14

Price Fixing and Repeated Games

In February 2007, the European Union Competition Directorate imposed their largest-ever fines on companies found guilty of colluding to fix prices. Five elevator manufacturers were fined a total of €992 million (approximately $1.4 billion) for operating a cartel that controlled prices in Germany, Belgium, Luxembourg and the Netherlands. ThuysenKrupp received the heaviest fine, of more than €479 million since it was judged to be a "repeat offender" by the Commission. Otis was fined €225 million, Schindler €144 million, Kone €142 million, and Mitsubishi's Dutch subsidiary €1.8 million.[1]

The elevator case came just one month after another case involving gas insulated switchgear projects in which the Commission imposed fines totally €750 million on 11 companies for their parts in a price-fixing cartel. In this case, the largest fine of €396.5 million was imposed on Siemens, Germany. This case is particularly interesting because it was broken open largely as a result of the Commission's leniency policy. Under that policy, the first firm in a conspiracy to confess and "fink" on its co-conspirators gets a much reduced penalty. In fact, the finking firm in the switch-gear case, ABB Switzerland, was granted full immunity and paid no penalties in return for its confession and provision of information to the authorities. That reflects a considerable savings from the €215 million it would otherwise have had to pay as a repeat offender.

Action to curb the activities of cartels has been equally active in the United States.[2] The Department of Justice has recently imposed a total of more than $732 million on companies operating a cartel to control the pricing of dynamic random access memory (DRAM). This includes a fine of $300 million imposed in 2005 on Samsung, the second-largest fine ever imposed on a single firm. The largest fine remains the $500 million penalty imposed in 1999 on Swiss pharmaceutical company Hoffman-LaRoche for its role in running a decade-long conspiracy to restrict competition and fix vitamin prices worldwide.

Table 14.1 shows the firms and products involved in the more than two dozen price-fixing cases this century in which the fine charged exceeded $10 million. Figure 14.1 shows the sharp increase in fines that has accompanied antitrust enforcement in recent years.

1 Details of the European Union cases can be obtained at http://ec.europa.eu/comm/competition/antitrust/cases/index.html.

2 Details can be found at http://www.usdoj.gov/atr.

Table 14.1 Violations yielding a corporate fine of $10 million or more since 2000

Firm	*Year*	*Product*	*Fine (U.S. dollars, millions)*
Samsung Electronics Company, Ltd. And Samsung Semiconductor, Inc.	2006	DRAM	300
Hynix Semiconductor Inc.	2005	DRAM	185
Infineon Technologies AG	2004	DRAM	160
Mitsubishi Corp.	2001	Graphite Electrodes	134
Elpida Memory, Inc.	2006	DRAM	84
Dupont Dow Elastomers L.L.C.	2005	Chloroprene Rubber	84
Bayer AG	2004	Rubber Chemicals	66
Bilhar International Establishment	2002	Construction	54
Daicel Chemical Industries, Ltd.	2000	Sorbates	53
ABB Middle East & Africa Participations AG	2001	Construction	53
Crompton	2004	Rubber Chemicals	50
Sotheby's Holdings Inc.	2001	Fine Arts Auctions	45
Odfjell Seachem AS	2003	Parcel Tanker Shipping	43
Bayer Corporation	2004	Polyester Polyols	33
Philipp Holzmann AG	2000	Construction	30
Irving Materials, Inc.	2005	Ready Mix Concrete	29
Arteva Specialties	2003	Polyester Staple	29
Jo Tankers, B.V.	2004	Parcel Tanker Shipping	20
Merck KgaA	2000	Vitamins	14
Degussa-Huls AG	2000	Vitamins	13
Akzo Nobel Chemicals, BV	2001	Monochloracetic Acid	12
Hoechst Aktiengesellschaft	2003	Monochloracetic Acid	12
Ueno Fine Chemicals Industry, Ltd.	2001	Sorbates	11
Zeon Chemicals L.P.	2005	NBR	11
De Beers Centenary AG	2004	Industrial Diamonds	10
Morganite, Inc.	2003	Carbon Products	10

Source: U.S. Department of Justice, Antitrust Division, www.usdoj.gov/atr

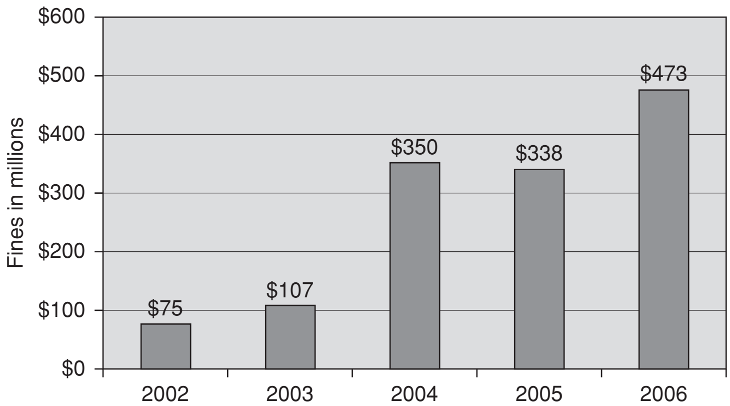

Figure 14.1 Criminal antitrust fines for fiscal years 2002–6
Source: U.S. Department of Justice, Antitrust Division, www.usdoj.gov/atr

As both Table 14.1 and Figure 14.1 illustrate, the foregoing examples are just a few of the many cartels that have been successfully prosecuted over the past few years. Together, these cases and the supporting data illustrate two important points. First, it is clear that cartels happen. There appears to be no shortage of firms that enter into collusive agreements to fix prices and avoid competition. This is so despite the many difficulties conspiring firms must overcome in order to implement such collusion. Perhaps more tellingly, firms appear to enter price-fixing agreements frequently despite the fact that both the antitrust laws of the United States and the legal framework established in Europe's Treaty of Rome, as well as the laws of most other nations, are explicit in making such collusion illegal.[3]

The second fact revealed by Table 14.1 and Figure 14.1 is that government agencies can and sometimes do catch the culprits. The recent historical experience in both Europe and the United States suggests that the ability of legal authorities to uncover and prosecute cartel conspirators successfully has been greatly enhanced by the use of leniency programs that offer either a reduced penalty or amnesty to the first cartel member that cooperates with officials. Of course, we do not know how many cartels remain undetected. The record of the last several years, however, must surely be regarded as encouraging.

The obvious reason why firms choose to break the law and enter into collusive price fixing arrangements, risking fines and even imprisonment, is profit. Competing firms recognize that by limiting competition they may be able to replicate the monopoly outcome and maximize their joint profits. However, the cooperative monopoly outcome is rarely if ever the Nash equilibrium outcome of strategic interaction between two or more firms. This means that achieving a cooperative, monopoly outcome requires overcoming the fact of life that cooperating is not a best response.

To be specific, in any collusive price-fixing agreement each member must resist the strong temptation to cheat on the agreement. Why is that temptation so strong? To begin with, when all other firms are charging a high price, any one firm cannot help but realize that it can reap enormous profits by charging a somewhat lower price that will attract lots of customers from the high-priced conspirators. Further, each firm will not only recognize this opportunity for itself but also understand that other cartel members face the same temptation. The fear that others will cheat also acts as a powerful incentive for a cartel member to deviate from the agreement before others do.

If the agreement to collude was a legally enforceable contract, cheating would not be much of a problem. However, in the language of U.S. antitrust law, price-fixing agreements are *per se* illegal. Essentially, there is no acceptable defense. The firms cannot argue that there is some "reasonable explanation" for the collusion or that price fixing is necessary to prevent ruinous competition that would lead to the industry being monopolized.[4] Hence, cartel members cannot call on the courts to enforce their agreements. This then raises the question of how firms effectively enforce and execute any collusive agreement that they make. Given the temptation that members have to cheat, some sort of enforcement is likely to be necessary for a collusive agreement to hold. The fact that a formal contract is not enforceable does, however, have one small plus for the conspirators. It means that no such written contract is ever created, and this makes life more difficult for the antitrust authorities. In the absence of such a document the existence of the crime can be hard to prove.

[3] If anything, the language of European Union law is even stronger in that it also treats "concerted practices" based upon a "concordance of wills" as *per se* illegal. In practice, however, the U.S. and European policy is nearly identical.

[4] This argument was tried but rejected in The *Trans-Missouri* case, 166, U.S. 290 (1897).

In this chapter and the next, we explore the balance between the various forces just described. Specifically, we investigate the incentives to form cartels, the temptations of cartel members to cheat on the price-fixing agreement, the enforcement mechanisms that cartels may use to prevent such cheating, and the ability of the antitrust authorities to deter cartel formation. For the most part, we focus on the underlying theory in this chapter and reserve for the next one a discussion of the collusion in practice.

14.1 THE CARTEL'S DILEMMA

The motivation to form a price-fixing cartel is obvious. The profit of a monopolist is the maximum profit the industry can earn. By acting as "one," the cartel members hope to achieve that monopoly profit as a group. Since that is the maximum industry profit it follows that there is, in principle, some way to share that profit so that all firms (though not consumers) are better off with the cartel than without it. However, the challenge the firms face in forming a cartel to increase prices *and sustain the increased prices* is equally clear. At the price set by the cartel, each firm's price–cost margin is relatively large, with price significantly in excess of marginal cost. This gives each individual firm a strong profit incentive to sell a little more output—to cheat on the agreement. Yet if every firm acts on this incentive and chisels on the agreement by selling a little more, the extra output on the market will not be a little but a lot. Market price will fall and the price-fixing agreement will break down.

Another factor that complicates price-fixing is the fear of discovery and legal prosecution. Most antitrust law makes collusive behavior illegal. In the United States, the courts have consistently refused to consider any mitigating circumstances that might justify collusion.

Reality Checkpoint

School for Scandal—Bid Rigging by Suppliers to New York City Schools

On June 1, 2000 almost all of the companies that supply food to New York City's schoolchildren were charged in a bid-rigging scheme that overcharged the city at least $21 million for frozen goods and fresh produce. Twelve of the officials and six of the companies involved immediately pled guilty. Some of these defendants were also charged with rigging the bids to supply schools in Newark as well. The defendants reportedly designated which of the companies would be the low bidder on several contracts with the New York Board of Education. The system of schools supervised by the Board services a student population of nearly 1.1 million and serves about 640,000 lunches and 150,000 breakfasts every day. The school board buys more food than any other single U.S. customer except the Defense Department. The conspirators allegedly agreed on prices to bid for supplying such standard items as French fries, meat, and fish sticks. One firm would be designated as the low bidder and all others would either refrain from bidding or submit intentionally high or complementary bids on the contracts. The cartel also allegedly paid potential suppliers not to bid competitively, including a payment of $100,000 to one produce company.

Source: A. Smith, "N.Y. Schools' Food Suppliers Accused of Bid-rigging," *Washington Post*, June 2, 2000, p. A8.

That is, there is no defense[5] and the firms that are party to the agreement face potentially heavy legal penalties.[6] As a result, any cartel-like agreements that the firms make must necessarily be kept secret—covert as opposed to overt—so as to reduce the likelihood of being caught. Yet the more secretive the agreement is—the more hidden the firms' actions are—the more opportunities arise for firms to cheat on the agreement and sell more output without being caught. This of course undermines the cartel still further.

Some international cartels such as OPEC are, on the other hand, overt. Here, the members come from different countries at least some of which have governments that support the cartel. The diamond cartel De Beers is another example in this regard. While such cartels violate the antitrust laws of the U.S. and other nations, prosecution of these international cartels is difficult because it requires that one country reach into the sovereign affairs of others.[7] Nevertheless, even overt international cartels have to worry about members cheating or breaking the agreement because there is no supra-national authority to enforce the agreement. Here too, the cartel is faced with the problem of how to implement its agreements.

Stories of cheating and agreement breakdown have accompanied virtually all of the major cartels such as the electrical conspiracy of the 1950s, OPEC, and the NASDAQ pricing agreement (see the inset). In order to understand how cartels might work, we can begin by understanding why they might not and identify the sources of conflict between cartel members.[8]

A good place to begin is with the simple Cournot duopoly model that we introduced in section 9.3 in Chapter 9. There we had two identical firms, each producing the same good and facing the same costs of production. Suppose, for example, that the inverse market demand curve for this duopoly market is described by the linear function, $P = 150 - Q$, where Q is total industry output and $Q = q_1 + q_2$ is the sum of outputs produced by firms 1 and 2, respectively. Assume also that the marginal cost of production is the same for each firm and constant at \$30 per unit.

When the firms act noncooperatively, each firm maximizes profit by choosing an output on its best response function. Given this demand function, we know that firm 1's best response function is $q_1^* = 60 - q_2/2$, and firm 2's is $q_2^* = 60 - q_1/2$. From these best response functions it is easy to confirm that in a Cournot–Nash equilibrium each firm chooses to produce an output level $q_1^* = q_2^* = 40$, which leads to an aggregate market output of $Q^C = 80$ and to a market-clearing price $P^C = \$70$. In this Cournot–Nash equilibrium each firm earns profit of $\pi_i^C = \$1{,}600$.

How do matters change if instead the firms cooperate with each other and form a cartel? Ideally, the cartel will act like a pure monopolist, in which case it agrees on a joint output of $Q^M = 60$, with each firm producing a share $q_i^M = 30$. As a result, the market-clearing price rises to $P^M = \$90$, giving the aggregate cartel or industry profit of $\pi^M = \$3{,}600$. Dividing this equally between the two firms, gives each a profit of $\pi_i^M = \$1{,}800$ which is greater than the profit earned in the Cournot–Nash noncooperative outcome.

5 See Chapter 1 for a brief history of earlier antitrust cases and a discussion of how price-fixing agreements have been viewed by the courts as *per se* violations of Section 1 of the Sherman Act and hence have been uniformly condemned.

6 Posner (1970) found that cartels were more active when the regulatory authorities were relatively lax in their enforcement of antitrust legislation.

7 It is worth noting, however, that the United Sates has become increasingly active in pursuing international cartels.

8 A terrific guide to the intuition underlying the cartel problem and, indeed, all of game theory is Schelling (1960).

Cooperation obviously pays but the cartel solution has one problem: the temptation that both firms have to cheat on their agreement. We know this for one very simple reason. The cooperative output levels of $q_1^M = q_2^M = 30$ do not constitute a pair of best responses. That is, 30 is not firm 1's best response to firm 2's production of 30, and similarly, 30 is not firm 2's best response to firm 1's production of 30. If firm 1 believes that firm 2 is going to stick to their agreement, then firm 1's best course of action is to produce an output q_1^d where the superscript d denotes defecting from the agreement and q_1^d is a best response to $q_2^M = 30$. From firm 1's best response function we can see that $q_1^d = 60 - q_2^M/2 = 45$. With firm 1 producing 45 and firm 2 producing 30, total output will then be $Q^d = 75$, which leads to a price of $P^d = \$75$. As a result, the profit to firm 1 is now $\pi_1 = \$2{,}025$, noticeably higher than the \$1,800 it earned by acting cooperatively. Thus, firm 1 has a real incentive to break the agreement. Of course, when it does, it drives down the profit at firm 2 to $\pi_2 = \$1{,}350$. But firm 1 did not go into business to make firm 2 rich. Firm 1's management cares only about firm 1's profit and if firm 2 is really going to produce 30 units, then firm 1 maximizes its profit by producing 45 units.

The non-cooperative Cournot–Nash solution $q_1^* = q_2^* = 40$ is, of course, a pair of best responses. And for this example, the Cournot outcome is the only Nash equilibrium. This is made clear by the payoff matrix of Table 14.2(a). The unfortunate fact of life for the would-be colluding firms is that the collusive outcome $q_1 = q_2 = 30$ cannot be supported by any equilibrium strategies available to these firms. Each firm has a stronger profit incentive to defect or to cheat upon the cooperative agreement than to stick with it.[9]

What if the two firms compete in prices rather than in quantities? Now we have the Bertrand duopoly case. We know from our discussion of the Bertrand model in section 10.1, Chapter 10, that when the two firms act noncooperatively competition for customers drives price down to marginal cost. In our example, the Bertrand outcome has both firms setting a price of \$30. Aggregate demand is $Q^B = 120$, which will be shared equally by the two firms. Both firms break even with profit to each firm of $\pi_i^B = 0$.

If the firms enter into a price-fixing agreement they will earn maximum industry profit by agreeing to set the monopoly price. So each firm sets a price of \$90, aggregate demand is 60 units, again shared equally between the two firms, and each firm earns a profit of $\pi_i^M = \$1{,}800$. The temptation to cheat is, if anything, even stronger in the Bertrand case. Suppose that firm 1 believes that firm 2 will set a price of \$90. Then firm 1 knows that it can win the entire market by just undercutting firm 2, perhaps by setting a price of \$89.50. Aggregate demand at this price is 60.5 units. Firm 1's profit is approximately \$3,600 while firm 2 sells nothing and so makes nothing.

Of course, firm 2 can make the same calculations, as a result of which we obtain the payoff matrix of Table 14.2(b). As in the Cournot case, the only Nash equilibrium to this game has both firms cheating on their agreement and charging a price that is arbitrarily close to marginal cost and making a profit that is arbitrarily close to zero rather than the significantly greater returns they both would make if they could only enforce their agreement.

The games we have just described and illustrated in Table 14.2 are examples of many games in which players share possibilities for mutual gain that cannot be realized because

[9] Throughout this and succeeding chapters we restrict our analysis to pure strategies. The reader should be aware, however, that the analysis can be extended, with some qualifications, to include mixed strategies: see, for example, Harsanyi (1973).

Table 14.2a Payoffs (U.S. dollars, thousands) to cooperation (M) and defection (D) in the Cournot duopoly game

		Strategy for firm 2	
		Cooperate (M)	Defect (D)
Strategy for firm 1	Cooperate (M)	(\$1.8, \$1.8)	(\$1.35, \$2.025)
	Defect (D)	(\$2.025, \$1.35)	(\$1.6, \$1.6)

Table 14.2b Payoffs (U.S. dollars, thousands) to cooperation (M) and defection (D) in the Bertrand duopoly game

		Strategy for firm 2	
		Cooperate (M)	Defect (D)
Strategy for firm 1	Cooperate (M)	(\$1.8, \$1.8)	(\$0, \$3.6)
	Defect (D)	(\$3.6, \$0)	(\$$\varepsilon$, \$$\varepsilon$)

of a conflict of interest. Such games are often referred to as "prisoners' dilemma" games because one of the earliest illustrations of this case involved dealings between a prosecutor and two suspects. (See Practice Problem 14.1, below)

Each firm has a mutual interest in cooperating and achieving the monopoly outcome. However, there is also a conflict. If one firm cooperates and sticks to the agreement, then the other firm can do much better for itself in terms of profit by deviating from the cooperative agreement and producing more output in the Cournot case, or lowering price in the Bertrand case. In deciding whether to cooperate or not each firm must take this conflict of interest into account. In so doing, each firm could reason as follows: "If I cooperate and the other firm cooperates, then we share the monopoly profit. However, if the other firm does not cooperate while I do, then I lose a lot of profit. If, on the other hand, I don't cooperate and the other firm does, then I make a lot of money; and if the other firm does not cooperate, then it's as if we were playing noncooperatively anyway. No matter what the other firm does, I am better off not cooperating."

If both firms follow the logic just described, we will not observe cooperation. Such is the prisoners' dilemma. Together, both firms are worse off not cooperating than if they cooperate. Individually, however, each firm gains by not cooperating. Unless there is some way to overcome this conflict, it would appear that antitrust policy need not be terribly worried about cartels because logically they should not happen. But cartels do happen. The evidence is compelling that collusive agreements are not uncommon and firms do pursue cooperative strategies. The prisoner's dilemma argument cannot be the full story. There must be some way that firms can create incentives that will sustain cartel agreements among them.

14.1 **Practice Problem**

Jacoby and Myers are two attorneys suspected of mail fraud in the small principality of Zenda. In an effort to obtain a confession, Sergeant First Brigadier Morse has had the two suspects brought in and subjected to separate questioning. Each is given the following options: (1) Confess (and implicate the other), or (2) Do not confess. Morse indicates to each suspect that if only one suspect confesses that one will be released in return for providing evidence against the other and spends no time in jail. The one not confessing in this case will "have the book thrown at her" and do ten years. If both confess, Morse indicates that he will be a bit more lenient and each will spend six years behind bars. When asked what will happen if neither confesses, Morse responds that he will find some small charge that he knows will stick, so that, in this case, each will do at least one year.

Using Confess and Do not confess as the possible actions of either Jacoby or Myers, derive the payoff matrix and Nash equilibrium for the game between these prisoners of Zenda.

Since the 1970s, economists have come to understand that there is a clear way around the logic of the prisoner's dilemma. The way around requires that firms look at their strategic interaction from a somewhat different perspective than that described in the static Cournot and Bertrand models. Specifically, the different perspective is not found in a single period framework in which the colluding firms interact only once but rather a dynamic one in which the strategic interaction is repeated over time. This of course is a quite reasonable change. The firms considering the formation of a cartel are very likely to have been competing with each other for some time—otherwise how did they meet in the first place? More importantly, they are likely to believe that their market interactions will continue or repeat into the future.

Recognizing this "shadow of the future" fundamentally alters the incentives that firms have to defect on collusive agreements. When market interaction is repeated over and over again it is possible for the firms that are party to a collusive agreement to reward "good" behavior by sticking with the agreement and to punish "bad" behavior by guaranteeing a breakdown in the cartel. In order to work out such a strategy we need to analyze what is called a repeated game. Repeated games are dynamic games in which a simultaneous market interaction is repeated in each stage of the dynamic game. By moving from one period to many, we are changing the rules of the game. The appropriate strategies therefore also change. How and why the firms' strategic choices change in the dynamic setting of repeated games is the subject matter of the next section.

14.2 REPEATED GAMES

Let's return to the game of Table 14.2(a). Collusion between the two firms to produce the monopoly output is unsustainable in that it is not a Nash equilibrium to the single period game. Now suppose that firm 2 for example thinks forward a bit, knowing that its interactions with firm 1 are going to occur several, perhaps many, times. Then firm 2's calculations may go very differently. Firm 2 might calculate as follows: "If I cheat on the cartel my profits go up to \$2,025 and I gain a one-off increase in profits of \$225. But then the cartel falls apart, and we revert to the non-cooperative, Cournot, equilibrium with profits to me of \$1,600 per period, so that I earn \$200 less per period than if I had not cheated in the first place. Is it worth my while to cheat?"

The foregoing reasoning suggests that if firm 2's horizon is sufficiently long and if firm 2 does not discount the future too heavily, then contrary to our earlier analysis, firm 2 may decide not to leave the cartel. The short, one-period gain of $225 may be offset by the loss of $200 every period thereafter. Whether or not this is in fact the case—whether or not firm 2's calculations are fully reasonable—remains to be seen. Nevertheless, one can see that moving from a static one-period game to a repeated game may alter a firm's thinking in a manner that dramatically raises the profitability of cooperative, cartel behavior.

The reason that repetition makes successful collusion more likely is that when the market interaction among firms extends over a number of periods, there is the real possibility that cartel members are able to retaliate against defectors. Because potential defectors will rationally anticipate such retaliation, punishment can act as a deterrent—stopping the non-cooperative behavior before it starts.

The formal description of a strategy for a repeated game is quite complicated because current and future actions are now conditional on past actions. That is, a firm's action today depends critically on what has happened in previous plays of the game. To get some idea of how rapidly the complexity grows, consider the simple Cournot game in Table 14.2(a). Suppose that this game, which we will call the stage game, is played 3 times in succession. At the end of the first round there are 4 possible outcomes, that is, 4 possible histories. At the end of the second round, we have 16 possible game histories—four second-round outcomes for each of the first-round results. By the third round, 64 game histories are possible—and this assumes that there are only 2 players with 2 possible actions to take in each round. Since, formally speaking, a strategy must define how a player acts at each round of play depending on the precise history of the game to that point, the complexity introduced by considering repeated games is formidable.

There are, fortunately, a few mental shortcuts available to us. The critical concept in this regard is the familiar one of Nash equilibrium. We know that resolving the outcome of any game requires identifying the game's Nash equilibrium (or equilibria). The same holds true in repeated games. It is possible to identify the Nash equilibrium or equilibria for a repeated game relatively quickly if one keeps a few key principles clearly in mind. We can best illustrate these by working through our Cournot example.

Recall that when this game is played once its only equilibrium is that both firms defect. This is referred to as the "one-shot" equilibrium. Our interest is to see what happens when the firms interact with each other over and over again. We shall show that the key factor is whether the interaction is repeated over a finite (though perhaps large) number of periods or whether it goes on forever indefinitely. In other words, we can separate repeated games into two classes: (1) those in which the number of repetitions is finite *and known to the potentially colluding firms*, and (2) those in which the number of repetitions is infinite.

14.2.1 Finitely Repeated Games

When is it reasonable to assume that the number of times that the firms interact is finite *and known to both firms*? At least three situations come to mind. First, it may be that the firms exploit an exhaustible and non-renewable resource such as oil or natural gas. Secondly, the firms might operate in a market with proprietary knowledge protected by patents. All patents are awarded for a finite period—in the United States, the duration is 20 years dated from the filing of the application. Once the patent expires a market protected from entry suddenly becomes competitive. For example, as the patents on serotonin-based antidepressants, Prozac, Zoloft, and Paxil, expire the manufacturers of these drugs can expect a major increase in the number of competitors in this market, ending the market interaction of the original three firms that had previously prevailed. Finally, while we conventionally equate the players in the game with firms, the truth is that it is ultimately individuals who make the output or price decisions. The same management teams can be expected to be around for only a finite number of years. When there is a major change in management at one or more of the firms the game is likely to end. Often this end can be foreseen.

It turns out that what happens in a one-shot or stage game gives us a very good clue to what is likely to happen in a repeated game when the number of repetitions is finite. After all, a one-period game is just one that is very finite. Consider a simple extension of our Cournot game from one-period to two and determine what the equilibrium will be in this limited but nonetheless repeated setting.[10] When we do this we find that the two-period repeated game will have the same non-cooperative outcome in each round as the one-shot game. To see why, consider the following alternative strategy for firm 1:

First play: Cooperate.
Second play: Cooperate if firm 2 cooperated in the first play, otherwise Defect.

The idea behind this strategy is clear enough. Start off on a friendly footing. If this results in cooperation in the first round, then in the second round firm 1 promises to continue to cooperate. However, should firm 2 fail to reciprocate firm 1's initial cooperation in the first round then in the second round firm 1 will "take the gloves off" and fight back.

The problem with this strategy is that it suffers from the same basic credibility problem that afflicted many of the predatory threats that we discussed in the preceding chapters. To see why, suppose firm 2 chooses to cooperate in the first round. Now think of firm 2's position at the start of its second and last interaction with firm 1. The history of play to that point is one in which both firms adopted cooperative behavior in the first round. Further, firm 2 has a promise from firm 1 that, because firm 2 cooperated in the first round, firm 1 will continue to do so in the second. However, this promise is worthless. When firm 2 considers the payoff matrix for the last round, the firm cannot fail to note that—regardless of firm 1's promise—the dominant strategy for firm 1 in the last round is not to cooperate. This breaks firm 1's promise, but there is nothing firm 2 can subsequently do to punish firm 1 for breaking its promise. There is no third round in which to implement such punishment. Firm 2 should rationally anticipate that firm 1will adopt the noncooperative behavior in the last round.

Firm 2 has just discovered that any strategy for firm 1 that involves playing the cooperative strategy in the final round is not credible, i.e., it is not subgame perfect. The last round of the game is a subgame of the complete game, and a strategy that calls for firm 1 to cooperate in this last period cannot be part of a Nash equilibrium in that period. No matter what has transpired in the first round, firm 1 can be counted upon to adopt noncooperative behavior in the final period of play. Of course, the same is true viewed when from firm 1's perspective. Firm 2's strategy in the last round is likewise not to cooperate. In short, both firms realize that the only rational outcome in the second round is the noncooperative equilibrium in which each earns a profit of $1,600.

[10] Even though the game lasts for two market periods we will keep things simple and assume that profits in the second period are not discounted. In other words we will assume that the discount factor $R = 1$ or, equivalently, the interest rate $r = 0\%$. See the discussion of discounting in Chapter 2.

The fact that we have identified the equilibrium in the final round may seem like only a small part of the solution that we were originally seeking—especially if the game has 10 or 100 rounds instead of just 2. However, as you may recall from the Chain Store Paradox in section 11.4, Chapter 11, the outcome for the terminal round can lead directly to a solution of the entire game. Consider again our two-period repeated game. In the first round firm 1 will see that firm 2's first-round strategy is not to cooperate. The only hope that firm 1 has of dissuading firm 2 from such noncooperative action in the first round is to promise cooperation in the future if firm 2 cooperates today. Yet such a promise is not credible. No matter how passionately firm 1 promises to cooperate tomorrow in return for cooperation today, firm 2 will recognize that when tomorrow actually comes, firm 1 will not cooperate. It follows that the only hope firm 1 had of dissuading firm 2 from noncooperative action in the first round is gone.

Again symmetry implies the same reasoning holds true for any hope firm 2 had of inducing cooperation from firm 1. Hence, we have identified the subgame perfect equilibrium for the entire game. Both firms adopt strategies that call for noncooperative behavior in *both* period one and period two. In other words, running the game for two periods produces outcomes identical to that observed by playing it as a one-period game.

14.2

Practice Problem

Consider our first example but now assume that the interaction between the firms extends to three periods. What will be the outcome in the final period? What does this imply about the incentive to cooperate in period two? If both firms believe that there will be no cooperation in either period two or period three, will either cooperate in period one?

We have identified the subgame perfect equilibrium for our example when the game is played for two periods. However, as Practice Problem 14.2 illustrates, our reasoning also extends to a solution for the game whether it is played two, three, or any finite number of periods, T. In all such cases, no strategy that calls for cooperation in the final period is subgame perfect. Therefore, no such strategy can be part of the final equilibrium. In the last period, each firm always chooses not to cooperate regardless of the history of the game to that point. But this means that the same noncooperative behavior must also characterize the penultimate, or $T - 1$, period. The only possible gain that might induce either firm 1 or firm 2 to cooperate in period $T - 1$ is the promise of continued cooperation from its rival in the future. Since such a promise is not credible, both firms adopt noncooperative behavior in both period $T - 1$ and period T. In other words, any strategy that calls for cooperative behavior in either of the last two periods can also be ruled out as part of the final equilibrium. An immediate implication is that a three-period game must be one in which the players simply repeat the one-shot Nash equilibrium three times.

We can reiterate this logic for larger and larger values of T. The outcome will always be the same Nash equilibrium as in our first example no matter how many times it is played, so long as that number is finite and known. The one-shot Nash equilibrium is just repeated T times, with each firm taking noncooperative action in every period.

The foregoing result is by no means a special case. Rather, the foregoing analysis is an example of a general theorem first proved by Nobel Prize winner Reinhard Selten (1973).

Selten's theorem: If a game with a unique equilibrium is played finitely many times, its solution is that equilibrium played each and every time. Finitely repeated play of a unique Nash equilibrium is the Nash equilibrium of the repeated game.[11]

Introducing repetition into a game theoretic framework adds history as an element to the analysis. When players face each other over and over again, they can adopt strategies that base today's action on the behavior of their rivals in previous periods. This is what rewards and punishments are all about. What Selten's theorem demonstrates is that history, or rewards and punishments, really do not play a role in a finitely repeated game in which one-shot or stage game has a unique Nash equilibrium.

Nevertheless, we know that effective collusion does occur in the real world. So, there must be some way to escape the logic of Selten's theorem. In fact, the "solution" is suggested by the theorem itself. We have so far limited our analysis to finitely repeated games in which the firms understand exactly when their interaction together will end. If firms think that their interactions will be repeated over and over, indefinitely, it turns out that the outcome can be radically different.

14.2.2 Infinitely or Indefinitely Repeated Games

There are situations in which the assumption of finite repetition makes a great deal of sense. However, for many, and perhaps most, situations it does not. Firms may be regarded as having an infinite or, more precisely, an indefinite life. General Motors may not last forever but nobody inside or outside the giant automaker works on the assumption that there is some known date T periods from now at which GM will cease to exist. Our assumption that everyone knows the final period with certainty is probably far too strong. The more likely situation is that after any given period, the players see some positive probability that the game will continue one more round. So, while firms may understand that the game will not last forever, they cannot look ahead to any particular period as the last. Alternatively, as long as there is some chance of continuing on it makes sense to treat General Motors and other firms as if they will continue indefinitely

Why is this important? Recall the argument that we used to show that finite repetition will not lead to cooperation in a Cournot, or Bertrand game. Cooperation is not an equilibrium in the final period T, and so is not an equilibrium in $T - 1$, and so in $T - 2$ and so on. With infinite or indefinite repetition of the game this argument fails *because there is no known final period*. So long as the probability of continuing into another round of play is positive, there is, probabilistically speaking, reason to hope that the next round will be played cooperatively and so reason to cooperate in the present. Whether that motivation is strong enough to overcome the short-run gains of defection, or can be made so by means of some reward-and-punishment strategy will depend on certain key factors that we discuss below. We will see that once we permit the possibility that strategic interaction will continue indefinitely, the possibility of successful collusion becomes a good bit more real.

In developing the formal analysis of an infinitely repeated game we must first consider how a firm values a profit stream of infinite duration. The answer is simply that it will apply the discount factor R to the expected cash flow in any period. Suppose that a firm knows that its profits are going to be π in each play of the game. Suppose also that the firm knows that in each period there is a probability p that the market interaction will continue into the

[11] A formal proof can be found, for example, in Eichberger (1993).

next period. Then starting from an initial period 0, the probability of reaching period 1 is p, the probability of reaching period 2 is p^2, of reaching period 3 is p^3, . . . of reaching period t is p^t and so on. Accordingly, the profit stream that the firm actually expects to receive in period t is $p^t\pi$.

Now apply the firm's discount factor is R. The expected present value of this profit stream is given by:

$$V(\pi) = \pi + pR\pi + (pR)^2\pi + (pR)^3\pi + \ldots + (pR)^t\pi + \ldots \tag{14.1}$$

To evaluate $V(\pi)$ we use a simple trick. Rewrite equation (14.1) as:

$$V(\pi) = \pi + pR(\pi + pR\pi + (pR)^2\pi + (pR)^3\pi \ldots + (pR)^t\pi + \ldots) \tag{14.2}$$

Now note that the term in brackets is just $V(\pi)$ as given by (14.1), so (14.2) can be rewritten:

$$V(\pi) = \pi + pRV(\pi)$$

Solving this for $V(\pi)$ then gives:

$$V(\pi) = \frac{\pi}{1 - pR} = \frac{\pi}{1 - \rho} \tag{14.3}$$

where $\rho = pR$ can be thought of as a "probability-adjusted" discount factor. It is the product of the discount factor reflecting the interest rate and the belief the firm holds regarding the probability that the market will continue to operate from period to period.

At first sight, consideration of games that are infinite or indefinitely repeated, which are often referred to as supergames, may seem hopeless. Repetition allows history to figure in strategy making and with infinitely repeated play the number of possible histories also becomes infinite. Once again, however, we have a shortcut available to us. It turns out that the actual strategies on which firms rely to secure compliance with cartel policy can be made remarkably simple. The type of strategy that will work is called a *trigger strategy*. A player will play the cooperative action upon which the players have agreed as long as all the players have always stuck to the agreement. However if any player should deviate from the agreement then the player will revert to the Nash equilibrium forever.

To see how a trigger strategy might work, consider a simple duopoly example.[12] Suppose that the firms formulate a price-fixing agreement that gives them both profits of π^M. Each firm knows that if it deviates optimally from this agreement it will earn in that period of deviation a profit of π^D. Finally, the Nash equilibrium profit to each firm is π^N. Common sense and our Cournot and Bertrand examples of Table 14.2 tell us that $\pi^D > \pi^M > \pi^N$.

Now consider the following trigger strategy:

Period 0: Cooperate.
Period $t \geq 1$: Cooperate if both firms have cooperated in every previous period. Switch to the Nash equilibrium forever if either player has defected in any previous period.

It should be clear why strategies of this type are called trigger strategies. Firm 1's switch to the Nash equilibrium is triggered by a deviation from the agreement by firm 2. The promise

[12] Our analysis generalizes to an n-firm oligopoly as we note below.

or threat to make this move, that is, to punish firm 2, is credible precisely because it simply requires that firm 1 moves to the noncooperative Nash equilibrium.

To identify the conditions under which the adoption of this trigger strategy by both firms can work to achieve an equilibrium that is different from the one-shot noncooperative Nash equilibrium, consider again our duopoly example. Assume that at the beginning of the game both firms announce the trigger strategy just described. Now consider a possible deviation from the agreement by firm 2. We already understand the temptation to deviate. If firm 1 sticks by the cooperative agreement in any period then firm 2 can increase its profit in that period to π^D by defecting.

However, that gain lasts for only one period, given that firm 1 has adopted the trigger strategy. In the next period following firm 2's deviation, firm 1 retaliates by switching to the Nash equilibrium. Since firm 2's best response is to do the same, the result of its initial defection is that the one period of higher profit π^D is followed by an endless number of periods in which its profit is only π^N. This represents a real cost to firm 2 since, had it not broken the agreement, it could have enjoyed its share of the cartel profit, π^C indefinitely. In short, firm 1's adoption of the trigger strategy means that firm 2 realizes both a gain and a loss if it breaks the cartel agreement. The gain is an immediate, but only one-period rise in profit. The loss is a delayed, but permanent fall in profit in every period that the game continues thereafter.

The only way to compare the gain with the loss is in terms of present values. The present value of profits from sticking to the agreement is, using equation (14.3):

$$V^C = \pi^M + \rho\pi^M + \rho^2\pi^M + \ldots = \frac{\pi^M}{1-\rho} \tag{14.4}$$

Now consider the present value of the profits that firm 2 makes if it deviates. We can always number the period in which firm 2 deviates as period 0 (today). Its profit stream from deviation is then:

$$\begin{aligned} V^D &= \pi^D + \rho\pi^N + \rho^2\pi^N + \rho^2\pi^N + \ldots \\ &= \pi^D + \rho[\pi^N + \rho\pi^N + \rho^2\pi^N + \ldots] = \pi^D + \frac{\rho\pi^N}{1-\rho} \end{aligned} \tag{14.5}$$

Cheating on the cartel is not profitable, and so the cartel is *self-sustaining* provided that $V^C > V^D$, which requires that:

$$\frac{\pi^M}{1-\rho} > \pi^D + \frac{\rho\pi^N}{1-\rho} \tag{14.6}$$

Multiplying both sides by $(1 - \rho)$ and simplifying gives:

$$V^C > V^D \Rightarrow \pi^M > (1-\rho)\pi^D + \rho\pi^N \Rightarrow \rho(\pi^D - \pi^N) > \pi^D - \pi^M$$

In other words, the critical value of ρ above which defection on the cartel does not pay and so firms will voluntarily stick by the cartel agreement is:

$$\rho > \rho^* = \frac{\pi^D - \pi^M}{\pi^D - \pi^N} \tag{14.7}$$

Equation (14.7) has a simple underlying intuition. Cheating on the cartel yields an immediate, one period gain of $\pi^D - \pi^M$. However, starting the next period and continuing through every period thereafter, the punishment for cheating is a loss of profit of $\pi^M - \pi^N$. The present value of that loss starting next period is $(\pi^M - \pi^N)/(1 - \rho)$. Its present value as of today when the profit from cheating is realized is $\rho(\pi^M - \pi^N)/(1 - \rho)$. Cheating will be deterred if the gain is less than the cost when both are measured in present value terms, i.e., if $\pi^D - \pi^M < \rho(\pi^M - \pi^N)/(1 - \rho)$. It is easy to show that this condition is identical to that in equation (14.7). Because $\pi^D > \pi^M > \pi^N$ it follows that $\rho^* < 1$. Hence, *there is always a probability-adjusted discount factor above which a cartel is self-sustaining*.

Consider our two examples in Table 14.2. In the Cournot case we have $\pi^D = 2{,}025$, $\pi^M = 1{,}800$ and $\pi^N = 1{,}600$. Substituting into (14.7) the critical probability adjusted discount factor above which our Cournot duopolists can sustain their cartel is $\rho^*_C = 0.529$. In the Bertrand case $\pi^D = 3{,}600$, $\pi^M = 1{,}800$ and $\pi^N = 0$. The critical probability adjusted discount factor above which our Bertrand duopolists can sustain their cartel is $\rho^*_B = 0.5$. Practice Problem 14.3 below asks you to prove that these critical discount factors hold for *any* Cournot or Bertrand duopoly with linear demand and constant, equal marginal costs.

Suppose that both firms playing the Cournot game believe that their interaction will always be repeated with certainty, so that $p = 1$. Then the critical probability adjusted discount factor ρ^*_C corresponds to a pure discount factor of $R = 0.529$. That is, if $p = 1$, neither firm will deviate so long as the firm's discount rate r does not exceed 89 percent. Now suppose instead that both firms perceive only a 60 percent probability that their interaction lasts from one period to the next i.e. $p = 0.6$. Now the cartel agreement is self-sustaining only when the pure discount factor $R > 0.529/0.6 = 0.882$. That is, successful collusion now requires that the discount rate r does not exceed 14.4 percent, which is a more restrictive requirement. This example points to a general result. An indefinitely lived cartel is more sustainable the greater is the probability that the firms will continue to interact and the lower is the interest rate.

Practice Problem 14.3

Assume a duopoly and let demand be given by $P = A - bQ$. In addition, let both firms have the same marginal cost c. Show that:

a. If the firms compete in quantities, the probability adjusted discount factor must satisfy $\rho^*_C \geq 0.529$ for collusion to be sustained; and
b. If the firms compete in prices, the probability adjusted discount factor must satisfy $\rho^*_B \geq 0.5$ for collusion to be sustained.

14.2.3 Some Extensions

Our analysis easily extends to cases where the number of firms is more than two. All we need do is to identify the three firm-level profits $\pi^D > \pi^M > \pi^N$ for each firm and substitute these values into equation (14.7) to identify the critical probability-adjusted discount factor for each firm.

However, there are two objections to trigger strategies. First, these strategies are based on the assumption that cheating on the cartel agreement is detected quickly and that punishment is swift. What if, as seems likely, it takes time for cartel members to discover a firm that is cheating and additional time to retaliate?

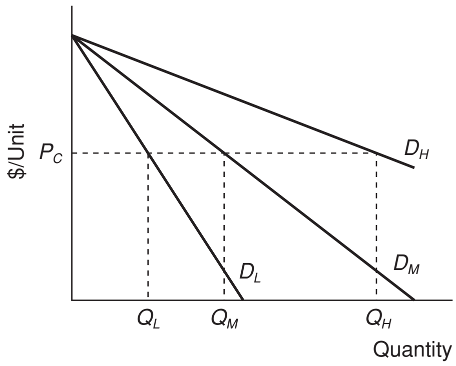

Figure 14.2 Cartel maintenance with uncertain demand
If demand is uncertain and varies between D_L and D_H with a mean of D_M, cartel members will not be able to tell whether a variation in their output is the result of normal variation in the market or cheating by other cartel members.

The fact that detection and punishment of cheaters takes time certainly makes sustaining the cartel more difficult. Delay allows the culprit to enjoy the gains for more periods and this raises the incentive to engage in cheating behavior. Nevertheless, this does not necessarily make collusion impossible. Trigger strategies can still work even if detection of cheating on the agreement takes more than one period, and even if it takes the remaining cartel members some time to agree on the proper punishment.

A second and related objection to the trigger strategy is that it is harsh and unforgiving because it does not permit mistakes. For example, suppose that market demand fluctuates within some known bounds, as shown in Figure 14.2, and that the cartel has agreed to set a price P^C or has agreed to production quotas that lead to that market price. In this setting, a cartel firm that observes a decline in its sales cannot tell whether this reduction is due to cheating by one of its partners or to an unanticipated reduction in demand. Yet under the simple trigger strategies we have been discussing, the firm is required quickly and permanently to move to the retaliatory behavior. Clearly, this will lead to some regret if the firm later discovers that its partners were innocent and that it has needlessly unleashed a damaging price war.[13]

This objection too can be overcome. The trick is to adopt a modified trigger strategy. For instance, the firm might only take retaliatory action if sales, or price fall outside some agreed range. The firm refrains from retaliation against minor infractions. A different modification would impose punishment swiftly after any deviation from the cartel agreement is observed but limit the period of punishment to a finite period of time. Thus, we can envision a trigger strategy of the form "I will switch to the Nash equilibrium for $\tau \geq 1$ periods if you deviate from our agreement but will then revert to our agreed cooperative strategies." This approach may mistakenly punish innocent cartel members, but by limiting the period of such punishment, it permits reestablishment of the cartel at a later date.

The point is that in an infinitely repeated game there are many trigger strategies that allow a cartel agreement to be sustained. Indeed, in some ways, there are almost too many. This

[13] Two different views of oligopolistic behavior with uncertain demand that makes detection difficult may be found in Green and Porter (1984) and Rotemberg and Saloner (1986).

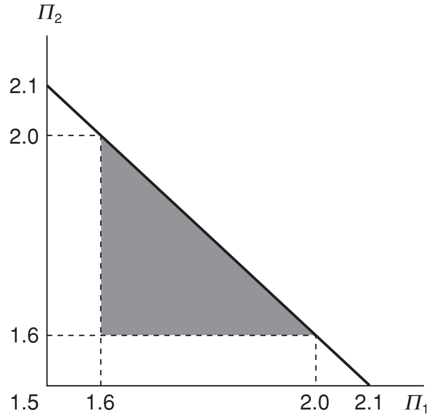

Figure 14.3 The Folk theorem
Any distribution of profits in the shaded area can be supported by a trigger strategy for some discount factor sufficiently close to unity.

point is made clear by what is known as the *Folk theorem* for infinitely repeated games (Friedman 1971):[14]

> *Folk theorem*: Suppose that an infinitely repeated game has a set of payoffs that exceed the one-shot Nash equilibrium payoffs for each and every firm. Then any set of feasible payoffs that are preferred by all firms to the Nash equilibrium payoffs can be supported as subgame perfect equilibria for the repeated game for some discount rate sufficiently close to unity.

We can illustrate the folk theorem using our first example. If the two firms collude to maximize their joint profits, they share aggregate profits of \$3,600. If they act noncooperatively they each earn \$1,600. The folk theorem says that any cartel agreement in which each firm earns more than \$1,600 and in which total profit does not exceed \$3,600 can, at least in principle, be sustained as a subgame perfect equilibrium of the infinitely repeated game. The shaded region of Figure 14.3 shows the range of profits for this example that can be earned by each firm in a sustainable cartel.

A qualifying note should be added here. The folk theorem does not say that firms can always achieve a total industry profit equal to that earned by a monopoly. It simply says that firms can do better than the noncooperative, Cournot–Nash or Bertrand–Nash equilibrium. The reason that exact duplication of monopoly may not be possible is that the monopoly outcome always results in the highest possible price relative to marginal cost. At such a high price, any cartel member can earn substantial short-term profit with even a small deviation from the cartel agreement. Consequently, duplicating the monopoly outcome gives members a tremendous incentive to cheat unless the probability adjusted discount factor is fairly large. Yet the incentive to deviate and break the monopoly agreement does not mean that no cartel can be sustained. Firms can still earn profits higher than the noncooperative equilibrium by means of a sustainable cartel agreement, even if they cannot earn the highest possible profits that the industry could yield. This is what the folk theorem says.

[14] The term "Folk theorem" derives from the fact that this theorem was part of the "folklore" or oral tradition in game theory for years before Friedman wrote down a formal proof.

9781405176323_4_014.qxd 10/19/07 8:12 PM Page 340

Reality Checkpoint

Was It to Their Credit That Visa and MasterCard Cooperated?

Together, the two major credit card companies, Visa and MasterCard, process 75 percent of the dollar volume of credit card transactions, with the split being two-thirds Visa and one-third MasterCard. Historically, both companies have operated as "membership corporations." Here, the members are banks that sit on the board of directors, choose the management, and serve on policy-making committees. The card companies issue cards to consumers and businesses, provide merchants with access to credit-processing networks, and allow banks to issue credit cards with access to their network. Before 1970, different banks controlled Visa and MasterCard. However, starting in the mid-1970s, Visa and MasterCard began to allow their member banks to join each other, a practice known in the industry as "duality." The result has been that the same set of banks controls both credit card networks.

In 1996, Wal-Mart Stores filed suit against Visa and MasterCard, alleging that the two networks were illegally tying their credit and debit products. They were later joined by several other retailers in a class action suit. Their complaint was that because of their common control, Visa and MasterCard did not compete against each other. In turn, it was argued that this lack of competition allowed the firms to impose harmful tying requirements that required a retailer to accept any bank debit card if it accepted the Visa or MasterCard. Wal-Mart and others had wanted to issue their own debit cards and felt the collusion between Visa and MasterCard prevented them from doing so. They further claimed that MasterCard and Visa charged $1.50 for a $100 debit card transaction while similar ATM networks charged only 14 to 30 cents. In 2003, Visa and MasterCard and settled the case, agreeing to pay $3 billion to merchants over the next ten years, to lower their transaction fees, and to stop tying credit and debit card acceptance. Almost immediately, Wal-Mart and other retailer began to issue debit and credit cards of their own.

In 1998, almost simultaneously with these events, the Department of Justice filed suit against Visa and MasterCard charging a conspiracy in violation of the Sherman Act. The government charged that the duality arrangement itself was a conspiracy violation. It further argued that in cooperating with each other the two networks had consciously conspired to prevent the emergence of strong credit card rivals. In particular, both Visa and MasterCard prohibited their member banks from issuing American Express ("Amex") or Discover cards. The government provided quotes from company officials and internal records such as this 1992 quote from the Executive Vice President of Visa International that "it is very difficult for us to take a step, an aggressive step that hurts MasterCard because the same banks who sit there on the board, who are in Visa are also in MasterCard." There was also this 1997 quote from the President of MasterCard International U.S. Region that: "It is clear that because of duality today you don't see MasterCard and Visa in the marketplace attacking each other."

With respect to blocking entry, the government noted that processing transactions involves transmitting transaction data from a merchant's terminal to a central computer that directs the information to the appropriate card network for authorization and settlement. Visa and MasterCard permit banks to process transactions for both networks through a single merchant terminal, enhancing the ability of both networks to convince merchants to accept their cards. In response, both American Express and Discover developed their own acceptance terminals. Initially, they also entered into agreements with some Visa and MasterCard banks the each would allow the other to use their respective terminals. Very shortly, however, a number of other Visa and MasterCard banks complained that this was hurting their business. Soon afterwards, Visa and

MasterCard issued regulations preventing such sharing by their member banks. The government provided many similar examples of what appeared to be deliberate and coordinated efforts by Visa and MasterCard to prevent the emergence of strong rivals.

In October, 2004, after a very short, 34-day trial, the district court issued its finding that Visa and MasterCard were guilty of Sherman Act violations, mainly those that prevented the emergence of rivals. The decision was later upheld by an Appellate Court and the Supreme Court declined to question that judgment. Again, market reaction was swift. Banks belonging to the Visa and MasterCard networks immediately began to accept other cards. Competition seemed to be emerging as American Express quickly raised its market share by 3 percentage points.

Sources: *United States v. Visa U.S.A., Inc.*, 163 F.Supp.2d 322; and J. Kingston, "Credit Card Issuers Adjust to Open Field," *New York Times*, March 26, 2005, p. C4.

In sum, once we consider a framework of infinitely or indefinitely repeated interaction between firms, there is a real possibility for sustainable collusive behavior among these firms so long as the discount rate is not too low and the probability of their continued interaction is not too low. Indeed, the examples noted at the start of this chapter offer ample evidence that this is the case.

We have focused our attention on identifying conditions under which cartels are self-sustaining, but there are in addition other explicit actions that help cartel members sustain collusive agreements. There is ample evidence, that cartel members engage in a whole series of actions to monitor compliance with the cartel agreement. Regular strategy meetings, usually in plush hotels and resorts, explicit checking on compliance by lower level executives, the formation of trade associations are all mechanisms that firms have used to sustain cartel agreements.[15] There appears then to be good reasons for the Justice Department and other antitrust authorities to worry about collusion.

14.3 COLLUSION: THE ROLE OF THE ANTITRUST AUTHORITIES

The authorities would be misguided, if not foolish, to rely on cartels failing of their own accord as a result of cheating by cartel members. In a recent survey Levenstein and Suslow comment: "in many case studies, authors asserted that cheating was simply not a problem for the cartel." (2006, p. 78). Explicit action is needed to search for and prosecute cartels if they are to be apprehended. Such action will do more than simply disrupt existing cartels. Because of its deterrent effect, the prosecution of price-fixing arrangements should also lead to fewer collusive agreements to emerge in the first place.[16] We now present a simple model that captures the impact of enforcement on cartels.

Suppose that a cartel has been formed and that it satisfies equation (14.7) so that it is potentially self-sustaining. Now introduce an antitrust authority, which is charged with looking for and attempting to prosecute cartels. In any given period assume that there is a

[15] *The Informant* (2000) by Kurt Eichenwald provides an informative and amusing illustration of how the lysine cartel that operated in the 1990s was sustained and eventually prosecuted.

[16] The approach that we take in this section is simplified and adapted from Motta and Polo (2003).

probability a that the authority will investigate our cartel. If no investigation is instituted the cartel continues to the next year. The investigation takes one period and we assume that there is a probability s that it leads to successful prosecution, in which case the cartel members are subjected to a fine of F and the cartel breaks down.[17] If, by contrast, the investigation is unsuccessful the cartel continues.

We denote the expected present value of the profits that each cartel member receives as V^C. To evaluate this expected value we need to consider three possibilities:

(1) No investigation in period 0, which has probability $1 - a$: the cartel continues and expected profit is:

$$V_1 = (1 - a)(\pi^M + \rho V^C) \tag{14.8}$$

The first term in the second bracket is profit in the current period given that the cartel is active. The second term uses the same reasoning as we used to derive equation (14.3). Given that there is no investigation the "cartel game" begins again in period 1 and so has expected profit V^C, which has to be discounted one period.

(2) Unsuccessful investigation in period 0, which has probability $a(1 - s)$: the cartel continues and expected profit is:

$$V_2 = a(1 - s)(\pi^M + \rho V^C) \tag{14.9}$$

Similar to equation (14.8) the second term in the second bracket reflects the fact that the cartel game begins again in period 1 after an unsuccessful prosecution.

(3) Successful prosecution, which has probability as: each cartel member is fined and the cartel collapses after the prosecution. Expected profit is:

$$V_3 = as\left(\pi^M - F + \frac{\rho}{1-\rho}\pi^N\right) \tag{14.10}$$

The assumption that the cartel continues during an investigation deserves some comment. As we show in the next chapter, firms may stop colluding before an actual indictment is issued or while an investigation is still under way. However, this does not mean that they stop colluding as soon as an investigation begins. In the first place, the firms may not actually know that they are being investigated for some considerable amount of time. In the second place, they may continue to collude even after they discover that they are under suspicion because a sudden change in their behavior could be interpreted by the authorities as a sure sign that their behavior to date is not innocent of all wrongdoing. For these and other reasons, firms may continue to collude for some time after an investigation into their operations has begun, leading to our assumption here that they collude while being investigated.

[17] Motta and Polo (2003) assume that the cartel begins again after one period of punishment. We prefer our approach since, in the former case, the antitrust authority, having once found a cartel, could simply keep on investigating the same firms. We are aware, of course, that the evidence does show that there are repeat offenders.

Putting together all the possibilities in (14.8), (14.9) and (14.10) gives us the expected present value of profit for a cartel member, $V^C = V_1 + V_2 + V_3$:

$$\begin{aligned} V^C &= (1-a)\pi^M + a(1-s)\pi^M + as\pi^M - asF + \frac{as\rho}{1-\rho}\pi^N \\ &\quad + (1-a)\rho V^C + a(1-s)\rho V^C \\ &= \pi^M - asF + \frac{as\rho}{1-\rho}\pi^N + (1-as)\rho V^C \end{aligned} \tag{14.11}$$

Solving for V^C gives the expected profit of each firm in the cartel:

$$V^C = \frac{\pi^M - asF + \dfrac{as\rho}{1-\rho}\pi^N}{1-\rho(1-as)} \tag{14.12}$$

Comparing (14.12) with (14.4) confirms, as we would have expected, that the introduction of an antitrust authority reduces the expected profit from cartel formation, even if the authority merely breaks up the cartel while imposing no fines.

It should be clear from equation (14.12) that antitrust policy has two major tools. The first and most obvious tool is the fine F. As F increases the expression in equation (14.12) decreases for any positive values of a and s. Even with small detection probabilities, a large enough fine would deter cartel formation. The second tool is the probability of investigation and successful prosecution as. As this term increases, the expression in equation (14.12) becomes smaller. In the extreme case of $as = 1$, the expression becomes $\pi^M - F + [\rho/(1-\rho)]\pi^N$. For this expected profit to exceed the gains from cheating on a collusive agreement, or $\pi^D + [\rho/(1-\rho)]\pi^N$, requires that $\pi^M - F > \pi^D$, which of course is not possible even if the fine F is zero. In other words, a sufficiently high rate of successful cartel discovery and prosecution would end cartel formation even if there were no penalty. For the case of a zero fine, a bit of manipulation (see the Derivation Checkpoint) of equations (14.5) and (14.12) indicates that the critical probability adjusted discount factor ρ^A for this case is:

$$\rho > \rho^A = \frac{\pi^D - \pi^M}{(1-as)(\pi^D - \pi^N)} \tag{14.13}$$

Comparison of equations (14.13) and (14.7) confirms that $\rho^A > \rho^*$ and that ρ^A rises as either a or s increases. The underlying reason is that there are now two forces that can cause the cartel to fail. One of these is the ever-present pursuit of self-interest that induces individual cartel members to cheat on the agreement. The other is the newly introduced force stemming from the possibility of successful prosecution by the authorities.

Take our Bertrand example. We know that $\pi^M = 1{,}800$, $\pi^D = 3{,}600$ and $\pi^N = 0$. Substituting into (14.13) we find that the critical probability adjusted discount factor for this cartel to be self-sustaining despite the presence of an antitrust authority (which causes cartel breakdown but does not impose a penalty) is $\rho^A = 1/2(1 - as)$. If there had been no investigative effort ($as = 0$), then ρ need only be greater than 1/2 for the cartel to be self-sustaining. However, as a or s rises, the likelihood that the cartel can survive declines. For $as \geq 1/2$, no cartel can be self-sustaining.

Derivation Checkpoint

Probability-adjusted Discount Factor When There Are No Fines

In the absence of fines, the cartel will be self-sustaining if the expected gains from staying in the cartel exceed the net benefits obtained by cheating on the cartel and earning profit π^D for one period but then earning just the non-cooperative Nash profit π^N every period thereafter. That is, the requirement for the cartel to be self-sustaining is:

$$\frac{\pi^M + \dfrac{as\rho}{1-\rho}\pi^N}{1-\rho(1-as)} > \pi^D + \frac{\rho\pi^N}{(1-\rho)}$$

This may be rewritten as:

$$\frac{(1-\rho)\pi^M + as\rho\pi^N}{1-\rho(1-as)} > (1-\rho)\pi^D + \rho\pi^N$$

In turn, this implies:

$$(1-p)\pi^M + as\rho\pi^N > [1-\rho(1-as)](1-\rho)\pi^D + [1-\rho(1-as)]\rho\pi^N$$

Rearranging yields:

$$as\rho\pi^N - [1-\rho(1-as)]\rho\pi^N + \rho(1-as)\pi^D > [1-\rho(1-as)]\pi^D > (1-\rho)(\pi^D - \pi^M)$$

or

$$(1-\rho)\rho(1-as)(\pi^D - \pi^N) > (1-\rho)(\pi^D - \pi^M)$$

or

$$\rho > \rho^A = \frac{\pi^D - \pi^M}{(1-as)(\pi^D - \pi^N)}$$

It is self-evident that the hurdle for ρ rises as the probability of investigation and successful prosecution as rises. Again, this is the probability-adjusted discount factor when the fine F is zero. It will, of course, be an even higher hurdle if the fine is positive.

Which tool—fines or increased probability of apprehension and conviction—should the authorities use? Uncovering and prosecuting price-fixing conspiracies requires careful surveillance and legal work, which is expensive. In contrast fines may be imposed rather costlessly. This suggests that a heavy reliance on substantial punishment is likely to be the more cost-effective strategy. In turn, this helps to explain why the law imposes treble damages in private antitrust lawsuits. However, unlike detection efforts, fines can never be used by themselves as part of a deterrence strategy. The reason is simple. If either a or s is zero, then the probability of getting caught and paying the fine is also zero. In that case, a fine will have no deterrent effect no matter how large it is. It is also true that judges and juries are sometimes reluctant to find a party guilty if they suspect that the finding will lead to an incredibly harsh penalty. The general rule is that some reliance on both detection and fines is appropriate, though the latter may play the dominant role.

One point to make in considering equation (14.13) is that whether the authorities rely on investigations or fines, much of what antitrust enforcement is about is deterrence. The policy works by preventing cartels from forming in the first place and not just by breaking them up once they have been uncovered. Such deterrence means that we may have difficulty in evaluating the full impact of antitrust efforts because we cannot easily measure the number of cartels that would have formed were it not for these deterrent effects. Here again, the extreme case is insightful. Suppose that because of a combination of investigative efforts and punishments, as and F are set such that firms never find it worthwhile to form a cartel. Because no cartels are ever observed, it may seem to an outsider that price-fixing penalties are not necessary and that the funds spent on detection (as) are wasted. Yet in fact, it is precisely because of those expenditures and punishment policies that cartels have been eliminated.

Our analysis suggests that it is possible for active antitrust policy to deter cartels from forming. However these agencies have limited resources. Since they cannot patrol every industry and every market, they must focus on those settings where collusion is most likely to occur. Furthermore, they must develop methods to detect such collusion if and when it occurs or to encourage firms to turn themselves in if they fear prosecution. These are the subjects to which we turn in the next chapter.

14.4 EMPIRICAL APPLICATION Estimating the Effects of Price-fixing

In assessing the fines to be imposed on cartel members after a successful prosecution often the antitrust authorities must estimate the damage that the cartel has caused. This requires that the authorities, or more properly their expert econometric witnesses, estimate four numbers: the duration of the cartel, the price(s) charged and quantity (or quantities) sold by the cartel during the period the cartel is active, and the price(s) that the cartel would have charged if there had been no cartel—the "but for" price(s).

Of these, undoubtedly the most challenging is the last: estimating an inherently unobservable price. Several approaches have been suggested for estimating the "but-for" price. First, we could base the estimate on the Cournot model of competition in section 9.5 in Chapter 9, and solve for the "but for" price using the industry measure of concentration, costs and demand elasticity. Second, and related, we could solve for the price using the Lerner Index in combination with data on capacity utilization, fixed and marginal costs. Third, we could use a before-and-after approach. That is, identify a period during which the cartel was not active and generate a measure of the prices charged in that period. Fourth, we could specify and estimate a reduced-form, time-series econometric model to estimate demand and supply interactions in the market and include a dummy or other variable to capture the impact of the cartel. Of these the third and fourth are the most commonly used.[18]

[18] Connor (2001) provides a detailed discussion of the use of the before-and-after method in estimating the impact of the lysine cartel.

The econometric method is typically applied[19] by estimating a reduced-form price equation of the form:

$$\boldsymbol{P}_{it} = \alpha + \beta \boldsymbol{y}_{it} + \gamma \boldsymbol{w}_{it} + \delta \boldsymbol{s}_{it} + \lambda \boldsymbol{D}_{it} + \varepsilon_{it} \tag{14.14}$$

Here, $\boldsymbol{P}_{it}$ is price in region i at time t, $\boldsymbol{y}_{it}$ is a vector of variables that affect demand (income, prices of other goods), $\boldsymbol{w}_{it}$ is a vector of variables that affect supply (factor prices), $\boldsymbol{s}_{it}$ is a vector of market structure variables (concentration, some measure of the strength of economies of scale), $\boldsymbol{D}_{it}$ is a vector of dummy variables intended to capture the impact of the cartel and ε_{it} is an error term. This is referred to as a reduced form equation since it is derived from an equilibrium condition equating demand and supply functions, which are functions themselves of underlying structural parameters that are not directly estimated.

A potential drawback of this approach is, of course, that it is very demanding on data. There needs to be sufficient "before and after" the cartel observations to give reliable estimates of the dummy variables and some of the variables in $\boldsymbol{w}_{it}$ such as factor costs can only be obtained with the consent of the firms that are accused of being parties to the cartel. There will often be problems with endogeneity of the right-hand side variables requiring an instrumental-variables estimation technique, with the "correct" choice of instruments.

There are, however, examples where a variant of the econometric technique has been used with great effect. One such example is Kwoka (1997) who estimated the price impact of a long-running cartel to rig prices in a particular set of real estate auctions held in the District of Columbia.

The auctions related to properties that were either foreclosed as a result of mortgage default or were being sold under court supervision: the latter are referred to as nisi auctions. The cartel members constituted a relatively small and stable set of real estate investors who specialized in the purchase and subsequent resale of this type of property. They operated the cartel by designating a bidder who would submit an agreed winning bid at the auction while the other cartel members either did not bid or deliberately bid low. A non-cartel member who turned up at such an auction was discouraged in various ways. For example the cartel members might make negative remarks about the property, or the non-member might be paid not to bid or might be allowed to purchase one property. One measure of the success of this cartel at deterring entry and sustaining the cartel is that the cartel appears to have operated successfully for roughly 14 years, from January 1976 to August 1990.

At the end of the public auction the cartel members then conducted a second, private, "knockout" auction among themselves to determine the final ownership of the property. Since this auction was conducted as a normal ascending bid auction, the property went to the high bidder: presumably the cartel member who valued the property most highly. The winner of the public auction would then be reimbursed for the price that she had paid and the remaining difference between the public auction price and the knockout auction price would be distributed as side payments to the members of the bidding ring.

To see how this collusive arrangement works among N members in the bidding ring we denote the true value of the property by V, the public auction-winning bid by P, and the knockout auction bid by K. Only P and K are observable. There are $N - 1$ losing bidders who each receive a payoff of S where

$$S = \frac{K - P}{N - 1} \tag{14.15}$$

[19] Baker and Rubinfeld (1999) discuss the use of this method.

Every member of the ring knows that she will be paid at least S if she loses in the knockout auction. The winner of the knock out gets $V - K$ and so in equilibrium $S = V - K$. In other words, the true value of the property is $V = K + S$. Using equation (14.15) this condition implies gives:

$$V = K + \frac{K - P}{N - 1} = \frac{N}{(N - 1)}K - \frac{P}{(N - 1)} = P + \frac{N}{(N - 1)}(K - P) \tag{14.16}$$

Kwoka adds a bit more structure to the model by assuming that the fixed public auction price P on which the bidding ring agreed was a "constant fraction of a property's competitive valuation." If this fraction is m then $m = V/P$. Substituting $V = mP$ in (14.16) and solving for K we have the reduced form equation to be estimated:

$$K = P + (m - 1)P\frac{(N - 1)}{N} \tag{14.17}$$

where the independent variables in the regression are P and $P(N - 1)/N$ and m is to be estimated.

Members of the cartel kept detailed records of the identities of all the bidders in each auction and the payoffs that were made to each losing bidder. These records were central to the eventual prosecution of the cartel and are also essential to the estimation of the cartel's impact on prices. However, of the 12 individuals that were charged with Sherman Act violations, 10 pleaded guilty before trial and so no data are available for these cases. This left Kwoka with data for 30 of the 680 properties affected by the cartel, all of which were auctioned between 1980 and 1988.

Summary statistics for these auctions are reported in Table 14.3. The average number of bidders was 4.6 and ranged from 2 to 9. The average knockout price was 28 percent in excess of the public auction price, or alternatively the rigged public auction price was on average 22 percent less than the knockout price.

This is not, however, the full impact of the cartel, since we know that $V = K + S$. Moreover, it can be seen from Table 14.3 that there is considerable variance in K/P. Kwoka, therefore, estimated equation (14.17) directly, obtaining the results in column (a) of Table 14.4.

In the first regression in column (a) observe that the coefficients on the two terms P and $P(N - 1)/N$ are significant and have the expected signs and the fit is remarkable. In addition, the coefficient on P is (just) insignificantly different from unity, as required by equation (14.17). The coefficient on $P(N - 1)/N$ is an estimate of $m - 1$, giving $m = 1.86$. Since $P/V = 1/m$ this tells us that $P/V = 0.54$. In other words, the cartel results in public bid prices 46 percent lower than the true valuation of the properties being auctioned.

Table 14.3 Summary statistics for the auction cartel

	Mean	*Minimum*	*Maximum*
P	\$25,800	\$8,800	\$44,800
K	\$30,500	\$10,800	\$47,300
N	4.63	2	9
K/P	1.28	1.02	2.46

Table 14.4 Regression results

	(a)	*(b)*	*(c)*
P	0.519 (2.18)	0.520 (2.15)	0.703 (4.47)
$P(N-1)/N$	0.860 (2.58)	0.879 (2.58)	0.481 (2.01)
$DP(N-1)/N$		–0.045 (0.51)	0.014 (0.23)
UNEQUAL			3,501 (3.08)
R^2	0.979	0.980	0.995
S	667	433	694

Kwoka then estimated two refinements on the simple model of equation (14.17). First, of the thirty properties in his sample, nineteen were foreclosure auctions and eleven were nisi auctions. Since the latter are held under court supervision it is possible that the cartel members would be more careful in their public auction bidding. Suppose, therefore, that on nisi actions we have that $V/P = m - d$. Introduce a dummy variable D that takes the value of unity for nisi auctions and zero otherwise. Then the reduced form to be estimated becomes:

$$K = P + (m-1)P\frac{(N-1)}{N} - dDP\frac{(N-1)}{N} \tag{14.18}$$

The results are given in column (b) of Table 14.4. The coefficient on $DP(N-1)/N$ is the estimate of d. It has the correct sign (negative) but is statistically insignificant.

The second refinement modifies the mechanism by which losing bidders in the cartel were compensated. In some auctions losing bidders were compensated equally while in others the compensation was based on each losing bidder's final but losing bid. The impact of unequal compensation is potentially ambiguous. On the one hand it might make bidders more aggressive to secure them a higher share. On the other hand, aggressive bidding might result in a bidder winning an auction that she did not want to win. To test for this impact, Kwoka added a dummy variable UNEQUAL to equation (14.18) and ran the regression for the 18 auctions in which it was possible to distinguish the compensation mechanism.

The results are given in column (c) of Table 14.4. The coefficient on UNEQUAL is positive and significant, implying that unequal compensation increased the subsequent knockout price. Moreover, the coefficient on $P(N-1)/N$ gives a revised estimate for m of 1.48, implying that the cartel rigged the public auction prices to 32.5 percent below the true property values. From this and the rest of Kwoka's (1997) results, this cartel is seen to have had an unambiguous and significant impact on the prices at which these properties were traded in the public auctions.

Summary

At least since the time of Adam Smith, there has been the fear that firms in the same industry may try to collude and set a price close to the monopoly price rather than vigorously compete. The good news since the 1990s is that a large number of such collusive cartels have been caught and successfully prosecuted in the courts both in Europe and North America. The bad news is that this same evidence also reveals that collusion remains a real problem. Somehow firms are able to work out and implement cooperative strategies rather than noncooperative ones. So, while the competition authorities can feel good about the cartels that have been broken, they must also worry that there are many other price-fixing agreements that they have not uncovered.

It is the repetition of corporate interaction that makes cartels possible. Firms rarely meet on the corporate battlefield just once. Instead, they can expect to meet many times, and perhaps in many other markets as well. When a game is played only once, each firm has a strong incentive to cheat on the collusive agreement. Since the agreement is not legally enforceable, there is little any firm can do to deter others from cheating. However, when the game is played repeatedly over a number of periods, the scope for cooperation widens considerably. This is because a firm can threaten to "punish" any cheating on the collusive agreement in one period by being more aggressive in the subsequent periods.

While repetition of the game is necessary for firms to collude successfully, it is not by itself sufficient. In addition to the game being repeated it must have an indefinite end point. That is, in any given period, there is always a positive probability that the game will be played one more time. Absent these conditions, Selten's theorem makes clear that a finitely repeated game with a unique Nash equilibrium will simply result in that Nash equilibrium being the outcome in each period. However, for repeated games that go on indefinitely, the Folk theorem makes clear that collusion that allows for all firms to gain relative to the one-shot Nash equilibrium is possible.

We have further shown that an active antitrust policy reduces the likelihood of a cartel being self-sustaining. However, this by no means guarantees that cartels will not be formed. Based on the recent historical experience, it appears that the conditions for successful collusion are often met. Antitrust concern with price fixing agreements is then justified. Empirical work on assessing the welfare impact of collusive pricing is a rich and growing field in industrial organization. Designing and implementing antitrust policy to punish price fixing agreements is increasingly based on econometric work that identifies what would have happened had the cartel not been in operation. As we saw in section 14.4 there is sound empirical evidence that pricing rigging in auctions has a sizable impact on prices.

Problems

1. Suppose that two firms compete in quantities (Cournot) in a market in which demand is described by: $P = 260 - 2Q$. Each firm incurs no fixed cost but has a marginal cost of 20.
   a. What is the one-period Nash equilibrium market price? What is the output and profit of each firm in this equilibrium?
   b. What is the output of each firm if they collude to produce the monopoly output? What profit does each firm earn with such collusion?

2. Return to the cartel in problem 1. Suppose that after the cartel is established, one firm decides to cheat on the collusion, assuming that the other firm will continue to produce its half of the monopoly output.
   a. Given the deviating firm's assumption, how much will it produce?
   b. If the deviating firm's assumption is correct, what will be the industry price and the deviating firm's profit in this case?

3. Suppose that the market game described in problems 1 and 2 is now repeated indefinitely. Show that the collusive agreement can be maintained so long as the probability adjusted discount factor, $\rho R > 0.53$.

4. Suppose again that market demand is given by: $P = 260 - 2Q$ and that firms again have a constant marginal cost of 20, while incurring no fixed cost. Now, however, assume that firms compete in prices (Bertrand) and have unlimited capacity.
   a. What is the one-period Nash equilibrium price? Assuming that firms share the market evenly any time they charge the same price, what is the output and profit of each firm in this market equilibrium?
   b. What will be the equilibrium output and profit of each firm if each agrees to charge the monopoly price?

5. Return to problem 4. Assume that the cartel is established at the monopoly price. Suppose one firm now deviates from the agreement assuming that its rival continues to charge the monopoly price.
   a. Given the deviating firm's assumption, what price will maximize its profit of the other firm?
   b. If its assumption is correct, how much will the profit of the cheating firm be? How much will be the profit of its non-cheating rival?

6. Return again to the cartel in problems 4 and 5. Now suppose that the market game is repeated indefinitely. What probability adjusted discount factor is necessary now in order to maintain the collusive agreement?

7. Compare your answers in problems 3 and 6. Based on this comparison, which market setting do you think is more amenable to cartel formation, one of Cournot competition or one of Bertrand competition?

8. Once again, assume Cournot competition in an industry in which market demand is described by: $P = 260 - 2Q$ and in which each firm has a marginal cost of 20. However, instead of two firms let there now be four.
   a. What is the one-period Nash equilibrium market price? What is the output and profit of each firm in this equilibrium?
   b. What is the output of each firm if they collude to produce the monopoly output? What profit does each firm earn with such collusion?

9. Return to Problem 8. Suppose that one firm decides to cheat on the collusion, assuming that each of the three other firms continue to one-fourth of the monopoly output.
   a. Given the deviating firm's assumption, how much will produce?
   b. Assuming that its assumption is correct, what will be the industry price and the deviating firm's profit?

10. Consider again your results in problems 8 and 9. Suppose that the market game is repeated indefinitely. Show that the collusive agreement can be maintained so long as the probability adjusted discount factor, $\rho R > 0.610$.

11. Compare your answers in Problems 10 and 3. Based on this comparison, what do you infer about the ability of firms to sustain a collusive agreement as the number of firms in the industry expands?

12. Imagine that in the 1990s, the market demand for the food additive, lysine, had a price elasticity of 1.55. The structure of that market and the (assumed to constant) marginal cost per pound for each firm are shown below:

Firm	*Market share (%)*	*Marginal cost*
Ajinomoto	32	\$0.70
Archer Daniels Midland	32	\$0.70
Kiyowa Hakko	14	\$0.80
Sewon/Miwon	14	\$0.80
Cheil Sugar	4	\$0.85
Cargill	4	\$0.85

   a. Use elasticity, market share, and cost data above to determine the weighted average industry equilibrium price if the firms are competing in quantities.
   b. During the 1990s, the lysine producers formed a (now famous) cartel that maintained the shares shown in part a. Under the cartel, the world price of lysine rose to an average of \$1.12 per pound. Total world production at this time was about 100 thousand metric tons per year. A metric ton = 2,200 pounds.
   c. Focusing on Archer Daniels Midland (ADM), and assuming market shares are the same in the Cournot and collusive settings, use the above what you know about the Cournot equilibrium from Chapter 9 to determine:
      (i) ADM's profits in the Cournot equilibrium; and
      (ii) ADM's profits under the cartel.

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