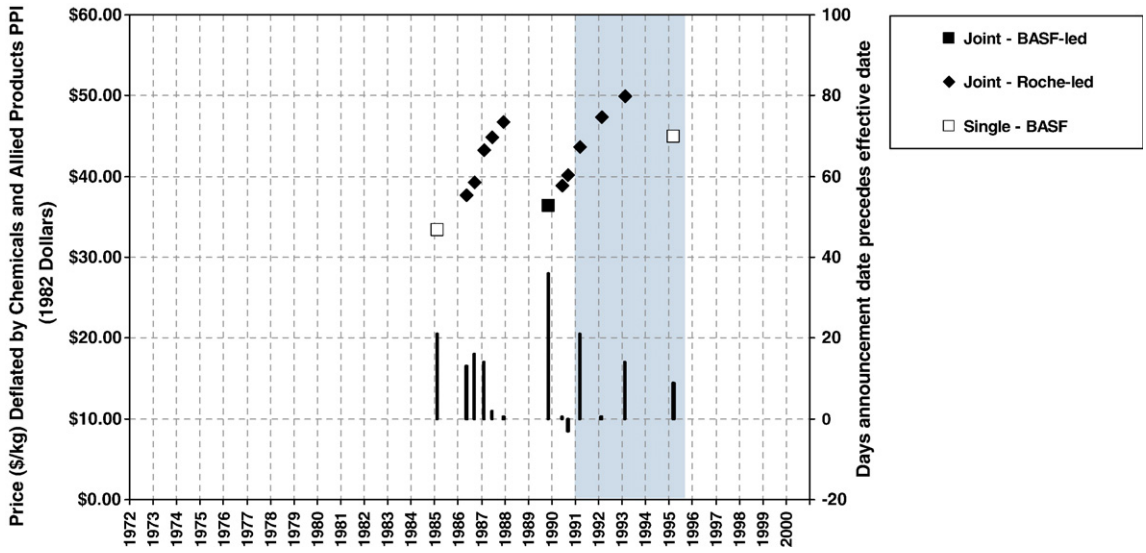

Fig. 3. Riboflavin (B2) 96% Feed Grade.

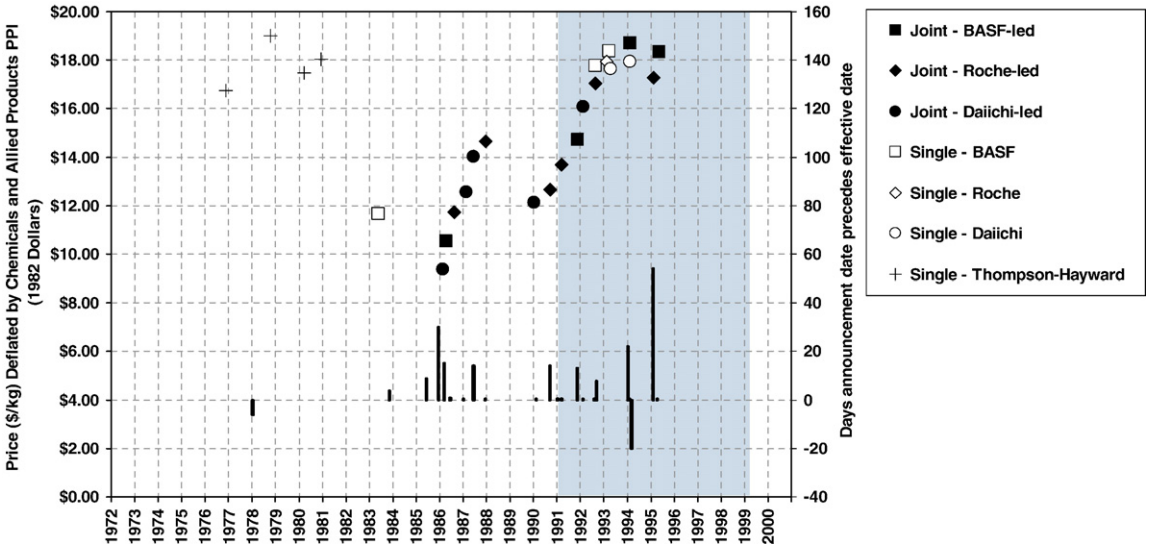

Fig. 4. Calpan (B5) Feed Grade.[56]

announcements prior to 1985, and announcements after 1985 are mainly joint price announcements led by Roche. As shown in Fig. 3, the sequence of price increases observed in the plea period starts before the official beginning of the plea period. This also occurs in Calpan (B5) Feed Grade.

Fig. 4 shows the data for Calpan (B5) Feed Grade. The cartel members are Roche, BASF, and Daiichi. Prior to 1985, there are four singleton price announcements by Thompson-Hayward. We have been unable to determine whether or not Thompson-Hayward was the dominant producer of B5 Feed Grade in the 1970s. After

[56] Entries in the *Chemical Marketing Reporter* on February 10, 1986 and March 25, 1991 indicate that Duphar was acting as a distributor for Daiichi, so we classify these as announcements by Daiichi. On May 29, 1995, BASF announced a 7% increase in the price of B5 Feed Grade, but did not provide an exact price; however, it seems BASF's intent was to match Roche's announcement of May 8, 1995, so we classify that announcement as a joint announcement led by Roche (Daiichi announced the same price as Roche on May 29, 1995).

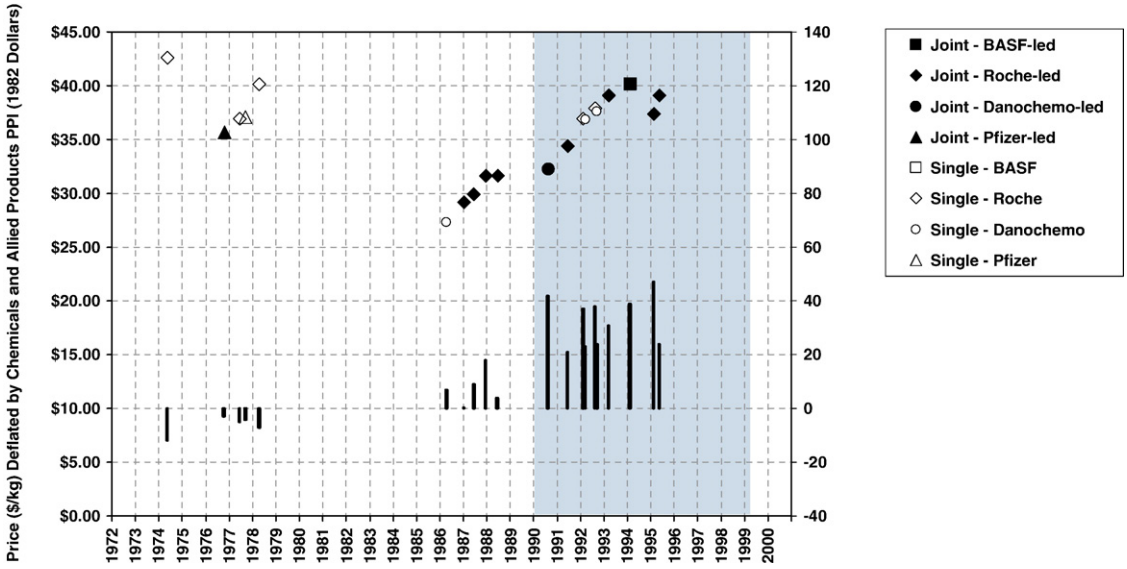

Fig. 5. Vitamin A500 USP.[57]

1985, we see mainly joint price announcements led by the various cartel members. As shown in Fig. 4, there is a period of singleton announcements from mid-1992 to early 1994. In August 1992, BASF announces a price of $22.50. Shortly thereafter, Roche and Daiichi jointly announce a price of $21.60. Then, in February 1993 Roche announces a price of $23.00, the next month BASF announces a price of $23.50, and the month after that Daiichi announces a price of $22.70. This group of singleton price announcements occurs at prices near the top of the plea period prices.

Taking the four feed grade vitamin products together, if we view the period prior to 1985 as being one without explicit collusion, then the price announcement data for that period can be understood in terms of the model of Section 4. Consistent with the model, we see no joint announcements led by firms other than Roche. Most singleton price announcements are made by Roche. After 1985, price announcements tend to be joint. After 1985, joint price announcements are regularly led by cartel firms other than Roche. (Joint price announcements are never led by firms outside the cartel.) This behavior is inconsistent with Proposition 1, suggesting that the price announcements after 1985 are not consistent with non-collusive behavior. However, the behavior is consistent with the explicitly collusive behavior described in Section 4.

5.3. Human vitamin products

As with the feed grade vitamin products, some specific comments about each of the figures for human vitamin products are warranted.

Fig. 5 shows the data for Vitamin A 500 USP. The cartel members are Roche and BASF. Prior to 1985, there are singleton announcements by Roche and Pfizer and one joint announcement by Pfizer, all made after the effective dates for the price increases. After 1985, there are mainly joint announcements led by Roche, plus one joint announcement led by BASF and one led by Danochemo. There are also five singleton announcements after 1985. There is an interesting group of singleton announcements in 1992 in which Roche leads and Danochemo undercuts Roche's price by $0.15 and $0.25, respectively. Note that Danochemo did not admit to participating in the cartel, but it was purchased by BASF in 1993.

Fig. 6 shows the data for Vitamin E Acetate Oil UPS. The cartel members are Roche, BASF, and Eisai. Prior to 1985, there are only singleton announcements—three by

[57] On October 8, 1979, Roche announced a 7% increase in the price of A500 USP, but did not provide an exact price; this announcement is not included in the graph. On May 29, 1995, BASF announced a 7% increase in the price of A500 USP, but did not provide an exact price; however, it seems BASF's intent was to match Roche's announcement of May 8, 1995, so we classify that announcement as a joint announcement led by Roche (no other firms announced at that time). On March 23, 1993, the *Chemical Marketing Reporter* reported a price increase for Danochemo. As BASF had acquired Danochemo by this time, we classify the announcement as being made by BASF. Although Rhone-Poulenc is listed as a cartel member for Vitamin A in Table A.3, they did not produce human products such as A500 USP (see the EC decision in *Vitamins* at 95).

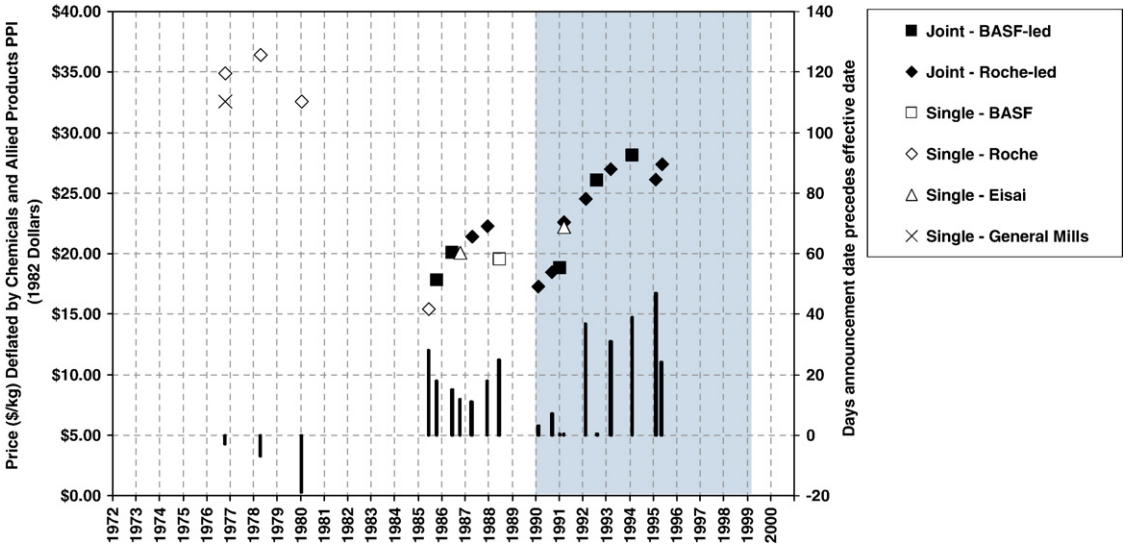

Fig. 6. Vitamin E Acetate Oil USP.[58]

Roche and one by General Mills. After 1985, there are mainly joint announcements made by Roche and BASF. As shown in Fig. 6, in March 1991, Roche and BASF make a joint announcement of $28.50, and shortly thereafter Eisai makes an announcement of $28.00.[59] In mid-1986, BASF and Roche jointly announce a price of $20.50. In October 1986, Eisai also announces a price of $20.50; but because Eisai's announcement is not within ninety days of BASF's announcement, it is reported on the graph as a singleton announcement by Eisai.

Fig. 7 shows the data for Ascorbic Acid 100% USP. The cartel members are Roche, BASF, Takeda, and Merck. Prior to 1985 there is frequent "undercutting." For example, in September 1978, Takeda and Merck jointly announce a price of $10.00, and shortly thereafter Roche and Pfizer jointly announce a price of $9.90. In March 1980, Roche and Merck jointly announce a price of $11.00, and Takeda follows with an announcement in May 1980 of $10.90. In April 1981, Roche announces a price of $12.00, and in June 1981, Merck announces a price of $11.90. In contrast, we do not observe this type of undercutting after 1985. Announcements after 1985 are mainly joint announcements by Roche, Takeda, or Merck, often made well in advance of the effective date of the price increase.

Fig. 8 shows the data for Beta Carotene FS 30% USP. The cartel members are Roche and BASF. There is only one price announcement prior to 1985, a singleton announcement by Roche. After 1985, there are joint announcements by both Roche and BASF, and one singleton announcement by Roche. As shown in this figure, as well as those for the other human products, human vitamin products seem to avoid the price downturn that affects feed grade products from mid-1988 to early 1990.

Fig. 9 shows the data for Riboflavin (B2) USP. The cartel members are Roche, BASF, and Takeda. It is notable that prior to 1985, the majority of the announcements are joint announcements or ties (multiple firms announcing the same price increase on the same day). This contrasts with most other vitamin products, where announcements prior to 1985 tend to be singleton announcements. One difference between the joint announcements prior to 1985 and those after is that the joint announcements prior to 1985 tend to be made after the effective date for the price increase, and those after 1985 tend to be made well in advance of the effective date.

Fig. 10 shows the data for Calpan (B5) USP. The cartel members are Roche, BASF, and Daiichi. Prior to 1985, there are singleton announcements by non-cartel firms Syntex and Thompson-Hayward and a tie announcement. After 1985, there are a large number of joint announcements led by the different cartel members and one singleton announcement by BASF. The fact that there is

[58] On May 29, 1995, BASF announced a 7% increase in the price of E USP, but did not provide an exact price; however, it seems BASF's intent was to match Roche's announcement of May 8, 1995, so we classify that announcement as a joint announcement led by Roche (no other firms announced at that time).

[59] Roche announced a price of $28.50 on March 4, 1991. BASF announced a price of $28 on March 11,1991, but then the *Chemical Marketing Reporter* published a correction on March 18, 1991, saying BASF's price was actually $28.50. Eisai then announced a price of $28.00 on March 25, 1991.

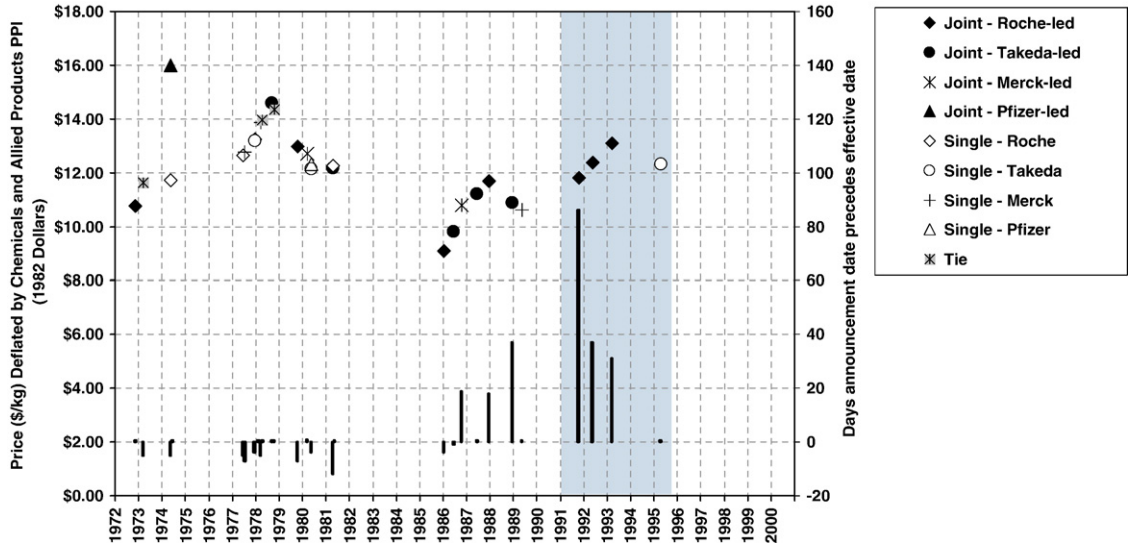

Fig. 7. Ascorbic Acid 100% USP.[60]

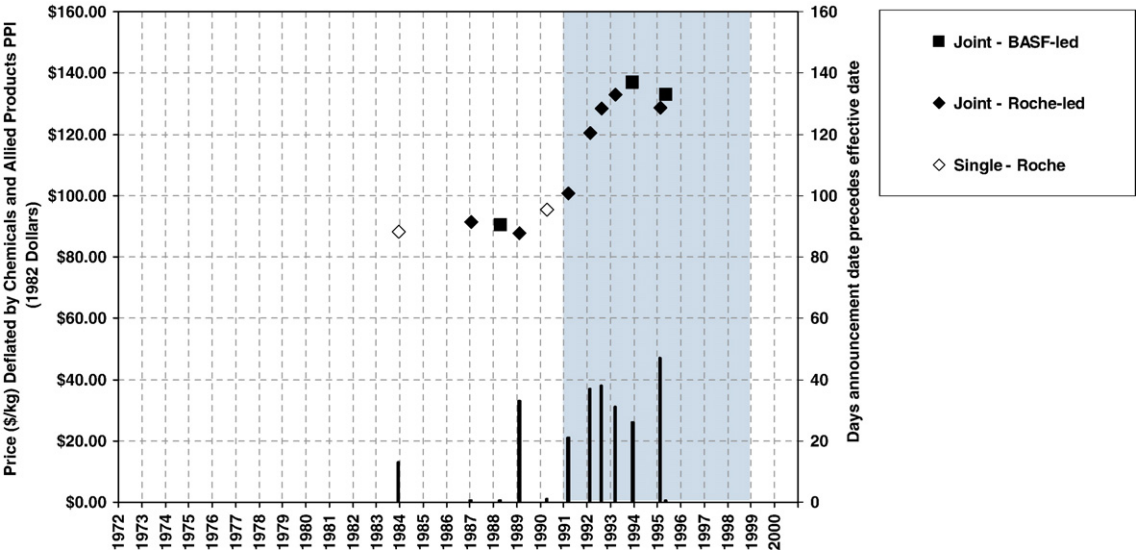

Fig. 8. Beta Carotene FS 30% USP.[61]

only one singleton announcement during the plea period is notable because there were five singleton announcements during the plea period in Calpan (B5) Feed Grade, and the cartels for Calpan (B5) Feed Grade and Calpan (B5) USP have the same membership.

6. Empirical analysis

There are three components to our empirical analysis of the data. We begin in Section 6.1 with a brief description of the roles played by Roche and BASF as

[60] Takeda announced a $0.40/kg increase on September 6, 1976, but since Takeda made no previous announcement, its previous list price is unknown, so this announcement is not included. Three price announcements did not include an explicit effective date: Pfizer's announcements on November 13, 1972 and May 13, 1974, and Merck's announcement on June 22, 1981. In these cases, we assume the effective date is the same as the announcement date.

[61] Roche's announcement on May 9, 1988 did not include an explicit effective date. We assume the effective date is the same as the announcement date.

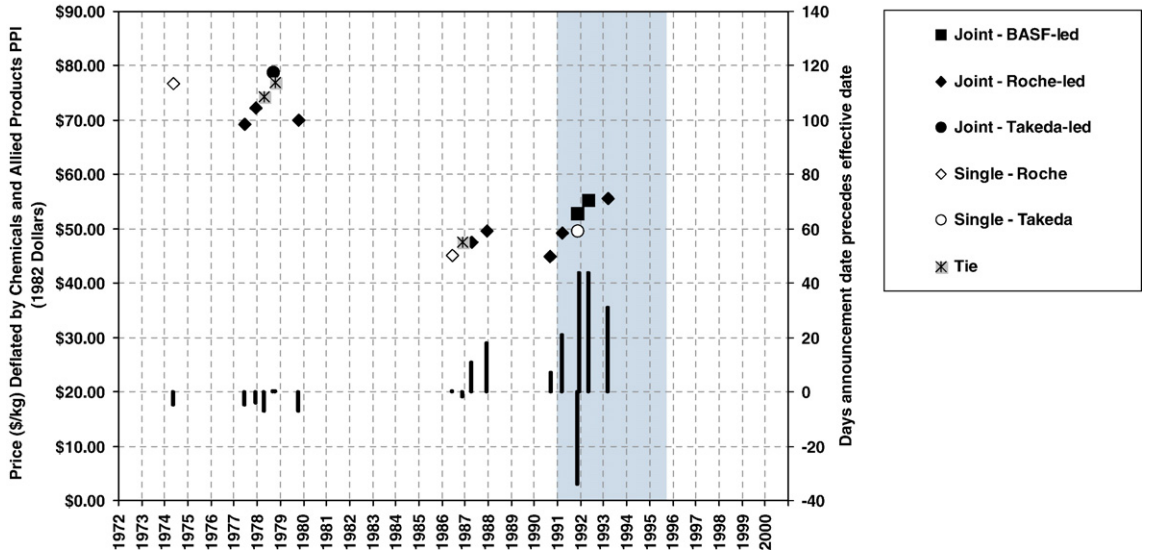

Fig. 9. Riboflavin (B2) USP.

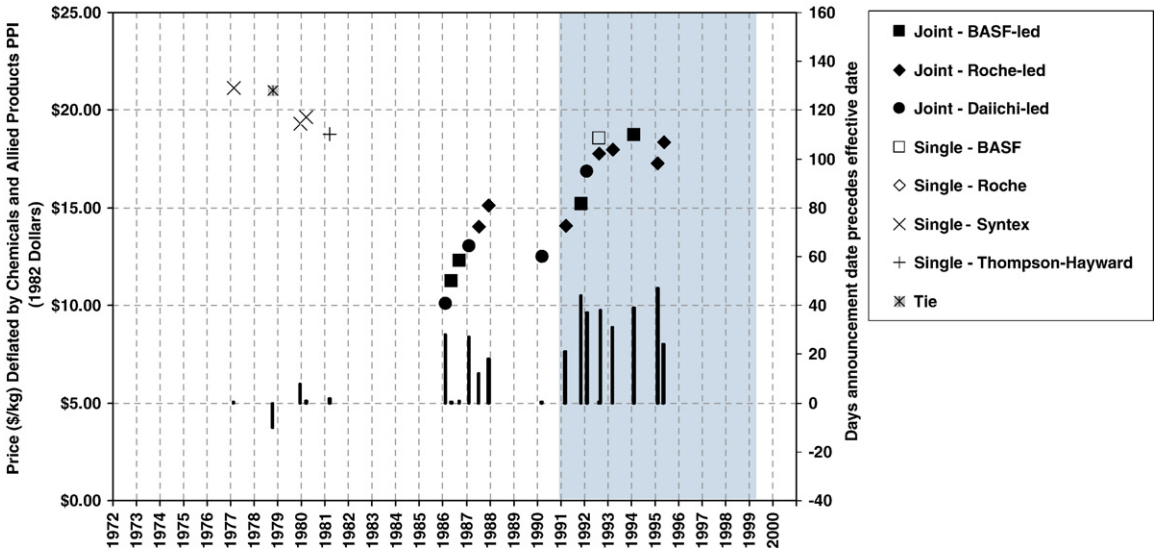

Fig. 10. Calpan (B5) USP.[62]

leaders of price announcements in different time periods. Assuming the period prior to 1985 is non-collusive and that the period after 1985 is collusive, this evidence is consistent with the implication of our model that one would expect few price announcements (possibly singleton announcements) in a non-collusive period and frequent joint price announcements in a collusive period. Next, in Section 6.2, we analyze the data on differences between announcement and effective dates for different time periods. Again, consistent with collusion after 1985 but not before and consistent with the implications of our model, announcements

[62] Several price announcements issued prior to April 1991 were made by Duphar. However, entries in the *Chemical Marketing Reporter* on February 10, 1986 and March 25, 1991 indicate that Duphar was acting as a distributor for Daiichi, so we classify these as announcements by Daiichi. On May 29, 1995, BASF announced a 7% increase in the price of B5 USP, but did not provide an exact price; however, it seems BASF's intent was to match Roche's announcement of May 8, 1995, so we classify that announcement as a joint announcement led by Roche (Daiichi announced the same price as Roche on May 29, 1995).

tend to be effective immediately in periods prior to 1985, but tend to be made well in advance of the effective date in periods after 1985. Finally, in Section 6.3, we examine whether the timing of price announcements can be explained by barometric forces. We do not find strong evidence that price announcements are driven by barometric forces, but we do find that after 1985 new price announcements are explained by the amount of time elapsed since the previous price announcement in a way that is consistent with regular cartel meetings.

6.1. Observations on leaders and followers

It is illuminating to consider some simple calculations about the frequency with which price announcements are followed. During the plea period (as defined in Table A.3) when both Roche and BASF had production capacity, for 73% of price announcements (52 out of 71 announcements), both firms announce the same price within ninety days of each other. During the period after 1985, but prior to the plea period, when a price announcement is made by either firm, the other firm announces the same price within ninety days 79% of the time (48 out of 61 announcements). Prior to 1985, there are 15 price announcements made in vitamin products during time periods when both Roche and BASF have production capacity. For these 15 pre-1985 announcements, Roche and BASF never announce the same price within a ninety day interval. Thus, the plea period and the period between 1985 and the plea period exhibit similar levels of coordination of price

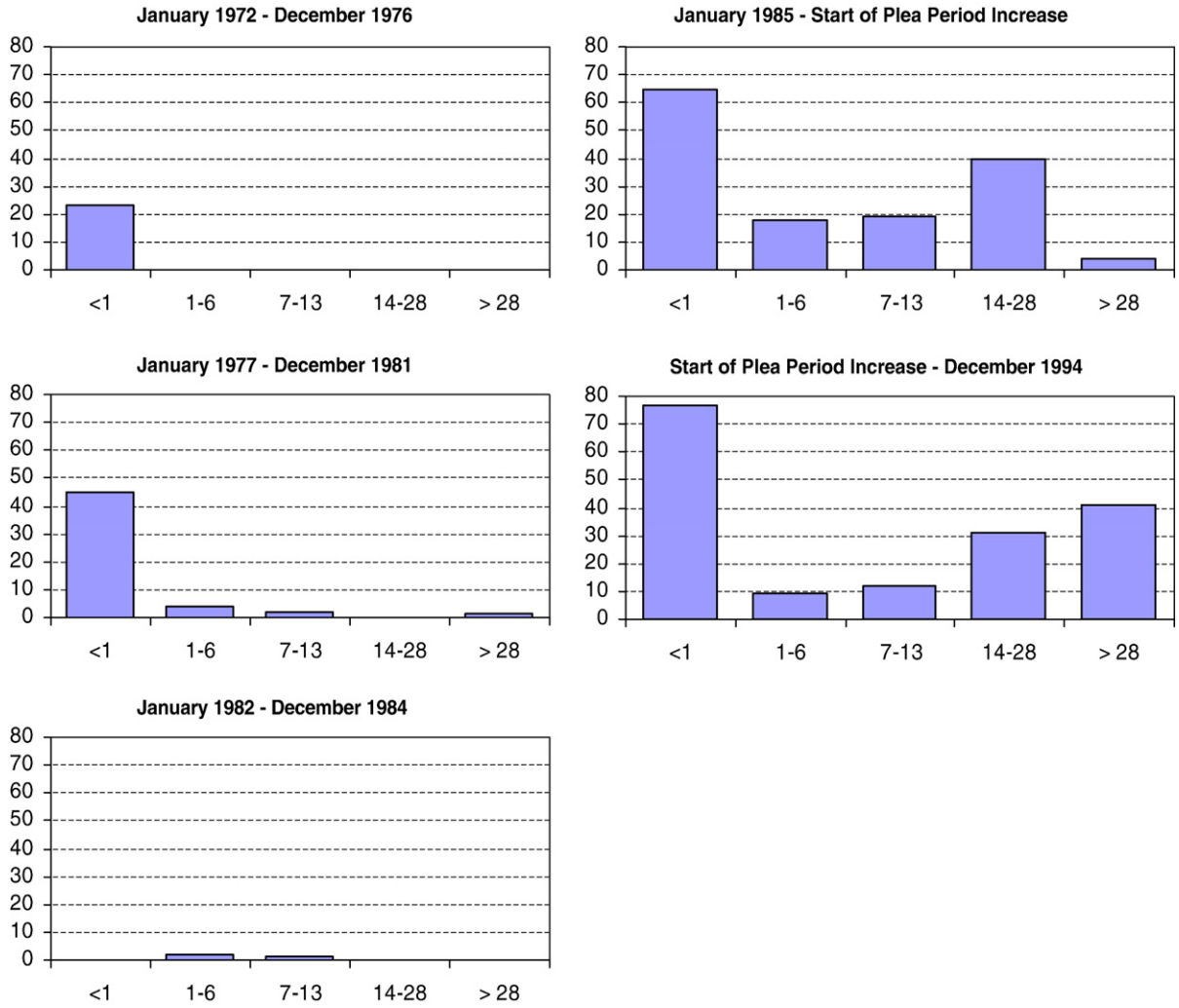

Fig. 11. Histograms of days of delay until the effective date.

announcements by Roche and BASF, while the period prior to 1985 shows no similarly coordinated behavior by these two producers.

6.2. Announcement and effective dates

As depicted in Figs. 1–10, it was not uncommon for the vitamin manufacturer making a singleton announcement or leading a joint announcement to announce the price increases prior to the effective date of the increase. There are also cases in which the announcement of a price increase in the trade press does not occur until after the effective date of the price increase, but these are rare and, except for one case with a delay of 20 days, they involve a delay in the announcement of seven or fewer days (the trade journals are weekly publications).

Fig. 11 below shows histograms for the number of days that the effective date follows the announcement date for singleton announcements and the lead announcement of joint announcements for the vitamin products in our sample. The figure shows the histograms for four approximately five-year periods, three before and one after the beginning of the period of admitted collusion, as well as for the period 1/1982–12/1984, which has few observations.

To define the relevant time periods, we use the data from the graphs in Section 5, rather than the admitted period of collusion, to define the *start of the plea-period price increase*. For example, for Riboflavin (B2) Feed Grade, the legal plea period begins January 1991. Yet it is clear from Fig. 3 that the price ascent associated with the DoJ's plea period begins well before January 1991. In fact, the price run clearly begins with the BASF-led joint price announcement of late 1989. Thus, we define the start of the plea-period price increase for Riboflavin (B2) Feed Grade to be late 1989. Comparable adjustments are made for the other vitamin products. For Vitamin A 650 Feed Grade, we use the Roche-led price announcement of 1989. For Calpan (B5) Feed Grade, we use the Daiichi-led price announcement of early 1990, and for Vitamin E Feed Grade we use the start of the legal plea period. The approximately five-year periods we consider are: 1/1972–12/1976, 1/1977–12/1981, 1/1985 to the start of the plea-period price increase, and from the start of the plea-period price increase to 12/1994.

Table 1
Distribution of delay until the effective date

Days of delay	1/1972–12/1984	1/1985–Plea Price Inc.	Plea Price Inc.–12/1994
6 or fewer	95%	57%	51%
7 or more	5%	43%	49%
# of obs	78	146	170

Table 2
Z-test for equality of proportion of delays of 7 days or more

Sample 1	Sample 2	*z*-statistic	*p* value
1/1972–12/1984	1/1985–Plea Price Inc.	6.01	0.0000
1/1972–12/1984	Plea Price Inc.–12/1994	6.86	0.0000
1/1985–Plea Price Inc.	Plea Price Inc.–12/1994	1.11	0.2659

One can see from Fig. 11 that prior to 1985 it was rare to see price announcements far in advance of the effective date; however, after 1985 this was relatively more common.

We summarize this data in Table 1, which shows that after 1985, delays until the effective date of one week or more and delays of less than one week are approximately equally likely, but prior to 1985, a delay of one week or more occurs in only 5% of announcements, while a delay of less than one week occurs in 95% of announcements.

Calculating a simple *z*-test for the equality between two proportions,[63] we get Table 2, which shows that we can reject the hypothesis that the proportion of long delays, defined as delays of 7 days or more, is the same in the period before 1/1985 as it is in either of the periods after 1/1985. And, we fail to reject the hypothesis that the proportion of long delays is the same in the two periods after 1/1985.

6.3. Logit estimates

Our description of the role of price announcements in explicit collusion in Section 4 suggests that joint price announcements by cartel members are desirable any time contracts are up for renewal. Furthermore, since joint price announcements are coordinated by the cartel in our model of explicit collusion, the timing of announcements might also be expected to be related to the timing of cartel meetings.

An alternative explanation for the timing of joint price announcements is that they are responses to changes in underlying cost or demand factors, as in the models of barometric price leadership described in the literature (see,

[63] This test is approximate and assumes that the number of observations in the two samples are sufficiently large to justify the normal approximation to the binomial. The test statistic is $(p_1 - p_2)/\sqrt{\frac{p_1 n_1 + p_2 n_2}{n_1 + n_2}\left(1 - \frac{p_1 n_1 + p_2 n_2}{n_1 + n_2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$, which is approximately distributed as a standard normal under the null hypothesis that $\pi_1 = \pi_2$. (See Kanji, 1993).

e.g., Stigler, 1947; Markham, 1951; Bain, 1960; Cooper, 1997). To distinguish between these explanations, in this section we consider what factors cause a firm to issue a price announcement. As described below, our results suggest that the primary drivers for price announcements are not cost or demand factors, but rather the length of time since the previous announcement.

During a period of explicit collusion, one would expect cartel firms that meet regularly to make regular price announcements, pushing the price up until the desired price is reached. In particular, one would expect the likelihood of a new price announcement to be an increasing function of how much time has passed since the previous price change. In contrast, in the absence of explicit collusion, one would not expect price announcements to be tied to the calendar or to the length of time since the previous announcement in any systematic way. To address this hypothesis, we estimate a logit model for the probability that a new price is announced in a given month conditional on the amount of time that has passed since the previous price change, with variables to control for potential cost and demand triggers for a price change.

To construct our dependent variable, we define a *new price announcement* to be any singleton price announcement or any lead announcement in a joint announcement (i.e., we exclude follower price announcements in a joint announcement). Then, for all months in our sample, we create a variable *new price* that is equal to 1 if there is a new price announcement in that month, and 0 otherwise.

To control for potential cost and demand triggers for a price change, we use the price of oil, the Deutsche Mark/U.S. dollar (DM/USD) exchange rate, and a weighted average of the number of hogs slaughtered (weighted 20%) and the number of chickens slaughtered (weighted 80%).[64] Because oil is a primary element in the manufacture of all vitamins, the price of oil provides a measure of costs. The DM/USD exchange rate is potentially relevant because the primary vitamin manufacturers were located in Germany, while the price announcement data are for the U.S. market. The numbers of hogs and chickens slaughtered provide a measure of demand, with hogs being a smaller share of the feed market than chickens. Data series for oil prices, the DM/USD exchange rate, and numbers of hogs and chickens slaughtered are in Figs. A.5, A.6, and A.7 of Appendix A.

[64] If price increases were tied to cost and/or demand factors, this would not preclude the possibility of explicit collusion; but it would make the task of disentangling the component attributions of a given price increase more challenging.

Table 3
Logit estimates for periods before and after the start of explicit collusion

	Period 1: 1/1972–12/1976	Period 2: 1/1977–12/1981	Period 3: 1/1985 to start of plea period price increase	Period 4: Start of plea period price increase to 12/1994
delay	0.0818	−0.1578	0.6493*	0.4247*
	0.34	−1.50	3.15	3.13
$delay^2$	0.0008	0.0027	−0.0452*	−0.0226*
	0.10	1.02	−2.83	−2.85
markdum10	2.2150	0.4756	1.6097*	0.5831
	1.77	0.60	4.16	1.20
oildum10	−1.4051	0.8369	0.6803	−0.4595
	−1.41	1.61	1.87	−1.43
demanddum10	3.0517	−0.8999	0.5996	−0.3556
	1.85	−1.17	0.72	−0.83
Constant	−4.2085*	−2.0037*	−4.382*	−3.3465*
	−2.95	−4.68	−8.09	−6.90
N obs	166	408	515	540
Wald Chi^2	15.37	11.32	57.52	14.86
Wald Chi^2 Prob	0.0089	0.0454	0.0000	0.0110
Pseudo R^2	0.1764	0.0347	0.1858	0.0482

Note: We estimate a logit model for the log odds ratio for the probability of a new price announcement in a given month. The *z*-statistics (ratio of the estimated coefficient to the robust standard error) are reported under the coefficients. Coefficients that are significant at the 5% level are indicated with an asterisk. The pseudo R^2 is calculated as $1-\ln(L)/\ln(L_0)$, where L is the likelihood and L_0 is the likelihood when only a constant is included on the right-hand side.

We code these independent variables as dummy variables because we are interested in determining whether a price announcement is triggered by a given change in a right-hand-side variable. We arbitrarily select a 10% threshold for these changes.[65] The variable *oildum*10 is a dummy variable that is 1 if the price of oil increased by 10% or more since the previous new price announcement, and 0 otherwise; *markdum*10 is a dummy variable that is 1 if the DM/USD exchange rate decreased by 10% or more since the previous new price announcement, and 0 otherwise[66]; and *demanddum*10 is a dummy variable that is 1 if demand factors increased by 10% or more since the previous new price announcement, and 0 otherwise.[67]

[65] We also considered thresholds of 5% and 20% and found no substantial changes in the results.

[66] Similar results obtain using other related specifications of the *oildum*10 and *markdum*10.

[67] The demand index is calculated as the weighted sum of the number of hogs slaughtered (20%) and chickens slaughtered (80%). Results are robust to other weighted averages.

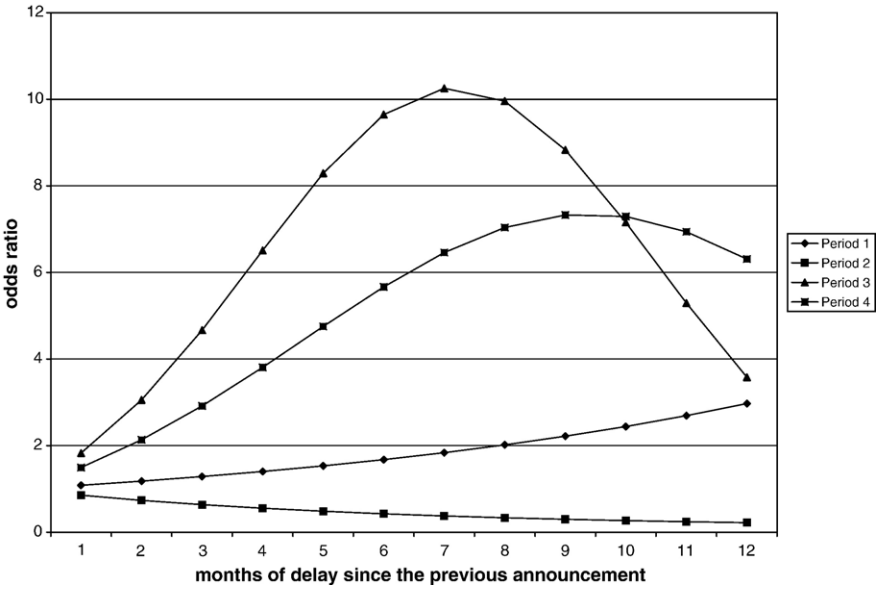

Fig. 12. Estimated effect of *delay* and $delay^2$ on the odds ratio. *Note:* Period 1 is 1/1972–12/1976; period 2 is 1/1977–12/1981; period 3 is from 1/1985 until the start of the plea-period price increase; and period 4 is from the start of the plea-period price increase until 12/1994. The horizontal axis shows the delay since the previous announcement in months.

Finally, we include the independent variables to capture the amount of time that has passed since the previous price change. The variable delay is the number of months since the previous new price announcement and $delay^2$ is the square of *delay*.[68]

We consider the same four approximately five-year periods as in Section 6.2: three before and one after the beginning of the period of admitted collusion. Using these time periods, we get the results of Table 3. The results for five-year periods prior to 1985, particularly prior to 1977, should be interpreted with caution because they are based on a small number of price announcements.

Note that the coefficients for *delay* and $delay^2$ are not statistically significant in the periods prior to 1985, but they are statistically significant for the periods after 1985.[69] Furthermore, the coefficient estimates indicate that for the periods after 1985, the log odds ratio increases rapidly with time in the first six months after a new price announcement; but for the periods prior to 1985, the log odds ratio either decreases or increases much more gradually (see Fig. 12). Another notable feature of Table 3 is that the coefficient on *markdum*10 is significant in the period between 1985 and the start of the plea-period price increase.

As an additional robustness check, we reran the analysis including quarterly dummy variables. These results are shown in Appendix C. There is little change in the coefficient estimates or their significance as a result of the inclusion of the dummies.[70] It continues to be the case that the coefficients for *delay* and $delay^2$ are not statistically significant in the periods prior to 1985, but they are statistically significant for the periods after 1985. A notable feature of these results is that the quarterly dummies are large, positive, and highly significant during the period 4 (the plea period).[71] This empirical evidence reflects the importance of cartel meetings and the fact that they tended to be held on a quarterly basis during the plea period, as discussed in the EC decision in

[68] Because our independent variables are not defined for months prior to the first-price announcement, the number of observations in the different time periods will differ.

[69] The only notable change when we use a probit model is that the coefficient on delay in the period 1/1977 to 12/1981 has a *z*-statistic of 2.04.

[70] One change is that the coefficient on *oildum*10 becomes significant in period 3.

[71] We use one dummy for the end-of-quarter months of March, June, September, and December, and another dummy for the months just prior to the end-of-quarter months, February, May, August, and November. The omitted category is the months just after the end-of-quarter.

Vitamins.[72] Relative to period 4, the coefficients on the quarterly dummies in period 3 are less significant, but as mentioned above, the coefficients on *delay* and $delay^2$ continue to be significant. This combination suggests that in period 3 the organization and structure of the cartel may have been different, and in some sense weaker, than in period 4. In period 2, only one of the quarterly dummies is significant, and in period 1 neither is significant.

Referring to Fig. 12, we see that the effect of *delay* on the odds ratio for a new price announcement is similar in the two periods after 1985, but remarkably less pronounced in the two periods prior to 1985. The positive, significant coefficient on *delay* and the negative, significant coefficient on $delay^2$ for the two time periods after 1985 are robust to a variety of specifications of the explanatory variables and are robust to whether we estimate a logit or probit model.

It appears that in both periods after 1985, the fact that a certain amount of time had elapsed since the previous price announcement is a significant driver in inducing firms to make new price announcements. We know from the Sentencing Statement that the cartel controlled new price announcements during the plea period. Given that the cartel met regularly to discuss cartel business, it is not particularly surprising to see results in Fig. 12 that suggest new price announcements for period 4 (early 1990s) on a schedule of approximately every six to twelve months.[73] In fact, our results suggest that the length of time between price announcements may provide a critical indicator of cartel meetings and explicitly collusive behavior. The results in Fig. 12 for period 3 (late 1980s), especially when compared with those for period 4 (early 1990s), suggest explicit collusive behavior well before the beginning of the plea periods described in Table A.3.

In period 1 (1/1972–12/1976), the coefficients on *delay* and $delay^2$ are not statistically significant, although the coefficients do indicate that a new price announcement is more likely the greater is the number of months that have passed since the previous new price announcement. This may reflect the collusive activity alleged in the early 1970s by Adams (1984). However, period 2 (1/1977–12/1981), shows no tendency for new price announcements to be more likely after more time has passed since the previous new price announcement. In fact, the results for period 2 indicate that new price announcements should be less likely if more time has passed since the previous announcement. These results are robust to various specifications of the explanatory variables and to whether we estimate a logit or probit model.

In conclusion, the analysis of the data on the probability of new price announcements provides a potentially valuable tool for identifying explicit collusive behavior. In particular, one would test for organized price announcements coordinated at regular cartel meetings by looking for an increasing probability of a new price announcement with the passage of time, especially at intervals related to the interval contract renewals and cartel meetings.

7. Discussion

This paper provides a window into price announcements when firms are acting non-cooperatively as well as when behavior is explicitly collusive. Our model captures the importance of public price announcements for a market-share-agreement cartel by incorporating the concept of buyer price "acceptance." The stylized facts of the price announcement data helped guide the construction of a model which in turn produced several empirical implications concerning the distinction between non-collusive and collusive price announcement behavior. For example, with vitamin products, the number of days between the date of a public price announcement and the date when the new price became effective was relatively large during the period of explicit collusion and almost non-existent prior to 1985.

As noted in Clark (1983), "Under some conditions, a systematic and parallel pattern of public announcements of prices or other terms of trade can provide important evidence that a group of firms has agreed to coordinate pricing and output strategies and therefore can support the finding of agreement that Section 1 of the Sherman Act requires."[74] This suggests one possible remedy—a prohibition on the announcement of prices prior to their effective date. Such a prohibition was imposed on an association of sugar refiners in 1934,[75] but the

[72] For example, related to Ascorbic Acid, the EC decision at 415 states: "As with the other vitamins, quarterly meetings were held for the purpose of implementing the cartel agreements." The time period of interest for the EC decision is the plea period.

[73] Perhaps the cartel required a certain (regular) amount of time to agree upon the next price announcement, or perhaps they decided on an interval that they felt would not generate customer resistance or arouse antitrust suspicion.

[74] Clark cites the example of Wall Products Co. v. National Gypsum Co. 326 F. Supp. 295, 316 (N.D. Cal. 1971), in which case the colluding firms announced pricing policies that were all to become effective on the same date.

[75] US v. Sugar Inst., 15 F. Supp. 817, 830, 908 (S.D.N.Y. 1934).

Supreme Court reversed that portion of the district court order.[76] More recently, a prohibition on advance price announcements was included in the 1967 consent agreement in US v. Pennsalt Chem. Corp.[77] In addition, in Ethyl Corp.,[78] the Federal Trade Commission found advance announcement of price changes to have an anticompetitive effect. This suggests that the prohibition of advance price announcements may be a feasible and useful remedy in cases in which public price announcements are used by a cartel.

Finally, although not a direct outgrowth of our model, we were able to investigate whether the timing of price announcements in the vitamins industry was largely explicable by cost and demand factors or more readily explained by the interval since the last announcement, where the latter would be consistent with price announcements emerging from cartel meetings.[79] The temporal regularity in price announcements that is consistent with cartel behavior showed up in our logit estimates for the periods after 1985, but was absent for the periods prior to 1985.

Appendix A. Vitamins Industry

See Table A.1 for the known and potential benefits of the six vitamins considered in this paper.

Vitamins are largely produced through processes of chemical synthesis, although there have been recent advances in fermentation technologies for the production of some vitamins. Throughout the study period, petroleum was a primary factor input for the production of each vitamin considered in this study.[80] For vitamins produced using fermentation technologies, such as C and B2, sugar is an important factor input.

The vitamins industry is highly concentrated. Table A.2 lists the firms that were involved in the production of specific vitamins according to the plea agreements and European Commission findings. The dominant firm in the industry is Roche, which produces almost all vitamins.[81] Another key firm in the industry is BASF.[82] Prior to 1982, BASF only produced Vitamins A and E; but in 1982 BASF began production of B5 and purchased Grinsted, a Danish producer, adding four vitamins to its portfolio—C, B1, B2, and B6. During the mid-1980s BASF gradually increased its production of Beta Carotene.

The large capital investments, and especially the production experience, required for the manufacture of vitamins are a barrier to entry in this industry. Although the major producers have similar production technologies, the chemical synthesis processes involve substantial "learning by doing." Each producer becomes better, through time, at debottlenecking the chemical synthesis process at any given plant.

When considering the cost of producing animal feed or human food, the incremental cost of the vitamin additives typically is small. Nevertheless, sales of vitamins in the U.S. alone during the 1990s were several billion dollars. Due to the significant nutritional impact of vitamin supplements, the demand for vitamins is inelastic.

Although it is common to think of vitamins as a single entity–such as Vitamin A or Vitamin E–in fact, specific vitamin products are manufactured within each vitamin type. For example, "A650" is a specific Vitamin A product that is used in the feed sector. Table A.1 lists some of the key vitamin products that are offered by the primary manufacturers.

A given vitamin product made by one firm is chemically identical to the same product made by another firm. For example, Roche's A650 is identical to BASF's A650. Purchasers are aware of the fact that vitamin products are homogeneous. As an indicator of the substitutability of the products for end users, in the 1970s, Roche actively tried to inhibit customer switching by using "fidelity contracts," contracts with large rebates paid at the terminal date if a customer purchased all of its vitamins from Roche.[83]

The Chinese began production of some vitamins in the 1980s and developed a major market presence by the middle of the 1990s in vitamins such as C and B1. The Chinese developed fermentation technologies (in contrast to chemical synthesis technologies) for the production of some vitamins. Entry barriers are far lower for fermentation processes.

[76] Sugar Inst. v. US, 297 U.S. 553, 603 (1936).

[77] US v. Pennsalt Chem. Corp., 1967 Trade Cas. (CCH) P71,982, at 83,475 (E.D. Pa. 1967).

[78] In re Ethyl Corp., 3 Trade Reg. Rep. (CCH) at 22,546 (F.T.C. Mar. 22, 1983).

[79] "The decisions on whether, when, and by how much to increase prices were taken by the heads of vitamin marketing in their periodic meetings." (EC decision in *Vitamins* at 201).

[80] The price of oil for the relevant time period is shown in Fig. A.5. The importance of oil as a factor input varies between vitamins—more for A, E, and Beta Carotene and less so for C.

[81] Notable exclusions are Niacin (B3), Choline Chloride (B4), and B12.

[82] During the 1990's, Roche and BASF jointly had the following percentages of the world vitamin market: A–80%, E–65%, C–45%, B2–75%, B5–65%, Beta Carotene–100% (see EC decision in *Vitamins* at 123).

[83] According to Adams (1984, p.76), in June 1976, the European Commission issued a decision requiring Roche to stop using fidelity contracts and to pay a fine of 1,098,000 DM.

Table A.1
Known and potential benefits of vitamins and product list

Vitamin	Vitamin Product	Benefits
Beta Carotene	BETAVIT/BETATAB 20% BCAROTENE FS 30% BETAVIT/BETATAB 10% BCAROTENE CWS 10% BCAROTENE CWS 1%	Vitamin A/Beta Carotene are important in the promotion of growth, strong bones, healthy teeth, skin, hair and gums. They also counteract night blindness, weak eyesight, and help build resistance to respiratory infections. Beta Carotene is associated with a protective effect against the development of certain cancers, and a high intake/status of this nutrient has been related to a decreased incidence of certain cancers and cardiovascular events. Findings in laboratory studies show that Beta Carotene acts in synergy with Vitamins E and C.
Calpan (B5)	CALPAN SD USP CALPAN FEED GRADE CALPAN 80 CALPAN 45% FEED GRADE CALPAN 160	Pantothenic acid (Calpan) is vital for the release of energy from food, for healthy growth, and for the production of antibodies. Pantothenic acid requires Vitamin A, Vitamin B6, Vitamin B12, Folic Acid, and biotin in order to function properly.
Riboflavin (B2)	RIBOFLAVIN USP RIBOFLAVIN 95/98 RIBOFLAVIN 80% SD RIBOFLAVIN 96% FEED GRADE RIBOFLAVIN FEED GRADE	Riboflavin is vital for the release of energy from foods and for healthy skin, eyes, and growth. It plays a major role in oxidation and reduction processes in cells. Deficiency is rare, and usually occurs in combination with deficiencies of other water soluble vitamins. In farm animals, even marginal Vitamin B2 deficiency leads to loss of appetite and impaired growth rate. Riboflavin deficiency also affects the nervous system, gastrointestinal tract, and reproductive organs.
Vitamin A	A ACET 650 FEED GRADE A PALM 1.7 A ACET 500 USP A PALM 250 A DLC 500	Vitamin A/Beta Carotene are important in the promotion of growth, strong bones, healthy teeth, skin, hair, and gums. They also counteract night blindness, weak eyesight, and help build resistance to respiratory infections.
Vitamin C	ASCORBIC ACID (AA) 100% AA COMPRESSIBLE 90% SODIUM ASCORBATE AA COMPRESSIBLE 95% AA COMPRESSIBLE 97.5%	Vitamin C is important for the production of collagen, connective tissue, and protein fibers that give strength to our teeth and gums, muscles, blood vessels, and skin. In the immune system, Vitamin C helps the white blood cells to fight infection. It helps the body to absorb iron. It is believed that the so called "antioxidant" properties of Vitamin C help protect the body from the harmful effects of too many free radicals. These are potentially damaging molecules in our bodies that may harm healthy cells. Together with Vitamin A and Vitamin E it forms the trio of antioxidant vitamins now believed to have a preventive effect on degenerative diseases such as cardiovascular disease and cancer. Vitamin C is also commonly used as a natural antioxidant, i.e., it prevents spoilage of foods and beverages by oxygen in the air.
Vitamin E	E ACETATE OIL USP E 50% ADSORBATE E ACETATE 50% SD E ACETATE OIL FEED GRADE E DLC 40%	Vitamin E plays an important role in protecting the fat molecules in cell membranes and the blood. Without Vitamin E, these polyunsaturated fat molecules could be damaged by the oxygen in aggressive molecules, called free radicals. Oxidized fat molecules can harm body tissues over long periods of time. Owing to its potent antioxidant properties in the body, Vitamin E has a stabilizing effect on Vitamin A, various hormones, and enzymes. It also plays an essential role in protecting cell membranes. Together with Vitamin A and Vitamin C it forms the trio of antioxidant vitamins now believed to have a preventive effect on degenerative diseases such as cardiovascular disease or cancer. In animals, Vitamin E is involved in reproduction, and has an immunomodulatory effect. Furthermore, meat and fish flesh from Vitamin E supplemented animals are protected against rancid deterioration.

Table A.2
Vitamin production by cartel members during the plea period, generally 1990 through 1998 [84]

	Vitamin A	Vitamin E	Vitamin C	Beta Carotene	Calpan (B5)	Riboflavin (B2)	Choline Chloride (B4)	Niacin (B3)	Biotin (H)	Thiamine (B1)	Vitamin B12	Pyridoxine (B6)	Carotenoids	Vitamin D3	Folic Acid (B9)
BASF	X	X	X	X	X	X	X			X			X	X	
Chinook							X								
Daiichi					X							X			
Degussa								X							
DuCoa							X								
Eisai		X													
Hoechst											X				
Kongo															X
Lonza								X	X						
Merck KGaA			X						X						
Nepera								X							
Reilly								X							
Rhone–Poulenc	X	X									X			X	
Roche	X	X	X	X	X	X			X	X		X	X	X	X
Solvay														X	
Sumika															X
Sumitomo									X						
Takeda			X			X				X		X			X
Tanabe									X						

[84] Based on plea agreements, statements of fact, and press releases. Rhone–Poulenc was named in Hoechst's Canadian Agreed Statement of Fact in the Vitamin B12 conspiracy.

Table A.3
Summary of guilty pleas and findings

Vitamin	Supplier	Source	Plea or finding start date	Plea or finding end date
Premix	Roche	U.S. plea	Jan 91	Dec 97
	BASF	U.S. plea	Jan 91	Dec 97
Vitamin E	Roche	U.S. plea	Jan 90	Feb 99
	BASF	U.S. plea	Jan 90	Feb 99
	Rhone–Poulenc	Canadian plea	Jan 90	Feb 99
	Eisai	U.S. plea	Jan 91	Feb 99
Vitamin A	Roche	U.S. plea	Jan 90	Feb 99
	BASF	U.S. plea	Jan 90	Feb 99
	Rhone–Poulenc	Canadian plea	Jan 90	Feb 99
Vitamin C	Roche	U.S. plea	Jan 91	"late Fall" 95
	BASF	U.S. plea	Jan 91	"late Fall" 95
	Takeda	U.S. plea	"early" 91	"Fall" 95
	Merck KGaA[1]	U.S. plea	"early" 91	"Fall" 95
Choline Chloride (B4)	BASF	Canadian plea	Nov 92	Jun 95
	Chinook	U.S. plea	Jan 88	Sep 98
	DuCoa	U.S. plea	Jan 88	Sep 98
Beta Carotene	Roche	U.S. plea	Jan 91	Dec 98
	BASF	U.S. plea	Jan 91	Dec 98
Calpan (B5)	Roche[2]	U.S. plea	Jan 91	Dec 98
	BASF[3]	U.S. plea	Jan 91	Dec 98
	Daiichi	U.S. plea	Jan 91	Feb 99
Niacin (B3)	Lonza	U.S. plea	Jan 92	Mar 98
	Degussa	U.S. plea	Jan 92	Mar 98
	Reilly	U.S. plea	Sep 94	Mar 98
	Nepera	U.S. plea	Jan 92	Jul 95
Riboflavin (B2)	Roche	U.S. plea	Jan 91	"Fall" 95
	BASF	U.S. plea	Jan 91	"Fall" 95
	Takeda	U.S. plea	"early" 91	"Fall" 95
Biotin (H)	Roche	EC finding	Oct 91	Apr 94
	BASF	EC finding	Oct 91	Apr 94
	Lonza	EC finding	Oct 91	Apr 94
	Merck KGaA	Canadian plea	Oct 91	Sep 95
	Sumitomo	EC finding	Oct 91	Apr 94
	Tanabe	EC finding	Oct 91	Apr 94
Thiamine (B1)	Roche	EC finding	Jan 91	Jun 94
	BASF	EC finding	Jan 91	Jun 94
	Takeda	EC finding	Jan 91	Jun 94
Vitamin B12	Hoechst	Canadian plea	Jan 90	Dec 97

[1]Canadian plea from May 1991 to November 1995: Indictment and Agreed Statement of Facts, Federal Court of Canada, Trial Division, Between Her Majesty the Queen and Merck KGaA, Court File No.: T-304-00 (March 24, 2000).
[2]EC finding from January 1991 to February 1999: "Commission imposes fines on vitamins cartels," Press Release, European Commission Internet web site (http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&doc=IP/01/1625|0|RAPID&lg=EN), November 21, 2001.
[3]EC finding from January 1991 to February 1999: "Commission imposes fines on vitamins cartels," Press Release, European Commission Internet web site (http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&doc=IP/01/1625|0|RAPID&lg=EN), November 21, 2001.

Table A.4
Fines levied on cartel members through 2003

Defendant	United States (in USD)	Europe (in USD)	Canada (in USD)	Total (in USD)
Roche	$ 500,000,000	$ 410,394,600	$ 32,496,107	$ 942,890,707
BASF	$ 225,000,000	$ 263,078,928	$ 12,863,042	$ 500,941,970
Rhone-Poulenc	Amnesty	$ 4,477,032	$ 9,478,031	$ 13,955,063
Takeda	$ 72,000,000	$ 32,920,398	$ 3,559,693	$ 108,480,091
Eisai	$ 40,000,000	$ 11,752,209	$ 1,354,004	$ 53,106,213
Daiichi	$ 25,000,000	$ 20,786,220	$ 1,692,506	$ 47,478,726
Merck	$ 14,000,000	$ 8,207,892	$ 684,556	$ 22,892,448
Degussa	$ 13,000,000		$ 1,584,284	$ 14,584,284

Table A.4 (*continued*)

Defendant	United States (in USD)	Europe (in USD)	Canada (in USD)	Total (in USD)
Lonza	$ 10,500,000		$ 697,085	$ 11,197,085
Nepera	$ 4,000,000		$ 152,091	$ 4,152,091
Reilly	$ 2,000,000		$ 22,180	$ 2,022,180
Bioproducts	Amnesty		$ 429,707	$ 429,707
Chinook	$ 5,000,000		$ 1,523,255	$ 6,523,255
Ducoa	$ 500,000			$ 500,000
Akzo Nobel			$ 716,178	$ 716,178
Solvay		$ 8,083,530		$ 8,083,530
Hoecsht		$ 250,406		$ 250,406
Totals	$ 911,000,000	$ 759,700,809	$ 67,503,127	$ 1,738,203,936

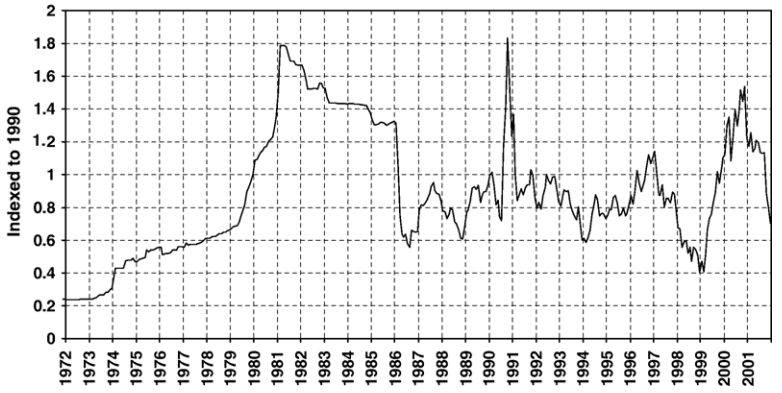

Fig. A.5. Oil prices—indexed to January 1990.

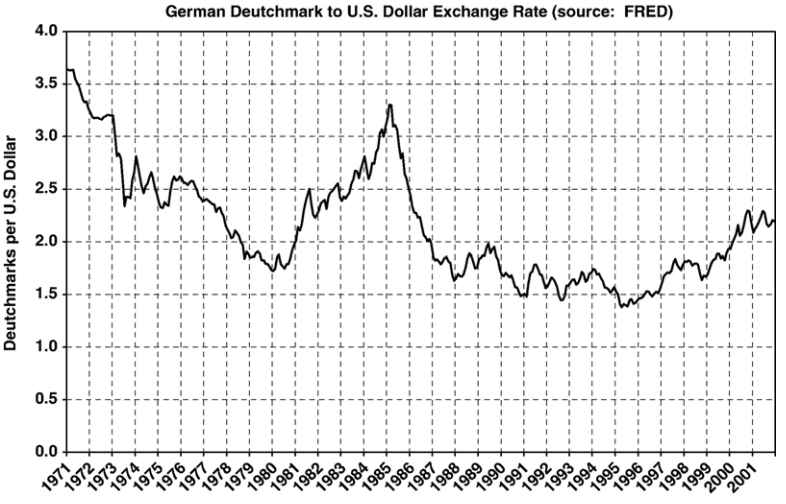

Fig. A.6. German Deutsche marks to one U.S. dollar.[85]

[85] Source: Federal Reserve Bank of St. Louis and Board of Governors of the Federal Reserve System, http://research.stlouisfed.org/fred2/series/EXGEUS/15.

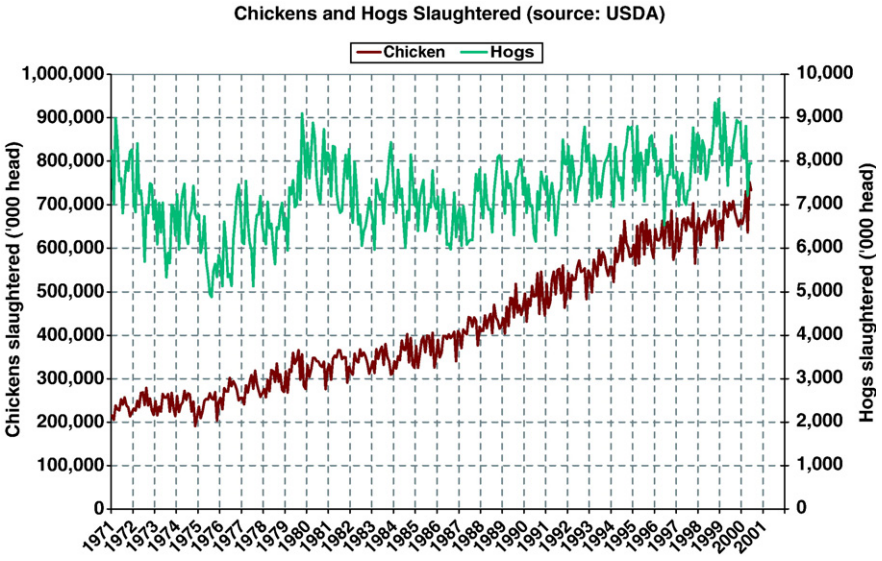

Fig. A.7. Chickens and hogs slaughtered.

With the possible exception of the Chinese, most sizable producers of vitamins were involved in explicit collusion throughout much of the 1990s.

Appendix B. Proofs

Proof of Proposition 1. If no seller announces a price in either period 1a or period 1b, then the sellers' payoffs in the unique equilibrium of the simultaneous announcement game in period 2 are $(\tilde{\pi}_1^S, \tilde{\pi}_2^S)$. Suppose there exists an equilibrium which seller 1 does not announce a price and seller 2 announces a price in period 1b. Then payoffs are $(\tilde{\pi}_1^F, \tilde{\pi}_2^L)$, and seller 2 can profitably deviate by not announcing, in which case its payoff is $\tilde{\pi}_2^S > \tilde{\pi}_2^L$, a contradiction.

In the subgame after no seller announces a price in period 1a, there is an equilibrium in which no seller announces a price, in which case payoffs are $(\tilde{\pi}_1^S, \tilde{\pi}_2^S)$, but there is also an equilibrium in which seller 1 announces a price and seller 2 does not, in which case payoffs are $(\tilde{\pi}_1^L, \tilde{\pi}_2^F)$. There is no equilibrium in which both sellers announce a price in period 1b, because a seller can profitably deviate by waiting until period 2 and best responding to the other seller's announced price. Using the argument above, there is also no equilibrium in which seller 2 announces a price and seller 1 does not. Thus, equilibrium payoffs in the subgame after no seller announces a price in period 1a are either $(\tilde{\pi}_1^S, \tilde{\pi}_2^S)$ or $(\tilde{\pi}_1^L, \tilde{\pi}_2^F)$.

Suppose there exists an equilibrium in which seller 2 announces a price in period 1a and seller 1 does not announce a price in period 1a. Then seller 2's payoff is $\tilde{\pi}_2^L$. By not announcing in period 1a, the argument above implies that seller 2's payoff in the continuation game is either $\tilde{\pi}_2^S$ or $\tilde{\pi}_2^F$. In either case, the deviation is profitable, a contradiction. Thus, there exists no equilibrium in which seller 2 announces its price before seller 1.

Finally, suppose there is a SPE in which sellers simultaneously announce. Then, in the period in which the sellers announce, the sellers use mixed strategies, giving payoffs $(\tilde{\pi}_1^S, \tilde{\pi}_2^S)$. Either seller can profitably deviate by not announcing and then in the next period choosing a best reply to the other seller's observed price, a contradiction. □

Proof of Proposition 4. Note that in the status quo, the smaller seller sells to capacity, so $k_2 = \tilde{s}_2 d(\tilde{p}_0)$. The larger seller's status-quo payoff is $\tilde{p}_0(d(\tilde{p}_0) - k_2)$. The status-quo price $\tilde{p}_0$ uniquely solves $\max_p p(d(p) - k_2)$.

The only possible use of pre-announcements to raise prices is if one or both sellers use the strategy of pre-announcing a higher price and then, if the other seller does not also pre-announce the same higher price, retracting the price increase. Suppose both sellers pre-announce a price p greater than $\tilde{p}_0$. If no seller retracts its pre-announcement, the smaller seller's quantity is $\min\{k_2, \tilde{s}_1 d(p)\}$ if $\theta = R$ or $\tilde{s}_2 d(p)$ if $\theta = A$. If the smaller seller retracts its price increase in period 3, and then in period 4 announces a price that slightly undercuts the larger seller's price, its payoff is $p \min\{k_2, d(p)\}$. We refer to this as the smaller seller's deviation payoff.

Case 1: $k_2 \geq d(p)$. The smaller seller's deviation payoff is $pd(p)$, and its payoff if it does not deviate is $p\tilde{s}_1 d(p)$ or $p\tilde{s}_2 d(p)$, depending on θ. Thus, the smaller seller retracts its pre-announcement in any equilibrium of the

continuation game. Since the smaller seller sells quantity $d(p)$, the larger seller sells zero and has zero payoff.

Case 2: $k_2 < d(p)$. The smaller seller's deviation payoff is pk_2. If $\theta = A$, the smaller seller's payoff if it does not deviate is $p\tilde{s}_2 d(p)$, and if $\theta = R$ it is $p \min\{k_2, \tilde{s}_1 d(p)\}$. Thus, the deviation is profitable if $\theta = A$ or if $\theta = R$ and $k_2 > \tilde{s}_1 d(p)$. In these cases, the smaller seller retracts its pre-announcement in any equilibrium of the continuation game and sells to capacity. If $\theta = R$ and $k_2 \leq \tilde{s}_1 d(p)$, then the smaller seller is indifferent between retracting its pre-announcement and not, but regardless of whether it retracts its pre-announcement, it sells to capacity. Since in all cases, the smaller seller sells to capacity, the larger seller's payoff is less than in the status quo (the status-quo price $\tilde{p}_0$ is chosen to maximize the larger firm's payoff conditional on the smaller seller's selling to capacity). □

Appendix C. Additional logit estimates

Table C.1
Logit estimates for periods before and after the start of explicit collusion

	Period 1: 1/1972–12/1976	Period 2: 1/1977–12/1981	Period 3: 1/1985 to start of plea period price increase	Period 4: Start of plea period price increase to 12/1994
delay	0.0929	−0.1844	0.6297*	0.4195*
	0.38	−1.69	3.06	3.05
$delay^2$	0.0004	0.0033	−0.0443*	−0.0228*
	0.06	1.22	−2.77	−2.81
markdum10	2.1617	0.6077	1.6361*	0.6393
	1.72	0.75	4.12	1.34
oildum10	−1.4900	0.8891	0.8081*	−0.5524
	−1.40	1.71	2.15	−1.70
demanddum10	2.8046	−1.0659	0.8159	−0.1479
	1.59	−1.33	1.03	−0.34
quarterly dummy (Feb, May, Aug, Nov)	−1.0041	−1.8324*	−0.3529	2.1156*
	−0.83	−2.36	−0.76	3.94
quarterly dummy (Mar, Jun, Sep, Dec)	−0.2148	0.2329	0.7804*	1.9840*
	−0.82	0.54	2.09	3.58
constant	−3.8739*	−1.6434*	−4.5981*	−4.9938*
	−2.81	−3.38	−7.17	−6.69
N obs	166	408	515	540
Wald Chi^2	19.40	20.82	56.74	26.17
Wald Chi^2 Prob	0.0070	0.0040	0.0000	0.0005
Pseudo R^2	0.1900	0.0937	0.2122	0.1147

Note: We estimate a logit model for the log odds ratio for the probability of a new price announcement in a given month. The *z*-statistics (ratio of the estimated coefficient to the robust standard error) are reported under the coefficients. Coefficients that are significant at the 5% level are indicated with an asterisk. The pseudo R^2 is calculated as $1 - ln(L)/ln(L_0)$, where L is the likelihood and L_0 is the likelihood when only a constant is included on the right-hand side.

Appendix D. Data source details

Table D.1
Vitamin A Acetate 650 Feed Grade

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	7Aug72	4Aug72	$ 8.38	Feedstuffs
1	Pfizer	14Aug72	7Aug72	$ 8.38	Feedstuffs
2	Roche	1Apr74	1Apr74	$ 11.35	Feedstuffs
3	Roche	15Sep75	15Sep75	$ 11.46	Feedstuffs
4	Roche	22Dec75	22Dec75	$ 12.68	Feedstuffs
5	Roche	5Jul76	5Jul76	$ 14.00	Feedstuffs
6	Roche	3Jan77	29Dec76	$ 15.43	Feedstuffs
7	Roche	10Nov80	3Nov80	$ 26.68	Feedstuffs
8	BASF	1Jun81	1Jun81	$ 26.68	Feedstuffs
9	Roche	14Jan85	1Feb85	$ 18.74	Feedstuffs

(continued on next page)

Table D.1 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
9	BASF	18Feb85	15Feb85	$ 18.74	Feedstuffs
10	BASF	21Oct85	15Nov85	$ 21.50	Feedstuffs
10	Roche	11Nov85	2Dec85	$ 21.50	Feedstuffs
10	Rhone Poulenc	25Nov85	2Dec85	$ 21.49	Feedstuffs
11	Roche	14Apr86	1May86	$ 23.92	Feedstuffs
11	BASF	28Apr86	9May86	$ 23.92	Feedstuffs
11	Danochemo	5May86	16May86	$ 23.92	Feedstuffs
12	Roche	4Aug86	4Aug86	$ 26.01	Feedstuffs
12	Danochemo	18Aug86	1Sep86	$ 26.01	Feedstuffs
12	BASF	25Aug86	18Aug86	$ 26.01	Feedstuffs
13	BASF	5Jan87	5Jan87	$ 27.78	Feedstuffs
13	Danochemo	19Jan87	2Feb87	$ 27.78	Feedstuffs
14	BASF	29Jun87	13Jul87	$ 30.20	Feedstuffs
14	Roche	6Jul87	6Jul87	$ 30.20	Feedstuffs
14	Danochemo	20Jul87	20Jul87	$ 30.20	Feedstuffs
14	Rhone Poulenc	20Jul87	15Jul87	$ 30.20	Feedstuffs
15	Roche	14Dec87	14Dec87	$ 32.41	Feedstuffs
15	BASF	21Dec87	21Dec87	$ 32.41	Feedstuffs
15	Danochemo	28Dec87	1Jan88	$ 32.41	Chemical Marketing Reporter
15	Rhone Poulenc	4Jan88	1Jan88	$ 32.41	Feedstuffs
16	BASF	27Jun88	15Jul88	$ 34.06	Feedstuffs
16	Roche	4Jul88	15Jul88	$ 34.06	Feedstuffs
16	Rhone Poulenc	11Jul88	15Jul88	$ 34.06	Feedstuffs
16	Danochemo	18Jul88	15Jul88	$ 34.06	Feedstuffs
17	Roche	13Nov89	13Nov89	$ 28.00	Feedstuffs
17	BASF	27Nov89	27Nov89	$ 28.00	Feedstuffs
17	Rhone Poulenc	11Dec89	1Dec89	$ 28.00	Feedstuffs
18	BASF	21May90	1Jun90	$ 30.20	Feedstuffs
18	Roche	4Jun90	4Jun90	$ 30.20	Feedstuffs
18	Rhone Poulenc	11Jun90	1Jun90	$ 30.20	Feedstuffs
19	Rhone Poulenc	17Sep90	1Oct90	$ 32.63	Feedstuffs
19	Roche	24Sep90	24Sep90	$ 32.63	Feedstuffs
19	BASF	1Oct90	1Oct90	$ 32.63	Feedstuffs
20	BASF	14Jan91	14Jan91	$ 34.83	Feedstuffs
20	Roche	21Jan91	21Jan91	$ 34.83	Feedstuffs
20	Rhone Poulenc	28Jan91	14Jan91	$ 34.83	Feedstuffs
21	Roche	11Mar91	1Apr91	$ 38.36	Feedstuffs
21	BASF	18Mar91	1Apr91	$ 38.36	Feedstuffs
21	Rhone Poulenc	18Mar91	11Mar91	$ 38.36	Feedstuffs
22	BASF	17Feb92	17Feb92	$ 40.57	Feedstuffs
22	Rhone Poulenc	24Feb92	24Feb92	$ 40.55	Feedstuffs
22	Roche	2Mar92	2Mar92	$ 40.57	Feedstuffs
23	Danochemo	9Mar92	9Mar92	$ 40.35	Chemical Marketing Reporter
24	BASF	10Aug92	10Aug92	$ 42.99	Feedstuffs
24	Rhone Poulenc	24Aug92	17Aug92	$ 42.99	Feedstuffs
24	Roche	24Aug92	1Sep92	$ 42.99	Feedstuffs
24	Danochemo	7Sep92	1Sep92	$ 42.99	Feedstuffs
25	Roche	15Feb93	1Mar93	$ 44.09	Feedstuffs
25	BASF	15Mar93	15Mar93	$ 44.10	Feedstuffs
26	Roche	6Feb95	1Apr95	$ 45.42	Feedstuffs
26	Rhone Poulenc	27Feb95	1Apr95	$ 45.40	Feedstuffs
26	BASF	6Mar95	15Mar95	$ 45.40	Feedstuffs
27	Rhone Poulenc	24Apr95	24Apr95	$ 48.70	Feedstuffs
27	Roche	8May95	8May95	$ 48.70	Feedstuffs
28	BASF	1May95	25Apr95	$ 48.75	Feedstuffs
29	Roche	26Jun00	1Jul00	$ 25.00	Feedstuffs

Table D.2
Calpan (B5) Feed Grade

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Thompson–Hayward	29Nov76	29Nov76	$ 10.80	Feedstuffs
2	Thompson–Hayward	23Oct78	1Nov78	$ 13.12	Feedstuffs
3	Thompson Hayward	10Mar80	10Mar80	$ 15.10	Feedstuffs
4	Thompson Hayward	1Dec80	1Jan81	$ 16.56	Feedstuffs
5	BASF	30May83	1Jun83	$ 11.60	Feedstuffs
6	Daiichi	10Feb86	1Mar86	$ 9.75	Feedstuffs
6	BASF	17Feb86	1Mar86	$ 9.75	Feedstuffs
6	Roche	17Feb86	7Mar86	$ 9.75	Feedstuffs
7	BASF	28Apr86	9May86	$ 10.80	Feedstuffs
7	Roche	19May86	1Jun86	$ 10.80	Feedstuffs
8	Roche	18Aug86	1Sep86	$ 11.90	Feedstuffs
8	BASF	25Aug86	18Aug86	$ 11.90	Feedstuffs
9	Daiichi	2Feb87	1Mar87	$ 13.00	Feedstuffs
9	BASF	23Feb87	9Mar87	$ 13.00	Feedstuffs
10	Daiichi	8Jun87	1Jul87	$ 15.00	Feedstuffs
10	BASF	29Jun87	13Jul87	$ 15.00	Feedstuffs
10	Roche	29Jun87	1Jul87	$ 15.00	Feedstuffs
11	Roche	14Dec87	14Dec87	$ 16.00	Feedstuffs
11	BASF	21Dec87	21Dec87	$ 16.00	Feedstuffs
12	Daiichi	8Jan90	8Jan90	$ 14.70	Feedstuffs
12	Roche	22Jan90	22Jan90	$ 14.70	Feedstuffs
12	BASF	5Mar90	5Mar90	$ 14.70	Feedstuffs
13	Roche	10Sep90	7Sep90	$ 15.75	Feedstuffs
13	BASF	1Oct90	1Oct90	$ 15.75	Feedstuffs
13	Daiichi	1Oct90	1Oct90	$ 15.75	Feedstuffs
14	Roche	11Mar91	1Apr91	$ 17.25	Feedstuffs
14	BASF	18Mar91	1Apr91	$ 17.25	Feedstuffs
14	Daiichi	18Mar91	1Apr91	$ 17.25	Feedstuffs
15	BASF	18Nov91	18Nov91	$ 18.40	Feedstuffs
15	Roche	25Nov91	25Nov91	$ 18.40	Feedstuffs
15	Daiichi	2Dec91	2Dec91	$ 18.40	Feedstuffs
16	Daiichi	24Feb92	1Apr92	$ 20.00	Feedstuffs
16	Roche	2Mar92	2Mar92	$ 20.00	Feedstuffs
17	BASF	10Aug92	10Aug92	$ 22.50	Feedstuffs
18	Roche	24Aug92	1Sep92	$ 21.60	Feedstuffs
18	Daiichi	26Oct92	1Dec92	$ 21.60	Feedstuffs
19	Roche	15Feb93	1Mar93	$ 23.00	Feedstuffs
20	BASF	15Mar93	15Mar93	$ 23.50	Feedstuffs
21	Daiichi	19Apr93	1May93	$ 22.70	Feedstuffs
22	Daiichi	7Feb94	1Mar94	$ 23.00	Feedstuffs
23	BASF	21Feb94	21Feb94	$ 24.00	Feedstuffs
23	Roche	7Mar94	1Mar94	$ 24.00	Feedstuffs
23	Daiichi	16May94	1Jul94	$ 24.00	Feedstuffs
24	Roche	6Feb95	1Apr95	$ 24.50	Feedstuffs
24	Daiichi	27Feb95	1Apr95	$ 24.50	Feedstuffs
24	BASF	6Mar95	15Mar95	$ 24.50	Feedstuffs
25	BASF	1May95	25Apr95	$ 26.50	Feedstuffs
25	Roche	8May95	8May95	$ 26.50	Feedstuffs
25	Daiichi	29May95	22May95	$ 26.50	Feedstuffs

Table D.3
Vitamin E Acetate 50% SD Feed Grade

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	9Jan78	3Jan78	$ 12.25	Feedstuffs
2	Roche	14Nov83	18Nov83	$ 10.85	Feedstuffs
3	Roche	24Jun85	3Jul85	$ 8.60	Feedstuffs

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Table D.3 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
3	Rhone Poulenc	12Aug85	12Aug85	$ 8.60	Feedstuffs
4	Roche	2Dec85	1Jan86	$ 9.45	Feedstuffs
4	BASF	9Dec85	1Jan86	$ 9.45	Feedstuffs
4	Rhone Poulenc	16Dec85	1Jan86	$ 9.45	Feedstuffs
5	BASF	31Mar86	15Apr86	$ 10.70	Feedstuffs
5	Roche	14Apr86	1May86	$ 10.70	Feedstuffs
6	Roche	30Jun86	1Jul86	$ 11.80	Feedstuffs
6	BASF	7Jul86	18Jul86	$ 11.80	Feedstuffs
7	BASF	5Jan87	5Jan87	$ 13.30	Feedstuffs
8	BASF	29Jun87	13Jul87	$ 14.40	Feedstuffs
8	Roche	6Jul87	6Jul87	$ 14.40	Feedstuffs
8	Rhone Poulenc	20Jul87	15Jul87	$ 14.40	Feedstuffs
9	Roche	14Dec87	14Dec87	$ 15.50	Feedstuffs
9	BASF	21Dec87	21Dec87	$ 15.50	Feedstuffs
9	Rhone Poulenc	4Jan88	1Jan88	$ 15.50	Feedstuffs
10	Roche	19Feb90	19Feb90	$ 12.10	Feedstuffs
10	BASF	5Mar90	5Mar90	$ 12.10	Feedstuffs
10	Rhone Poulenc	12Mar90	15Mar90	$ 12.10	Feedstuffs
11	Rhone Poulenc	17Sep90	1Oct90	$ 13.70	Feedstuffs
11	Roche	24Sep90	24Sep90	$ 13.70	Feedstuffs
12	BASF	14Jan91	14Jan91	$ 14.85	Feedstuffs
12	Roche	21Jan91	21Jan91	$ 14.85	Feedstuffs
12	Rhone Poulenc	28Jan91	14Jan91	$ 14.85	Feedstuffs
13	Roche	4Mar91	4Mar91	$ 16.50	Feedstuffs
13	Rhone Poulenc	11Mar91	1Mar91	$ 16.50	Feedstuffs
13	BASF	18Mar91	4Mar91	$ 16.50	Feedstuffs
14	BASF	18Nov91	1Dec91	$ 16.75	Feedstuffs
14	Rhone Poulenc	25Nov91	19Nov91	$ 16.75	Feedstuffs
14	Roche	25Nov91	25Nov91	$ 16.75	Feedstuffs
15	Roche	3Feb92	3Feb92	$ 18.15	Feedstuffs
15	BASF	17Feb92	4Feb92	$ 18.15	Feedstuffs
15	Rhone Poulenc	24Feb92	24Feb92	$ 18.15	Feedstuffs
16	BASF	10Aug92	10Aug92	$ 19.20	Feedstuffs
16	Rhone Poulenc	24Aug92	17Aug92	$ 19.20	Feedstuffs
17	BASF	21Feb94	21Feb94	$ 20.25	Feedstuffs
18	Rhone Poulenc	14Mar94	22Feb94	$ 20.20	Feedstuffs
19	Roche	6Feb95	1Apr95	$ 20.85	Feedstuffs
19	Rhone Poulenc	27Feb95	1Apr95	$ 20.85	Feedstuffs
19	BASF	6Mar95	15Mar95	$ 20.85	Feedstuffs
20	Rhone Poulenc	24Apr95	24Apr95	$ 22.30	Feedstuffs
20	BASF	1May95	25Apr95	$ 22.30	Feedstuffs
20	Roche	8May95	8May95	$ 22.30	Feedstuffs

Table D.4
Riboflavin (B2) 96% Feed Grade

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	BASF	18Feb85	11Mar85	$ 34.50	Feedstuffs
2	Roche	19May86	1Jun86	$ 38.50	Feedstuffs
2	Rhone Poulenc	26May86	1Jun86	$ 38.50	Feedstuffs
2	BASF	2Jun86	15Jun86	$ 38.50	Feedstuffs
3	Roche	15Sep86	1Oct86	$ 40.00	Feedstuffs
3	BASF	22Sep86	1Oct86	$ 40.00	Feedstuffs
4	Roche	16Feb87	2Mar87	$ 44.80	Feedstuffs
4	BASF	23Feb87	9Mar87	$ 44.80	Feedstuffs
5	Roche	29Jun87	1Jul87	$ 48.00	Feedstuffs
5	BASF	20Jul87	15Jul87	$ 48.00	Feedstuffs
5	Rhone Poulenc	20Jul87	15Jul87	$ 48.00	Feedstuffs
6	Roche	14Dec87	14Dec87	$ 51.00	Feedstuffs

Table D.4 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
6	BASF	21Dec87	21Dec87	$ 51.00	Feedstuffs
6	Rhone Poulenc	4Jan88	1Jan88	$ 51.00	Feedstuffs
7	BASF	27Nov89	2Jan90	$ 44.00	Feedstuffs
7	Roche	11Dec89	2Jan90	$ 44.00	Feedstuffs
7	Coors/Zeagen	22Jan90	15Jan90	$ 44.00	Feedstuffs
8	Roche	4Jun90	4Jun90	$ 47.50	Feedstuffs
8	BASF	18Jun90	8Jun90	$ 47.50	Feedstuffs
8	Coors/Zeagen	18Jun90	2Jul90	$ 47.50	Feedstuffs
9	Roche	10Sep90	7Sep90	$ 50.00	Feedstuffs
9	Coors/Zeagen	24Sep90	24Sep90	$ 50.00	Feedstuffs
9	BASF	1Oct90	1Oct90	$ 50.00	Feedstuffs
10	Roche	11Mar91	1Apr91	$ 55.00	Feedstuffs
10	BASF	18Mar91	1Apr91	$ 55.00	Feedstuffs
10	Coors/Zeagen	1Apr91	15Apr91	$ 55.00	Feedstuffs
11	Roche	3Feb92	3Feb92	$ 59.00	Feedstuffs
11	BASF	17Feb92	4Feb92	$ 59.00	Feedstuffs
11	Coors/Zeagen	17Feb92	17Feb92	$ 59.00	Feedstuffs
12	Roche	15Feb93	1Mar93	$ 64.00	Feedstuffs
12	Takeda	29Mar93	1Apr93	$ 64.00	Chemical Marketing Reporter
13	BASF	6Mar95	15Mar95	$ 64.00	Feedstuffs

Table D.5
Vitamin A Acetate 500 USP

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	13May74	1May74	$ 20.00	Chemical Marketing Reporter
2	Pfizer	4Oct76	1Oct76	$ 23.00	Chemical Marketing Reporter
2	Roche	6Dec76	1Dec76	$ 23.00	Chemical Marketing Reporter
3	Roche	6Jun77	1Jun77	$ 24.50	Chemical Marketing Reporter
4	Pfizer	5Sep77	1Sep77	$ 24.50	Chemical Marketing Reporter
5	Roche	10Apr78	3Apr78	$ 27.00	Chemical Marketing Reporter
6	Danochemo	21Apr86	28Apr86	$ 28.00	Chemical Marketing Reporter
7	Roche	5Jan87	5Jan87	$ 30.00	Chemical Marketing Reporter
7	Danochemo	19Jan87	2Feb87	$ 30.00	Chemical Marketing Reporter
8	Roche	22Jun87	1Jul87	$ 32.00	Chemical Marketing Reporter
8	Danochemo	17Aug87	1Aug87	$ 32.00	Chemical Marketing Reporter
9	Roche	14Dec87	1Jan88	$ 34.50	Chemical Marketing Reporter
9	Danochemo	28Dec87	1Jan88	$ 34.50	Chemical Marketing Reporter
10	Roche	27Jun88	1Jul88	$ 36.50	Chemical Marketing Reporter
10	Danochemo	4Jul88	1Jul88	$ 36.50	Chemical Marketing Reporter
11	Danochemo	20Aug90	1Oct90	$ 39.50	Chemical Marketing Reporter
11	Roche	27Aug90	1Sep90	$ 39.50	Chemical Marketing Reporter
12	Roche	10Jun91	1Jul91	$ 43.00	Chemical Marketing Reporter
12	Danochemo	1Jul91	1Jul91	$ 43.00	Chemical Marketing Reporter
13	Roche	24Feb92	1Apr92	$ 46.00	Chemical Marketing Reporter
14	Danochemo	9Mar92	1Apr92	$ 45.85	Chemical Marketing Reporter
15	Roche	24Aug92	1Oct92	$ 48.00	Chemical Marketing Reporter
16	Danochemo	7Sep92	1Oct92	$ 47.75	Chemical Marketing Reporter
17	Roche	1Mar93	1Apr93	$ 50.00	Chemical Marketing Reporter
17	BASF	22Mar93	1Apr93	$ 50.00	Chemical Marketing Reporter
18	BASF	21Feb94	1Apr94	$ 51.50	Chemical Marketing Reporter
18	Roche	28Feb94	1Apr94	$ 51.50	Chemical Marketing Reporter
19	Roche	13Feb95	1Apr95	$ 53.00	Chemical Marketing Reporter
19	BASF	13Mar95	13Mar95	$ 53.00	Chemical Marketing Reporter
20	Roche	8May95	1Jun95	$ 56.50	Chemical Marketing Reporter
20	BASF	29May95	29May95	$ 56.50	Chemical Marketing Reporter

Table D.6
Ascorbic Acid 100% USP

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	6Nov72	6Nov72	$ 3.85	Chemical Marketing Reporter
1	Pfizer	13Nov72	13Nov72	$ 3.85	Chemical Marketing Reporter
1	Merck	20Nov72	13Nov72	$ 3.85	Chemical Marketing Reporter
2	Merck	26Mar73	21Mar73	$ 4.25	Chemical Marketing Reporter
2	Pfizer	26Mar73	21Mar73	$ 4.25	Chemical Marketing Reporter
2	Roche	26Mar73	19Mar73	$ 4.25	Chemical Marketing Reporter
3	Roche	6May74	1May74	$ 5.50	Chemical Marketing Reporter
4	Pfizer	13May74	13May74	$ 7.50	Chemical Marketing Reporter
4	Merck	3Jun74	3Jun74	$ 7.50	Chemical Marketing Reporter
5	Roche	6Jun77	1Jun77	$ 8.40	Chemical Marketing Reporter
6	Merck	18Jul77	11Jul77	$ 8.45	Chemical Marketing Reporter
7	Roche	5Dec77	1Dec77	$ 8.80	Chemical Marketing Reporter
7	Pfizer	19Dec77	8Dec77	$ 8.80	Chemical Marketing Reporter
8	Takeda	19Dec77	19Dec77	$ 8.75	Chemical Marketing Reporter
9	Merck	20Mar78	15Mar78	$ 9.30	Chemical Marketing Reporter
10	Pfizer	10Apr78	10Apr78	$ 9.40	Chemical Marketing Reporter
10	Roche	10Apr78	3Apr78	$ 9.40	Chemical Marketing Reporter
11	Takeda	18Sep78	18Sep78	$ 10.00	Chemical Marketing Reporter
11	Merck	25Sep78	25Sep78	$ 10.00	Chemical Marketing Reporter
12	Pfizer	9Oct78	9Oct78	$ 9.90	Chemical Marketing Reporter
12	Roche	9Oct78	29Sep78	$ 9.90	Chemical Marketing Reporter
13	Roche	8Oct79	1Oct79	$ 10.40	Chemical Marketing Reporter
13	Pfizer	22Oct79	15Oct79	$ 10.40	Chemical Marketing Reporter
13	Merck	12Nov79	1Oct79	$ 10.40	Chemical Marketing Reporter
14	Merck	31Mar80	1Apr80	$ 11.00	Chemical Marketing Reporter
14	Roche	14Apr80	15Apr80	$ 11.00	Chemical Marketing Reporter
15	Pfizer	5May80	1May80	$ 11.05	Chemical Marketing Reporter
16	Takeda	5May80	1May80	$ 10.90	Chemical Marketing Reporter
17	Roche	13Apr81	1Apr81	$ 12.00	Chemical Marketing Reporter
18	Takeda	13Apr81	13Apr81	$ 11.90	Chemical Marketing Reporter
18	Merck	22Jun81	22Jun81	$ 11.90	Chemical Marketing Reporter
19	Roche	6Jan86	2Jan86	$ 9.50	Chemical Marketing Reporter
19	Takeda	10Feb86	10Feb86	$ 9.50	Chemical Marketing Reporter
20	Takeda	2Jun86	1Jun86	$ 10.00	Chemical Marketing Reporter
20	Roche	16Jun86	16Jun86	$ 10.00	Chemical Marketing Reporter
20	Merck	30Jun86	1Jul86	$ 10.00	Chemical Marketing Reporter
21	Merck	13Oct86	1Nov86	$ 11.00	Chemical Marketing Reporter
21	Roche	3Nov86	1Nov86	$ 11.00	Chemical Marketing Reporter
21	Takeda	3Nov86	1Nov86	$ 11.00	Chemical Marketing Reporter
21	BASF	10Nov86	10Nov86	$ 11.00	Chemical Marketing Reporter
22	Takeda	15Jun87	15Jun87	$ 12.00	Chemical Marketing Reporter
22	Roche	22Jun87	1Jul87	$ 12.00	Chemical Marketing Reporter
23	Roche	14Dec87	1Jan88	$ 12.75	Chemical Marketing Reporter
23	BASF	28Dec87	1Jan88	$ 12.75	Chemical Marketing Reporter
23	Takeda	28Dec87	1Jan88	$ 12.75	Chemical Marketing Reporter
23	Merck	4Jan88	1Jan88	$ 12.75	Chemical Marketing Reporter
23	Pfizer	18Jan88	15Jan88	$ 12.75	Chemical Marketing Reporter
24	Takeda	26Dec88	1Feb89	$ 13.25	Chemical Marketing Reporter
24	Roche	27Feb89	1Apr89	$ 13.25	Chemical Marketing Reporter
24	BASF	13Mar89	1Apr89	$ 13.25	Chemical Marketing Reporter
24	Pfizer	13Mar89	1Apr89	$ 13.25	Chemical Marketing Reporter
25	Merck	1May89	1May89	$ 13.25	Chemical Marketing Reporter
26	Roche	7Oct91	1Jan92	$ 14.75	Chemical Marketing Reporter
26	Takeda	4Nov91	1Jan92	$ 14.75	Chemical Marketing Reporter
26	BASF	18Nov91	1Jan92	$ 14.75	Chemical Marketing Reporter
26	Pfizer	9Dec91	1Jan92	$ 14.75	Chemical Marketing Reporter
27	Roche	25May92	1Jul92	$ 15.50	Chemical Marketing Reporter
27	Takeda	22Jun92	1Jul92	$ 15.50	Chemical Marketing Reporter

Table D.6 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
27	Pfizer	29Jun92	1Jul92	$ 15.50	Chemical Marketing Reporter
28	Roche	1Mar93	1Apr93	$ 16.75	Chemical Marketing Reporter
28	Takeda	29Mar93	1Apr93	$ 16.75	Chemical Marketing Reporter
28	BASF	26Apr93	1Jun93	$ 16.75	Chemical Marketing Reporter
29	Takeda	10Apr95	10Apr95	$ 17.75	Chemical Marketing Reporter

Table D.7
Beta Carotene FS 30%

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	19Dec83	1Jan84	$ 89.84	Chemical Marketing Reporter
2	Roche	5Jan87	5Jan87	$ 94.25	Chemical Marketing Reporter
2	BASF	2Feb87	2Feb87	$ 94.25	Chemical Marketing Reporter
3	BASF	11Apr88	11Apr88	$ 102.71	Chemical Marketing Reporter
3	Roche	9May88	9May88	$ 102.71	Chemical Marketing Reporter
4	Roche	27Feb89	1Apr89	$ 109.13	Chemical Marketing Reporter
4	BASF	13Mar89	1Apr89	$ 109.13	Chemical Marketing Reporter
5	Roche	30Apr90	1May90	$ 116.29	Chemical Marketing Reporter
6	Roche	11Mar91	1Apr91	$ 126.77	Chemical Marketing Reporter
6	BASF	1Apr91	1Apr91	$ 126.77	Chemical Marketing Reporter
7	Roche	24Feb92	1Apr92	$ 150.00	Chemical Marketing Reporter
7	BASF	16Mar92	1Apr92	$ 150.00	Chemical Marketing Reporter
8	Roche	24Aug92	1Oct92	$ 162.50	Chemical Marketing Reporter
8	BASF	14Sep92	1Dec92	$ 162.50	Chemical Marketing Reporter
9	Roche	1Mar93	1Apr93	$ 170.00	Chemical Marketing Reporter
9	BASF	15Mar93	1Apr93	$ 170.00	Chemical Marketing Reporter
10	BASF	6Dec93	1Jan94	$ 175.00	Chemical Marketing Reporter
10	Roche	31Jan94	1Apr94	$ 175.00	Chemical Marketing Reporter
11	Roche	13Feb95	1Apr95	$ 182.50	Chemical Marketing Reporter
11	BASF	13Mar95	13Mar95	$ 182.50	Chemical Marketing Reporter
12	BASF	29May95	29May95	$ 192.00	Chemical Marketing Reporter
12	Roche	26Jun95	1Aug95	$ 192.00	Chemical Marketing Reporter

Table D.8
Calpan (B5) USP

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Syntex	28Feb77	28Feb77	$ 13.75	Feedstuffs
2	Roche	9Oct78	29Sep78	$ 14.50	Chemical Marketing Reporter
2	Thompson Hayward	9Oct78	9Oct78	$ 14.50	Chemical Marketing Reporter
3	Syntex	24Dec79	1Jan80	$ 15.75	Chemical Marketing Reporter
4	Syntex	31Mar80	1Apr80	$ 17.00	Chemical Marketing Reporter
5	Thompson Hayward	30Mar81	1Apr81	$ 18.00	Chemical Marketing Reporter
6	Daiichi	10Feb86	10Mar86	$ 10.50	Chemical Marketing Reporter
6	BASF	24Mar86	24Mar86	$ 10.50	Chemical Marketing Reporter
6	Takeda	24Mar86	24Mar86	$ 10.50	Chemical Marketing Reporter
7	BASF	26May86	26May86	$ 11.50	Chemical Marketing Reporter
7	Roche	9Jun86	9Jun86	$ 11.50	Chemical Marketing Reporter
8	BASF	1Sep86	2Sep86	$ 12.50	Chemical Marketing Reporter
8	Roche	3Nov86	1Nov86	$ 12.50	Chemical Marketing Reporter
8	Daiichi	10Nov86	10Nov86	$ 12.50	Chemical Marketing Reporter
9	Daiichi	2Feb87	1Mar87	$ 13.50	Chemical Marketing Reporter
9	Roche	2Mar87	2Mar87	$ 13.50	Chemical Marketing Reporter
9	BASF	23Mar87	23Mar87	$ 13.50	Chemical Marketing Reporter
10	Roche	20Jul87	1Aug87	$ 15.00	Chemical Marketing Reporter
10	Daiichi	3Aug87	3Aug87	$ 15.00	Chemical Marketing Reporter

(continued on next page)

Table D.8 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
10	BASF	10Aug87	1Aug87	$ 15.00	Chemical Marketing Reporter
11	Roche	14Dec87	1Jan88	$ 16.50	Chemical Marketing Reporter
11	BASF	28Dec87	1Jan88	$ 16.50	Chemical Marketing Reporter
11	Takeda	28Dec87	1Jan88	$ 16.50	Chemical Marketing Reporter
11	Daiichi	25Jan88	25Jan88	$ 16.50	Chemical Marketing Reporter
12	Daiichi	12Mar90	12Mar90	$ 15.20	Chemical Marketing Reporter
12	Roche	26Mar90	1Apr90	$ 15.20	Chemical Marketing Reporter
12	BASF	9Apr90	9Apr90	$ 15.20	Chemical Marketing Reporter
13	Roche	11Mar91	1Apr91	$ 17.75	Chemical Marketing Reporter
13	Daiichi	25Mar91	1Apr91	$ 17.75	Chemical Marketing Reporter
13	BASF	1Apr91	1Apr91	$ 17.75	Chemical Marketing Reporter
14	BASF	18Nov91	1Jan92	$ 19.00	Chemical Marketing Reporter
14	Roche	2Dec91	1Jan92	$ 19.00	Chemical Marketing Reporter
14	Daiichi	9Dec91	1Jan92	$ 19.00	Chemical Marketing Reporter
15	Daiichi	24Feb92	1Apr92	$ 21.00	Chemical Marketing Reporter
15	Roche	2Mar92	1Apr92	$ 21.00	Chemical Marketing Reporter
15	BASF	16Mar92	1Apr92	$ 21.00	Chemical Marketing Reporter
16	BASF	3Aug92	3Aug92	$ 23.50	Chemical Marketing Reporter
17	Roche	24Aug92	1Oct92	$ 22.50	Chemical Marketing Reporter
17	Daiichi	26Oct92	1Dec93	$ 22.50	Chemical Marketing Reporter
18	Roche	1Mar93	1Apr93	$ 23.00	Chemical Marketing Reporter
18	Daiichi	19Apr93	1May93	$ 23.00	Chemical Marketing Reporter
19	BASF	21Feb94	1Apr94	$ 24.00	Chemical Marketing Reporter
19	Roche	28Feb94	1Apr94	$ 24.00	Chemical Marketing Reporter
19	Daiichi	16May94	1Jul94	$ 24.00	Chemical Marketing Reporter
20	Roche	13Feb95	1Apr95	$ 24.50	Chemical Marketing Reporter
20	Daiichi	6Mar95	1Apr95	$ 24.50	Chemical Marketing Reporter
20	BASF	13Mar95	13Mar95	$ 24.50	Chemical Marketing Reporter
21	Roche	8May95	1Jun95	$ 26.50	Chemical Marketing Reporter
21	Daiichi	29May95	29May95	$ 26.50	Chemical Marketing Reporter
21	BASF	29May95	29May95	$ 26.50	Chemical Marketing Reporter

Table D.9
Vitamin E Acetate Oil USP

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	General Mills	4Oct76	1Oct76	$ 21.00	Chemical Marketing Reporter
2	Roche	4Oct76	1Oct76	$ 22.50	Chemical Marketing Reporter
3	Roche	10Apr78	3Apr78	$ 24.50	Chemical Marketing Reporter
4	Roche	21Jan80	2Jan80	$ 27.40	Chemical Marketing Reporter
5	Roche	3Jun85	1Jul85	$ 16.00	Chemical Marketing Reporter
6	BASF	28Oct85	15Nov85	$ 18.50	Chemical Marketing Reporter
6	Roche	18Nov85	15Nov85	$ 18.50	Chemical Marketing Reporter
7	BASF	16Jun86	1Jul86	$ 20.50	Chemical Marketing Reporter
7	Roche	4Aug86	4Aug86	$ 20.50	Chemical Marketing Reporter
8	Eisai	20Oct86	1Nov86	$ 20.50	Chemical Marketing Reporter
9	Roche	20Apr87	1May87	$ 22.50	Chemical Marketing Reporter
9	BASF	4May87	1May87	$ 22.50	Chemical Marketing Reporter
10	Roche	14Dec87	1Jan88	$ 24.25	Chemical Marketing Reporter
10	BASF	28Dec87	1Jan88	$ 24.25	Chemical Marketing Reporter
11	BASF	20Jun88	15Jul88	$ 22.50	Chemical Marketing Reporter
12	Roche	26Feb90	1Mar90	$ 21.00	Chemical Marketing Reporter
12	BASF	5Mar90	5Mar90	$ 21.00	Chemical Marketing Reporter
13	Roche	24Sep90	1Oct90	$ 23.00	Chemical Marketing Reporter
13	BASF	1Oct90	1Oct90	$ 23.00	Chemical Marketing Reporter
14	BASF	14Jan91	14Jan91	$ 24.15	Chemical Marketing Reporter
14	Roche	21Jan91	21Jan91	$ 24.15	Chemical Marketing Reporter
15	Roche	4Mar91	4Mar91	$ 28.50	Chemical Marketing Reporter

Table D.9 (*continued*)

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
15	BASF	11Mar91	11Mar91	$ 28.50	Chemical Marketing Reporter
16	Eisai	25Mar91	25Mar91	$ 28.00	Chemical Marketing Reporter
17	Roche	24Feb92	1Apr92	$ 30.50	Chemical Marketing Reporter
17	BASF	16Mar92	1Apr92	$ 30.50	Chemical Marketing Reporter
18	BASF	3Aug92	3Aug92	$ 33.00	Chemical Marketing Reporter
18	Roche	24Aug92	1Oct92	$ 33.00	Chemical Marketing Reporter
19	Roche	1Mar93	1Apr93	$ 34.50	Chemical Marketing Reporter
19	BASF	15Mar93	1Apr93	$ 34.50	Chemical Marketing Reporter
20	BASF	21Feb94	1Apr94	$ 36.00	Chemical Marketing Reporter
20	Roche	28Feb94	1Apr94	$ 36.00	Chemical Marketing Reporter
21	Roche	13Feb95	1Apr95	$ 37.00	Chemical Marketing Reporter
21	BASF	13Mar95	13Mar95	$ 37.00	Chemical Marketing Reporter
22	Roche	8May95	1Jun95	$ 39.50	Chemical Marketing Reporter
22	BASF	29May95	29May95	$ 39.50	Chemical Marketing Reporter

Table D.10
Riboflavin (B2) USP

Announcement Group	Firm	Announcement Date	Effective Date	Price/KG ($)	Source
1	Roche	6May74	1May74	$ 36.00	Chemical Marketing Reporter
2	Roche	6Jun77	1Jun77	$ 46.00	Chemical Marketing Reporter
2	EM Labs	18Jul77	11Jul77	$ 46.00	Chemical Marketing Reporter
3	Roche	5Dec77	1Dec77	$ 48.00	Chemical Marketing Reporter
3	Takeda	19Dec77	19Dec77	$ 48.00	Chemical Marketing Reporter
4	Pfizer	10Apr78	3Apr78	$ 50.00	Chemical Marketing Reporter
4	Roche	10Apr78	3Apr78	$ 50.00	Chemical Marketing Reporter
5	Takeda	18Sep78	18Sep78	$ 54.00	Chemical Marketing Reporter
5	EM Labs	25Sep78	25Sep78	$ 54.00	Chemical Marketing Reporter
6	Pfizer	9Oct78	9Oct78	$ 53.00	Chemical Marketing Reporter
6	Roche	9Oct78	29Sep78	$ 53.00	Chemical Marketing Reporter
7	Roche	8Oct79	1Oct79	$ 56.00	Chemical Marketing Reporter
7	EM Labs	12Nov79	1Oct79	$ 56.00	Chemical Marketing Reporter
8	Roche	16Jun86	16Jun86	$ 46.00	Chemical Marketing Reporter
9	Roche	3Nov86	1Nov86	$ 48.50	Chemical Marketing Reporter
9	Takeda	3Nov86	1Nov86	$ 48.50	Chemical Marketing Reporter
9	BASF	10Nov86	1Nov86	$ 48.50	Chemical Marketing Reporter
10	Roche	20Apr87	1May87	$ 50.00	Chemical Marketing Reporter
10	Takeda	27Apr87	1May87	$ 50.00	Chemical Marketing Reporter
10	EM Industries	4May87	1May87	$ 50.00	Chemical Marketing Reporter
10	BASF	11May87	11May87	$ 50.00	Chemical Marketing Reporter
11	Roche	14Dec87	1Jan88	$ 54.00	Chemical Marketing Reporter
11	BASF	28Dec87	1Jan88	$ 54.00	Chemical Marketing Reporter
11	Takeda	28Dec87	1Jan88	$ 54.00	Chemical Marketing Reporter
11	EM Industries	4Jan88	1Jan88	$ 54.00	Chemical Marketing Reporter
12	Roche	24Sep90	1Oct90	$ 56.00	Chemical Marketing Reporter
12	BASF	1Oct90	1Oct90	$ 56.00	Chemical Marketing Reporter
13	Roche	11Mar91	1Apr91	$ 62.00	Chemical Marketing Reporter
13	BASF	1Apr91	1Apr91	$ 62.00	Chemical Marketing Reporter
14	Takeda	4Nov91	1Oct91	$ 62.00	Chemical Marketing Reporter
15	BASF	18Nov91	1Jan92	$ 66.00	Chemical Marketing Reporter
15	Roche	2Dec91	1Jan92	$ 66.00	Chemical Marketing Reporter
16	BASF	18May92	1Jul92	$ 69.00	Chemical Marketing Reporter
16	Roche	25May92	1Jul92	$ 69.00	Chemical Marketing Reporter
16	Takeda	22Jun92	1Jul92	$ 69.00	Chemical Marketing Reporter
17	Roche	1Mar93	1Apr93	$ 71.00	Chemical Marketing Reporter
17	BASF	15Mar93	1Apr93	$ 71.00	Chemical Marketing Reporter
17	Takeda	29Mar93	1Apr93	$ 71.00	Chemical Marketing Reporter

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