Noncooperative Game Theory: A Review with Potential Applications to Agricultural Markets

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Abstract

This paper is a survey on noncooperative game theory relevant to agricultural markets. It is divided into two parts. Part I discusses types of noncooperative games and reviews important developments in noncooperative game theory solution concepts, including Nash equilibrium, subgame perfect equilibrium, and perfect Bayesian equilibrium. Strengths and weaknesses of game theory as a modelling tool are also assessed. Part II illustrates applications of the theory to agricultural markets. Game theory is relevant when markets are imperfectly competitive, and this paper argues that this condition is commonly met in agriculture. Specific topics of application include principal-agent models, vertical control, auctions, and bargaining. A shortened version of this paper was published in the *Review of Marketing and Agricultural Economics*.

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The advent of Game theory is considered to be the publication of von Neumann and Morgenstern's book, *The Theory of Games and Economic Behavior* in 1944. In the immediately succeeding years important advances in game theoretic analysis were made by game theory's other pioneers including Nash (1950, 1951), and Shapley (1953). The state of the art during this era was summarized in Luce and Raiffa's classic book, *Games and Decisions: Introduction and Critical Survey*, published in 1957. However, few results useful to economics were developed over the next twenty years, and during this time, one could continue to recommend Luce and Raiffa's book as the definitive source on basic game theory.

An upsurge of interest in pure and applied game theory in economics began in the mid 1970s as research began to emphasize decision makers who were rational but had limited information and who interacted with others in explicitly dynamic settings. Much has been accomplished during this period, and game theory texts published today bear little resemblance to Luce and Raiffa's book. With the publication in 1990 of David Kreps text, *A Course in Microeconomic Theory*, game theory will be integrated into the training of most new Ph.Ds in economics and agricultural economics.

In this survey I attempt to chronicle recent conceptual advances in game theoretic analysis relevant to economics and assess its successes and failures. Further, I examine use of game theory tools to study behavior in agricultural markets. To date the methodology has been little used by agricultural economists, although I argue that the potential for application is quite good. If this assessment is correct, then perhaps a survey with emphasis on applications in agriculture can stimulate interest in the topic among agricultural economists.

Games are partitioned into two broad classes: *cooperative* and *noncooperative*. Players in cooperative games can make binding commitments, whereas in noncooperative games they cannot. This distinction must be interpreted narrowly. For example, communication among players can be modelled under either game structure. And players in a noncooperative game setting can agree to cooperate and sign contracts if the game structure allows it. However, if it is individually desirable for a player to defect from an agreement or breach his contract, he will do so in a noncooperative game setting. Cooperative game theory is most useful in settings where players can form groups or coalitions. The analysis then focuses on what these coalitions can accomplish with little or no emphasis on the processes whereby these outcomes are achieved within the coalition.

Most of the recent progress and interest in game theory has been in the area of noncooperative games, and, hence, those games are the focus of this paper.[1] The goal is not to provide a comprehensive introduction to noncooperative game theory. Rather, I hope to describe and illustrate some of the key concepts in use today and demonstrate their relevance to analysis of agricultural markets. A number of book-length treatments of the subject have appeared in recent years for the interested reader to pursue.[1]

The paper is organized into two parts. Part I reviews basic concepts and recent advances in noncooperative game theory. Part II discusses application of the theory to the study of agricultural markets.

Part I: Noncooperative Game Theory

1.1 Some Basic Classifications and Concepts

Noncooperative games are analyzed in either their *normal* or *extensive form*. The extensive form is manifest as the familiar game tree. It specifies the order of play, information, and actions available to each player and the ensuing payoffs that are contingent upon the players' actions. A player's *strategy* specifies his action at each point (node) in the game tree where the player has to move. The normal or *strategic* form is a summarized description of the extensive form. It usually is depicted as a matrix associating payoffs with each possible combination of (pure) strategy choices by the players.

Every extensive form has a corresponding normal or strategic form, but different extensive forms may be represented by the same normal form. A main reason is that the normal form necessarily abstracts from the dynamic aspects of most interesting games. Kreps (1990a) argues that the "great successes of game theory in economics" have

[1]This focus is for brevity's sake and is not meant to suggest that cooperative games do not provide a useful tool for analysis of agricultural markets. Indeed, institutions, such as agricultural cooperatives and marketing orders and agreements, that enable coalitions of farmers to form and make binding agreements concerning the marketing of their production are important in agriculture

arisen primarily due to the opportunity to think about the dynamic character of competitive interactions afforded by the extensive form. Constructing the extensive form is the very essence of the art of game theoretic modelling.

Because the discussion here will focus on games in extensive form, it is useful to review terminology relating to the extensive form. Refer to Figure 1. It is a simple model of *moral hazard*, a subject taken up in detail in Part II. There are two players, a grower (the principal) and a marketer (the agent). If the farm product is marketed effectively (e.g., no spoilage), it is worth 3.0 at retail. A marketing agent can provide these services at a cost of 0.5, or the grower, who is less efficient at marketing, can provide them at a cost of 1.0. The farm product net of marketing costs is worth 2.5 if the agent expends a high effort in marketing it. I assume that there are many competing agents, so that agents' services are priced at cost. The product is worth 2.0 if the farmer vertically integrates and markets the product himself. The product is only worth 1.5 if the agent shirks and expends low effort.

The points in Figure 1 at which either player takes an action are referred to as *nodes*. A *successor* to a node is any node that may occur later in the game if the given node has been reached. An *end node* is a node with no successors. A *branch* is one action from among a player's set of potential actions at a particular node. A *path* is a sequence of nodes and branches from the starting node to an end node. *Payoffs* for (grower, agent) are denoted at each terminal node.

The cornerstone solution concept for noncooperative games is the *Nash equilibrium*. A strategy combination is a Nash equilibrium if no player would wish to deviate from his strategy, given that no other players deviate. In other words, taking his opponents' actions as given, if no player would wish to change his own action, the resulting strategy combination is a Nash equilibrium.

The concept is worth stating formally. Define a set of players $N = \{1,\ldots,n\}$ with strategy sets S_i and payoff functions $\pi_i(s_1,\ldots,s_n)$, $i = 1,\ldots,n$. The strategy combination $s^* = \{s_1^* \ldots,s_n^*\}$ is a Nash equilibrium if

$$\pi_i(s_1^*,\ldots,s_n^*) \geq \pi_i(s_1^*,\ldots,s_{i-1}^*,s_i,s_{i+1}^*,\ldots,s_n^*),$$

$$\text{for all } s_i \in S_i, \text{ and for all } i = 1,\ldots,n.$$

Many well-known results in economics are Nash equilibria of their associated games. The most famous is mutual defection or "finking" in the various incarnations of the prisoners' dilemma game.[2] The Cournot equilibrium is the Nash equilibrium to the static game where oligopolists choose quantities, and the Bertrand equilibrium is the Nash equilibrium to the static game where they set prices. Von Stackelberg's

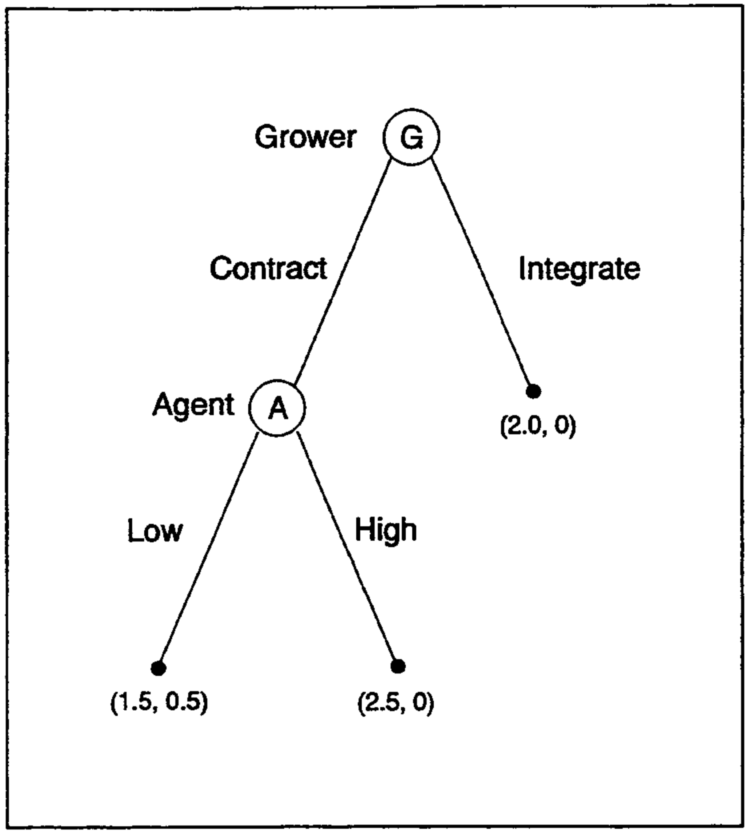

Figure 1 An Extensive Form Game: Post-Contractual Opportunism

leader-follower equilibrium is a Nash equilibrium to a dynamic game where the leader moves first and then the follower moves. The Nash equilibrium to the moral hazard game in Figure 1 is for the agent to expend low effort (if given an opportunity to play) and for the grower to vertically integrate.

A number of existence results for Nash equilibria have been proven, many of which are summarized by Friedman (1986). A fundamental result due to Nash (1951) is that every game with a finite number of pure strategies has at least one Nash equilibrium, possibly in mixed strategies. Mixed strategies involve a player randomizing among his pure strategies.[3] Similar existence results can be proven for games with a continuum of actions (such as the choice of a price or quantity), but complications enter when payoff functions are discontinuous or

nonquasi-concave in the strategy choices. Dasgupta and Maskin (1986) provide sufficient conditions for the existence of pure and mixed strategy equilibria in these cases.

The process of finding pure strategy Nash equilibria is usually quite straightforward. The analyst merely proposes candidate equilibrium strategies and then checks for each player if his strategy is optimal given the candidate strategies for all other players. If so, the candidate strategies are a Nash equilibrium.

It is worth commenting upon the Nash equilibrium as a solution concept because its problems have inspired refinements of the equilibrium concept that have comprised much of the recent progress in pure noncooperative game theory. The mutual best reply property of a Nash equilibrium is indeed an appealing property. However, three classes of criticisms of the Nash equilibrium as a solution concept can be raised:

1. Many games have multiple Nash equilibria, raising the question of how to choose among them.
2. Nash equilibria are very "noncooperative" in that the solutions they characterize often involve players doing distinctly worse than if they were somehow able to coordinate their actions.
3. Nash equilibria define necessary but not sufficient conditions for an "obvious way to play the game" (Kreps 1990a, 1990b).

I will consider each argument in turn. The games mentioned above in introducing the Nash equilibrium concept generally have a unique equilibrium, but many games have a multiplicity of equilibria in pure and/or mixed strategies. The most famous of these is *The Battle of the Sexes* illustrated in normal form in Figure 2. Here the players are cast in stereotypical roles–a male who prefers to go to a prize fight and a female who prefers the ballet, but they each prefer the other's company sufficiently that attending the less preferred event together is desired relative to attending the preferred event alone. The two Nash equilibria in the Battle of the Sexes are (PRIZE FIGHT, PRIZE FIGHT) and (BALLET, BALLET).

		WOMAN	
		Prize fight	*Ballet*
MAN	*Prize fight*	2, 1	-1, -1
	Ballet	-5, -5	1, 2

Payoffs to: (MAN, WOMAN)

Figure 2 Multiple Nash Equilibria: The Battle of the Sexes

Another example of multiple Nash equilibria is the simple game of entry and entry deterrence illustrated in extensive form in Figure 3. In this game the entrant moves first and chooses IN the market or OUT. The incumbent then responds by choosing either PREDATE or ACCOMMODATE, where the latter might imply either Cournot or collusive behavior. Denote the entrant by subscript E and the incumbent by subscript I. Denote monopoly, predation, and accommodation by superscripts M,P, and A respectively. Then

$$\pi_I^M > \pi_I^A > \pi_I^P, \text{ and}$$
$$\pi_E^A > 0 > \pi_E^P.$$

The Nash equilibria for this game are (IN, ACCOMMODATE) AND (OUT,PREDATE).

A multiplicity of Nash equilibria might signal either that the formal game specification fails to capture real-world elements that might suggest an obvious way to play the game or that the Nash equilibrium concept is ill-suited to analyze the game at hand. This is the case in the entry-deterrence game, where the equilibrium (OUT, PREDATE) involves a noncredible threat by the incumbent, i.e., if actually called upon to choose between PREDATE and ACCOMMODATE by the entrant's choice of IN, the incumbent rationally chooses ACCOMMODATE. Situations such as this have inspired refinements of Nash Equilibrium that we will examine shortly.

The notion of an obvious way to play a game is based on the pioneering work by Schelling (1960). The idea is that in many games that have multiple Nash equilibria, players may still know what to do. These equilibria are called *focal points*. They are Nash equilibria that are compelling for psychological reasons that are not easily incorporated in the formal game specification. Focal points may be based on past experience or a general sense of how people will behave.

The concern about the extreme "noncooperativeness" of Nash equilibria is that they often predict a distinctly suboptimal outcome from the perspective of the collective welfare of the players. All of the games I mentioned at the outset are this way. The "prisoners" in the prisoners' dilemma game both get long jail sentences from finking on each other, the Bertrand and Cournot equilibria both earn the oligopolists less than the join profit maximum output.[4] And in the moral hazard game or Figure 1, the Nash equilibrium outcome with vertical integration is Pareto dominated by contracting with an agent who expends high effort.

Two comments are in order. First, in these games' static contexts the noncooperative outcomes are probably realistic. Although superior

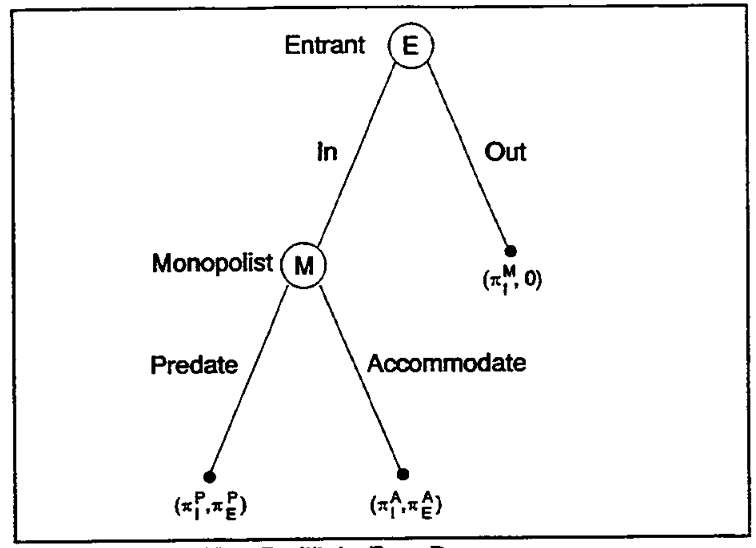

Figure 3 Multiple Nash Equilibria: Entry Deterrence

outcomes to the Nash equilibrium are available in each instance, players have unilateral incentives to defect from these solutions. People can be their own worst enemies. Second, the divergence between equilibrium and optimum (in the sense of maximizing total payoffs) behavior may signal that the model is a poor representation of real-world behavior. For example, in single play games, reputation is not an issue, nor are players able to make precommitments that might subsequently bind them to a more advantageous course of action. These considerations suggest the importance of including dynamics and information in game specifications, which, in fact, have been important dimension of recent game theory research.

Kreps' criticism (1990a, 1990b) based on the necessity but not sufficiency of Nash equilibrium is intertwined with the multiplicity-of-equilibria and extreme-noncooperativeness criticisms. Refining solution concepts to eliminate candidate equilibria is one means of moving from necessity to sufficiency; another is to identify obvious ways to play (focal points) if they exist. Kreps further notes that some games don't admit an obvious way to play, in which case pursing Nash equilibria can lead to precisely wrong inferences.

Having established the Nash equilibrium as a foundation to build upon, it is time now to consider the advancements that have lead to the recent years' explosion of interest in game theory modelling.

1.2 *Information and Extensive Form Games*

A player's *information set* at any particular point in a game consists of the different nodes in the game tree that he knows might be the actual node but cannot distinguish among by direct observation. Consider the simple coordination problem among farmers illustrated in Figure 4. There are two market periods, early and late, and either farmer can plant a perishable crop for harvest during one but not both periods. The early harvest period is more lucrative due to greater demand, and Farmer A, who runs a larger scale operation is better able to take advantage of the early market than is Farmer B. However, if the farmers can coordinate their plantings to smoothen supply across market periods, they will each do better than if they harvest for the same period and create a glut. A similar coordination story might involve scheduling harvests to best utilize fixed processing capacity. The ensuing payoffs under the alternative outcomes are listed at the end nodes in Figure 4.

Panels (a) and (b) in Figure 4 illustrate two alternative ways this game might be played. In panel (a) the players commit to planting decisions simultaneously. Thus, although Farmer A is depicted first on the game tree, Farmer B does not know A's choice when it is time to make his own choice, i.e., he does not know whether B_1 or B_2 is the actual node. His information set consists of $\{B_1,B_2\}$. Information sets are depicted on game trees by either encircling nodes that comprise an information set as in panel (a) or connecting the nodes with a dashed line.

Panel (b) depicts a case where Farmer A is able to move first. How he achieves this position might be an interesting strategic question. For example, he could sign a labor contract specifying an early planting cycle and containing a large penalty for breach. In this case Farmer B knows what action farmer A has taken when it is time to make his decision. Every information set in panel (b) consists of a single node or in game theory parlance is a *singleton*.

Figure 4 illustrates the distinction in game theory between perfect information and *imperfect information*. In a game of perfect information each information set is a singleton; otherwise it is a game of imperfect information.

What are the pure strategy Nash equilibria to the coordination games in Figure 4? The game in panel (a) has two equilibria for (A,B): (EARLY, LATE) and (LATE, EARLY). The total payoff from (EARLY, LATE), exceeds that from (LATE, EARLY), but there is no way in this noncooperative game structure for Farmer A to necessarily persuade Farmer B to undertake that option.

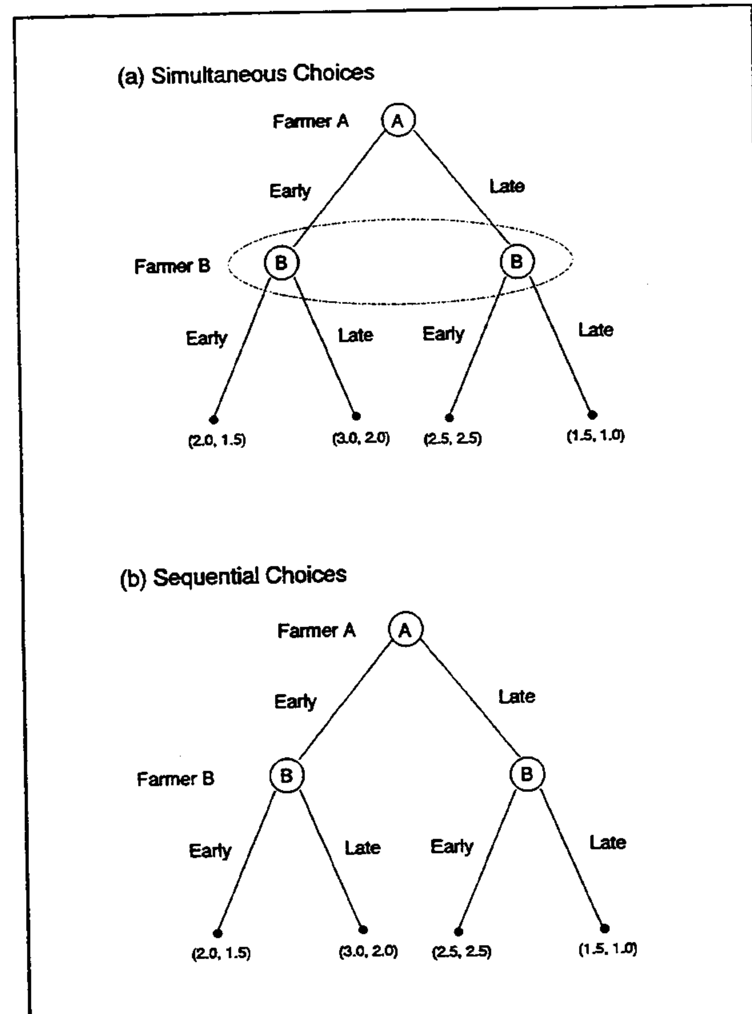

Figure 4 Coordination Games Between Farmers

Farmer B's strategy choices are complicated somewhat in the game depicted in panel (b). They must specify his move in response to either of A's possible actions. Three Nash equilibrium strategy combinations emerge:

1. (EARLY, if EARLY then LATE; if LATE then EARLY) with outcome that A plays EARLY and B plays LATE.
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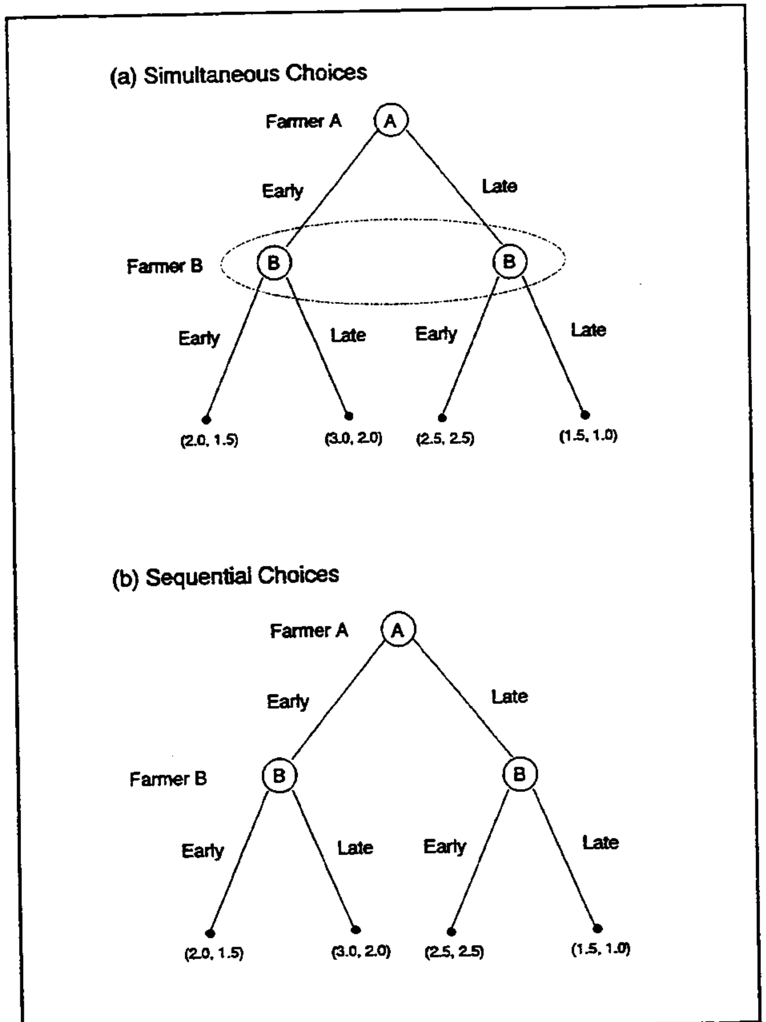

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2. (LATE, if EARLY then EARLY; if LATE then EARLY) with outcome that A plays LATE and B plays EARLY.

3. (EARLY, if EARLY then LATE; if LATE then LATE) with outcome that A plays EARLY and B plays LATE.

Now is a good time to introduce an important refinement of Nash equilibrium--the concept of *subgame perfect equilibrium (SPE)* due to Selton (1975). The game depicted in Figure 4(b) is dynamic in that A moves first and B observes his move. Yet the construct of Nash equilibrium requires A to take B's strategy as given in choosing his own move. This fact tends to produce Nash equilibria in dynamic games that involve noncredible threats on the part of some player(s). Both the second and third equilibrium to the game in panel (b) involve such threats. Equilibrium 2 involves a threat by B to play EARLY regardless of A's action. Taking this strategy as given, A's best reply is LATE. However, if A chose EARLY so that it was *fait accompli*, B's optimal response is to choose LATE, not EARLY. Similarly, the threat to play LATE if LATE in equilibrium 3 makes no sense, yet because B is never called upon to make that move in equilibrium, the strategy combination is a Nash equilibrium.

Subgame perfection works to eliminate noncredible threats. To understand the concept it is necessary to define a *subgame*. A subgame is a game consisting of a node that is a singleton for all players, that node's successors and the payoffs at the associated end nodes. The game in Figure 4(b) has three subgames: the complete game itself and the games beginning at nodes B_1 and B_2. Conversely in panel (a) the only subgame is the game itself. The game of entry and entry deterrence in Figure 3 has two subgames: the game itself and the game beginning at the node following the entrant's choice of IN. The moral hazard game in Figure 1 also has two subgames.

A SPE is a set of strategies for each player such that the strategies comprise a Nash equilibrium for the entire game and also for every subgame. Subgame perfection requires strategies to be in equilibrium everywhere along the game tree, not only along the equilibrium path.

The concept is exceedingly useful for analyzing dynamic games of perfect information such as those depicted in Figures 1,3 and 4(b) and also games that Tirole (1988) calls *games of 'almost perfect' information*. These are dynamic games where at a given date t players choose actions simultaneously knowing all actions taken during the preceding periods 1,...,t-1. The within-periods simultaneity is a deviation from perfect information. The most common example of these games are *repeated games* where players repeatedly play a simultaneous single period game, such as a prisoners' dilemma or choices of price or quantity by oligopolists in a static market environment.

The virtues of the SPE concept are twofold: SPE are usually straightforward to derive using *backward induction*, and requiring subgame perfection is often very effective at eliminating nonplausible Nash equilibria in dynamic games. Solution by backwards induction involves proceeding to the final play (a node whose successors are all end nodes) and deriving the optimal behavior for the player who has the move at that node. The solution at this point will be simple common sense; the player will choose whatever option maximizes his payoff among the alternatives. That portion of the game tree can then be replaced with the optimal action to take place there and the associated payoffs, and the analyst can proceed up the game tree to the next node or set of nodes. Optimal play can be derived here given that it is now known what will transpire subsequently. In this manner the game can continue to be folded back and solved. The manner in which the solution is derived insures that the properties of a SPE are satisfied, i.e., optimal behavior was derived at each node.[5]

The backwards induction algorithm can be used to solve the dynamic games posited thus far in this paper. In Figure 1's post-contractual opportunism game, if the agent gets the move, his best response is to exert LOW effort. Given the Nash equilibrium to this subgame, the grower's best response at his move is to vertically integrate. Thus (INTEGRATE, LOW) is the unique SPE.

Subgame perfection eliminates one of the equilibria in the entry-deterrence game. Given a choice of IN by the entrant, the monopolist's best response in the ensuing subgame is to ACCOMMODATE. Given accommodation, the entrant's best move at his play is to choose IN. Thus, (IN, ACCOMMODATE) is the unique SPE, and the Nash equilibrium (OUT, PREDATE) is eliminated because predation is not an equilibrium response to IN by the incumbent. In this manner, subgame perfection eliminates equilibria that involve noncredible threats.

Finally, the coordination game in Figure 4b had three Nash equilibria. It should be clear that two of them involve noncredible threats by B, and will not satisfy the requirements of subgame perfection. These are the threat to play EARLY in response to EARLY by A in the second equilibrium, and the threat to play LATE in response to LATE by A in the third. The unique SPE then involves A playing EARLY and B playing LATE.

Consider now dynamic games with "almost perfect" information. Two classic examples exist in the literature—the iterated prisoners' dilemma and the *chainstore game* made popular by Selton (1978). They are useful to consider because they suggest the failure of subgame perfection in certain contexts which has led to the consideration of further refinements of equilibrium.

Consider playing a prisoners' dilemma game some large but finite number of periods. Whereas the Nash equilibrium of mutual finking and joint punishment is intuitive in any single play of the game, it seems sensible that as the players repeated the game several times they would eventually learn to cooperate with each other and, thus, each achieve a better payoff. Such is not the case. Solving the game via backward induction, it is clear that mutual finking is the unique Nash equilibrium in the final period, because there can be no gain from playing a cooperative strategy. Since the final period's play is now determinate, there is no gain from cooperating in the penultimate period, so mutual finking ensues there also. And so the game unravels to produce a unique SPE wherein each player finks at any and every opportunity.

The chainstore game is essentially a many period replication of the entry-deterrence game of Figure 3. Whereas accommodation of a single entrant makes sense, the intuition is that a firm facing entry in different markets in successive periods ought to respond aggressively early in the game (choose PREDATE) in hopes of deterring subsequent entrants. Such is not the case, however, as the SPE calls for accommodation and entry in every period, a solution easily verified by backward induction.

1.2.1 Infinitely Repeated Games

If the game is repeated infinitely, the backward induction algorithm that generated the SPE described above breaks down; there is no final period to solve to begin folding the game back. The fundamental result for infinitely repeated games is the *folk theorem* which asserts that almost any outcome can be a Nash equilibrium provided players are sufficiently patient (don't discount the future too heavily). The idea is that any feasible, individually rational payoffs can be supported as a Nash equilibrium by the players espousing strategies to punish anyone who deviates from the prescribed equilibrium path. These strategies will satisfy the properties of a Nash equilibrium if the one period gain from cheating does not exceed the subsequent discounted losses from punishment.

Such strategies need not be subgame perfect, i.e., players may not have incentive to play their threat strategies if actually called upon to do so. However, restricting attention to SPE is not helpful in infinitely repeated games as another version of the folk theorem shows that this refinement does not reduce the limit set of equilibrium payoffs.[6]

What are the implications of repeated games and the folk theorems for applied researchers who may wish to use game theory? Most fundamentally, considerable suspicion is called for if anyone puts much

emphasis on a particular equilibrium for an infinitely repeated game. A second point is that infinitely repeated games are not very reflective of real-world contexts. Most decision makers do not have infinite horizons, but it is notable that this feature does not undermine the message of the folk theorems because the theorems also hold for games with a finite probability of ending in any period, provided this probability is sufficiently low.[7]

A more significant indictment of repeated games (whether finite or infinite) is that life does not usually involve repeated play of the same game. For example, a firm that cheated in Friedman's model (see note 8) might capture customer loyalties or achieve learning curve advantages that would influence play in subsequent periods. Consider also repeated play of Figure 1's moral hazard game. LOW effort by an agent may be interpreted to mean letting product quality deteriorate. Consequentially, consumers may be alienated from the product in subsequent periods, and, hence, the structure of those games is altered. In other words, what happens today usually affects the games to be played in the future.

The main virtue of repeated games lies not in their value as realistic modelling paradigms, but, rather, in suggesting, through the stark results they generate, that richer and more realistic specifications of the game environment are called for.[8] Providing richer game structures has also inspired further refinements in equilibrium that we now examine.

1.2.2 Games of Incomplete or Imperfect Information

An element missing from either the iterated prisoners' dilemma or chainstore games is reputation. It would seem that the "prisoners" have a great interest in acquiring a cooperative reputation. Similarly the chainstore should value a reputation as one who responds aggressively to entry. These elements have no way of emerging in the prototype finite-horizon versions of these games. Another important game that illustrates a shortcoming of finite-period, perfect-information games is Rosenthal's *centipede game* (1981) illustrated in Figure 5. By playing their cards right players (i.e., choosing DOWN) A and B can each secure payoffs of 10 in this game. Yet the unique SPE results in A playing RIGHT at his first opportunity, leading to payoffs of (0,0).

The intuition in the iterated prisoners' dilemma or centipede games is that a player might "take a chance" on playing cooperatively at the outset just to see what might happen. The backward induction algorithm of subgame perfection does not permit this intuition to emerge. The environment where it can emerge is in games of *incomplete information*. Analysis of these games was facilitated

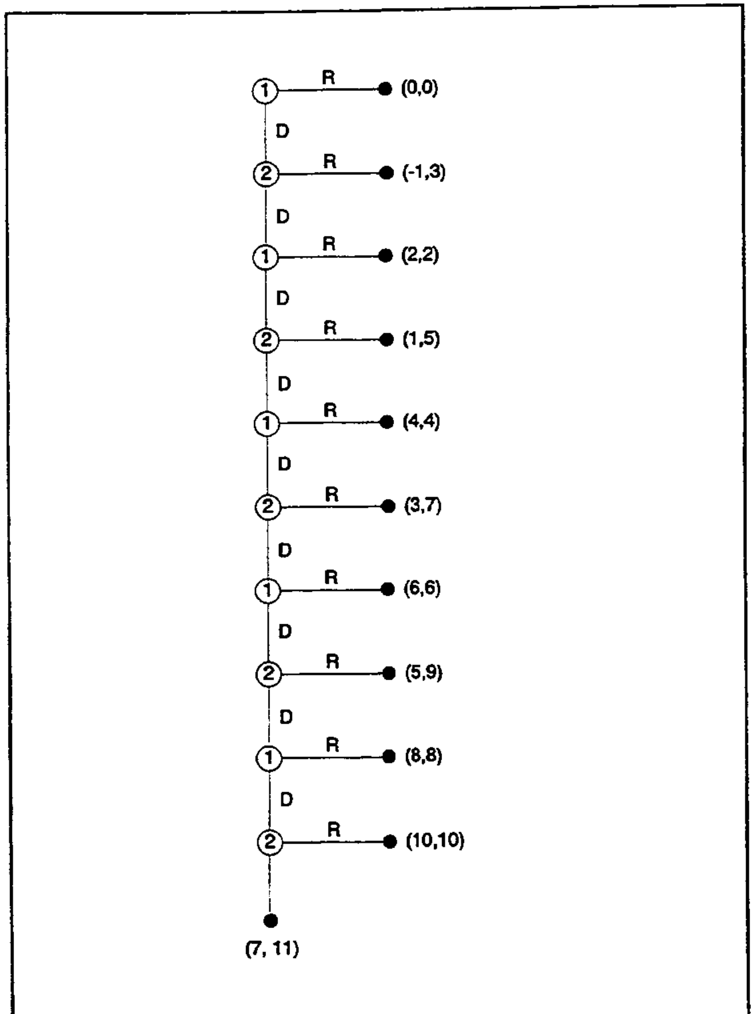


Figure 5 The Centipede Game

Harsanyi's observation (1967) that a game with incomplete information could be transformed into a game with imperfect information by introducing *Nature* as a player who moves first at the outset of a game. The choices made by Nature define a player's *type*, including possibly his strategy set, payoff functions, and knowledge concerning locations on the game tree—*information partition* in game theory parlance. When nature moves in these environments, she is said to establish a *state of the world*.

I will illustrate the modelling procedure for games with incomplete information and describe the refinements in equilibrium they have inspired. We can then demonstrate how incomplete information can be used to unravel the logic that produces the paradoxical equilibria in the games just discussed.

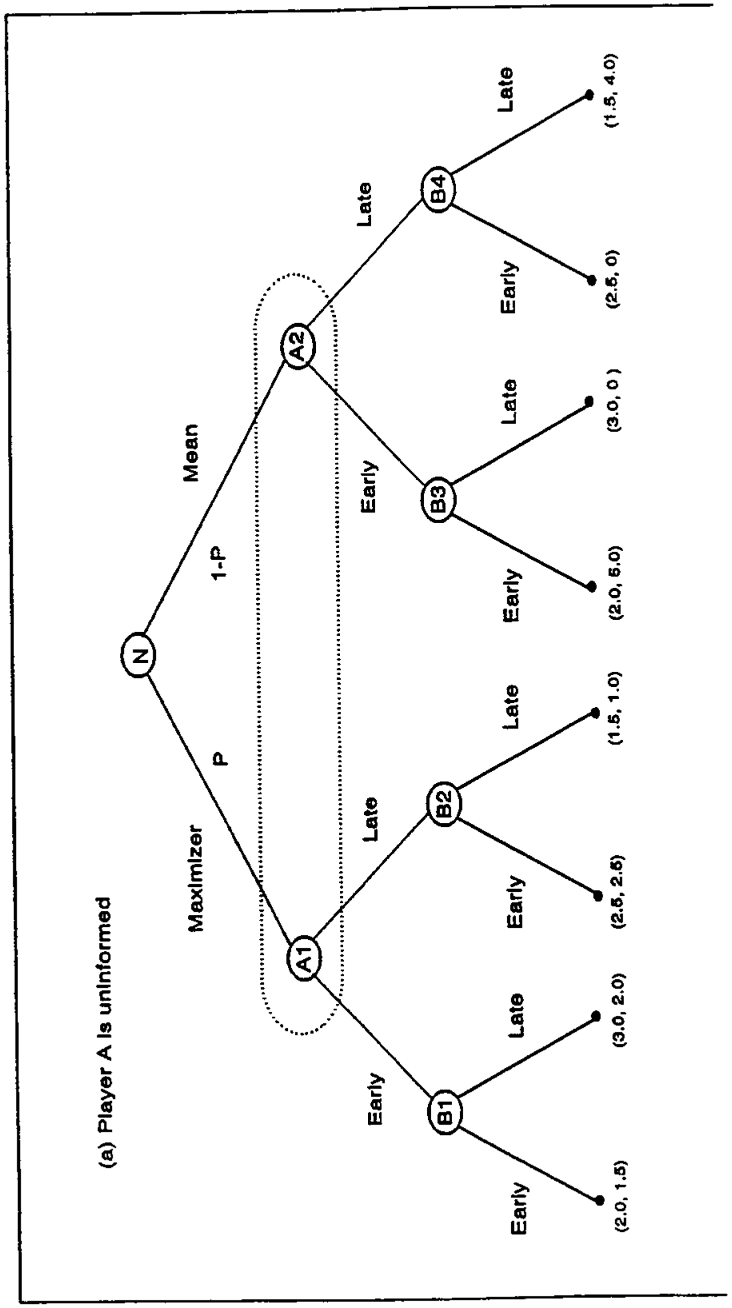
Figure 6 illustrates the modelling process for the sequential-choice version of the coordination game among farmers. The incomplete information concerns player B's type. He might be either a "profit maximizer" or "mean spirited." A profit-maximizing B has the same payoffs as in Figure 4. A mean-spirited B, however, obtains utility from inflicting pain upon his neighbor, and, hence, will always time his planting to diminish A's payoff. The way to model this uncertainty is to let Nature choose between (maximizer, mean) with probabilities (P, 1-P).

Moves by Nature at the outset of a game convert the game to one of incomplete information whenever at least one of the players is uninformed of Nature's choice. If some players observe nature's choice and others do not, then the game involves *asymmetric information*, and some players have valuable *private information*.[9]

In figure 6 the more sensible alternative is that A is uninformed, which produces the extensive form in Figure 6(a). The less realistic alternative in this particular example but the alternative with more important consequences for game theoretic modelling is that B is uninformed as illustrated in Figure 6(b). The dotted lines depict information sets which are not singletons. In Fig. 6(a) Farmer A does not know Nature's choice and, hence, whether the actual node is A_1 or A_2. Player B's information sets are all singletons because he observes both Nature's and A's move.

In Fig. 6(b) B cannot distinguish between B_1 and B_3 or between B_2 and B_4. The introduction of incomplete information in the manner depicted in Fig. 6(a) does not complicate solving the game in any meaningful way. A knows that Maximizer B will choose the opposite f A's choice of EARLY or LATE, and Mean B will choose the same as A. To solve this type of game, A is assumed to have a von Neumann-Morgenstern utility function and choose between {EARLY, LATE} to maximize his expected payoff. In this case EARLY is a dominant choice for A regardless of the value of P, so equilibrium involves A choosing EARLY and B choosing EARLY (LATE) if he is mean spirited (a profit maximizer).

The type of game depicted in Fig. 6(b) is interesting because it possibly allows the uninformed player to update his information based upon the informed player's move.[10] This type of scenario has prompted further important refinements of Nash equilibrium.



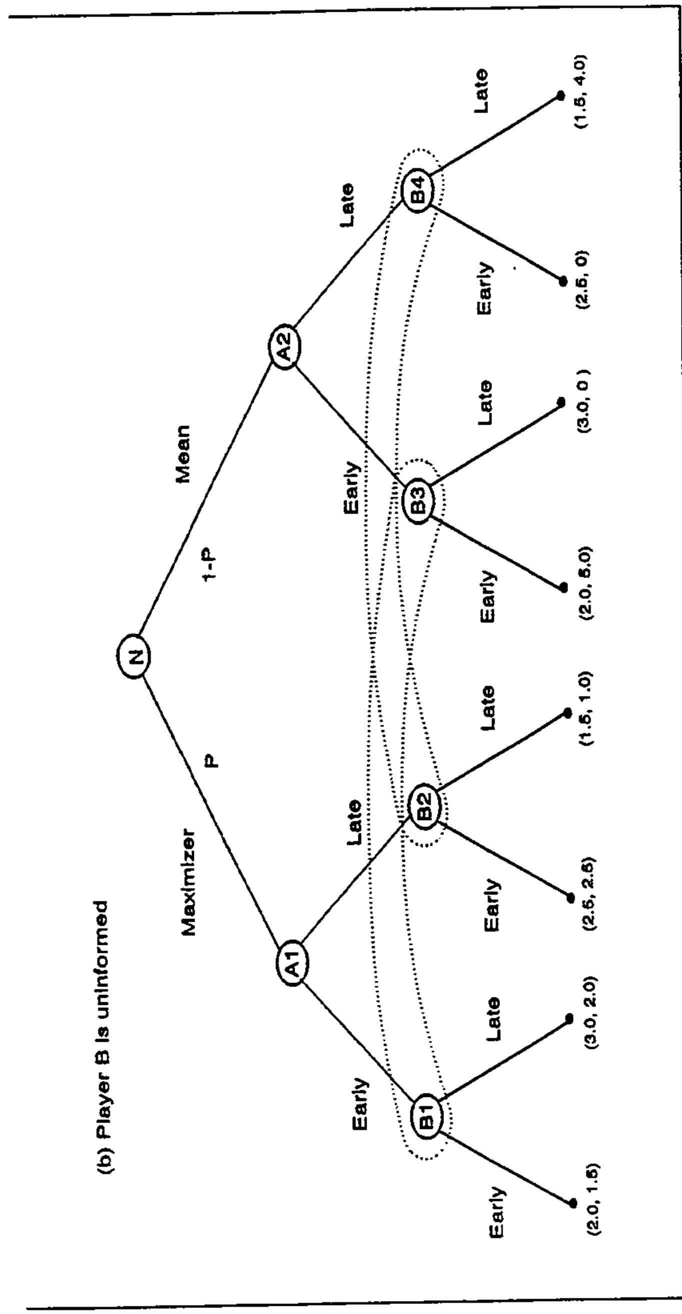


Figure 6 Coordination Between Farmers Under Incomplete Information

Figure 6(b) illustrates the problem that arises for subgame perfection as a solution concept for these types of games. Because of the imperfect information, the nodes where B moves are no longer subgames; none of nodes B1 - B4 are singletons. Thus, the only subgame is the entire game itself, and requiring subgame perfection does not eliminate either of the Nash equilibria that involve noncredible threats.

It is natural that a refinement of Nash equilibrium to accommodate games of incomplete and asymmetric information should consider both players' strategies and their beliefs and the manner in which those beliefs are updated as the game is played. A refinement that accomplishes this objective is *perfect Bayesian equilibrium* (PBE). In a PBE players' strategies are optimal given their beliefs and beliefs are obtained from strategies and observed actions using Bayes' rule whenever possible.[11]

The following formal definition of a PBE is due to Rasmusen: A PBE consists of a strategy combination and a set of beliefs such that at each node of the game: (1) the strategies are Nash for the remainder of the game, given the beliefs and strategies of the other players, and (2) the beliefs at each information set are rational given the evidence, if any, from previous play in the game. Condition (1) is a perfectness condition, and condition (2) says that beliefs should be formed using Bayesian updating whenever possible.[12]

There is no general solution method to calculate PBE comparable to the backward induction algorithm for SPE. Rather, solution is a thought process that involves proposing plausible strategy combinations and testing to see if they are best responses (i.e., Nash). Then each player's strategy is tested at each node to see if it is a best response given the player's beliefs at each node. Out-of-equilibrium beliefs and strategies are an important part of constructing a PBE. In particular, the analyst must check whether any player would like to take an out-of-equilibrium action in order to influence other players' beliefs.

To further develop the PBE concept, I will illustrate its application to an important class of incomplete information games—the *signalling game*.

1.2.3 Signalling Games

The basic signalling game is a two-period dynamic game. The player who moves first (the leader) has private information about his type that affects the player who moves last (the follower). Signalling's origin is Spence's model of education published in 1973 without the benefit of the formal concept of PBE. The model has proven to be rich in application in the succeeding years.

The following definition of PBE for a signalling game is from Fudenberg and Tirole (1989). Player 1 (the leader) observes private information as to his type t_1 and chooses action a_1. Player 2 observes a_1 and chooses action a_2. Payoffs for each player are $\pi_i(a_1,a_2,t_1)$. Prior to play, player 2 has beliefs $P_1(t_1)$ concerning player 1's type. Player 2 can update his belief about t_1 based upon his observation of 1's action, a_1. Denote this posterior probability as $P_1^*(t_1/a_1)$. However, player 1 anticipates that his action will influence player 2's posterior beliefs and, hence, his action. A PBE is a set of strategies $a_1^*(t_1)$ and $a_2^*(a_1)$ and posterior beliefs $P_1^*(t_1/a_1)$ that satisfy the following conditions:

1. $a_1^*(t_1)$ maximizes $\pi_1(a_1,a_2(a_1),t_1)$,
2. $a_2^*(a_1)$ maximizes $\sum_{t1} P_1^*(t_1/a_1)\pi_2(a_1,a_2,t_1)$
3. $P_1^*(t_1/a_1)$ is derived from the prior P_1, a_1, and Bayes rule whenever possible.

Conditions 1 and 2 are perfectness conditions, and condition 3 is the Bayesian updating requirement. Notice that condition 1 requires player 1 to take into account his role in influencing player 2's action. The qualifier on condition 3 is important because Bayes rule is not applicable for events that occur off the equilibrium path. These events occur with zero probability, which implies a division by zero in Bayes formula (see note 14), making the posterior undefined. Any posterior beliefs are compatible with Bayes rule in these cases. This result, in turn, admits many perfect Bayesian equilibria for some games and has inspired a search in recent years for what Rasmusen terms "exotic refinements" to eliminate some of the equilibria.

To illustrate the construction of PBE in a signalling game, consider Spence's model of education. Workers can be either HIGH or LOW ability based upon Nature's choice. Employers cannot observe ability, but they know the distribution of abilities and can observe workers' education levels. For simplicity a worker's strategy set is assumed to be dichotomous: {EDUCATION, NO EDUCATION}. Education is costly, but it is less costly for high-ability workers, i.e., they don't have to work as hard at it. Thus, education may provide a means for high-ability workers to signal their attribute, but it does not augment their ability. However, depending upon the relationship between wages and education, low-ability workers may also acquire education and thereby masquerade as high-ability workers.

Whether or not players succeed in signalling their types is an important dimension of signalling models. A PBE where signalling does distinguish among types is known as a *separating equilibrium*. A PBE where the types remain undistinguished is known as a *pooling equilibrium*. Many signalling games have both types of equilibria.[13]

In general three types of constraints must be satisfied to establish a separating equilibrium:

1. Participation—in games where the uninformed player is offering contracts to the informed players, the contracts offered in equilibrium must be financially viable for the uninformed player.

2. Incentive compatibility—in the context of the education game, low-ability workers must not be attracted to the high-ability workers' contract.[14]

3. Nonpooling—high ability workers must prefer their contract to the contract that emerges if all workers pool (and no one obtains education).

In a separating equilibrium observing the equilibrium choices of the informed players allows a complete inference to be made as to their types. In the context of the education model the posterior probability is P^*(HIGH/EDUCATION) = 1.0. Moreover, in games like the education model with dichotomous strategy sets, there is no need to specify out-of-equilibrium beliefs because both actions (EDUCATION, NO EDUCATION) may be observed in equilibrium. However,in a model with a continuous strategy space it is still necessary to assign probabilities to actions neither type of player would take in equilibrium.

Both types of players elect the same strategy in a pooling equilibrium. In the education model, depending upon parameterizations, pooling equilibria may involve both types acquiring education or neither type acquiring it. In a pooling equilibrium both types of players receive the same payoff—a composite of the payoffs for high- and low-ability workers in a separating equilibrium. The intuition for a pooling equilibrium is that it may not be worthwhile for the high-ability workers to incur the cost necessary to signal their type, or, alternatively, that it may be worthwhile for the low-ability workers to masquerade as high ability by acquiring education.

Because only one action is observed in equilibrium in a pooling equilibrium, the specification of beliefs off the equilibrium path is a crucial part of defining the PBE. Changing this specification may well cause the pooling equilibrium to break down. For example, P^*(LOW/EDUCATION) = 0 will not support a pooling equilibrium where neither type of worker obtains education under reasonable parameterizations of the game because high-ability types would want to acquire education. It is important to stress that, because Bayes rule does not apply to out-of-equilibrium actions, one choice for $P^*(\ )$ is technically as valid as any other under the PBE concept. This feature, as noted, has inspired the search for further refinements.

Explicit derivation of equilibria for the education signalling game requires formal parameterization of a model. Rasmusen, Ch. 9, provides several illustrations.

To further examine the application of PBE, consider the limit pricing model of Milgrom and Roberts (1982a). Milgrom and Roberts wished to show that limit pricing might emerge as a rational strategy under incomplete information. The asymmetric information concerns the incumbent's unit costs, which may be either HIGH or LOW and denoted respectively as c_H and c_L. If the entrant enters, he incurs a sunk cost $K > 0$, and post-entry play is assumed to be Cournot. Let the entrant's profits net of K be denoted by π_E and assume that

$$\pi_E(c_H) > 0 > \pi_E(c_L),$$

i.e., entry is profitable if the incumbent is high cost but not if he is low cost.[15]

Signalling enters the Milgrom-Roberts model because a low-cost incumbent produces more and charges less than a high-cost counterpart under normal conditions. For example, denote the static profit-maximizing monopoly outputs for high- and low-cost incumbents as $q^M(c_H)$ and $q^M(c_L)$, respectively. However, producing $q^M(c_L)$ may not be sufficient for a low-cost incumbent to signal its type because a high-cost incumbent may be willing to produce this output, thereby reducing its period 1 profit in order to masquerade as low cost in hopes of deterring entry.

Milgrom and Roberts show that this model also tends to have both pooling and separating equilibria. A separating equilibrium involves the incumbent producing an output, $q^*(c_L)$ sufficiently in excess of $q^M(c_L)$ that a high-cost version would not be tempted to pool (constraint no. 2 above) and, rather, would choose $q^M(c_H)$. The entrant correctly infers this result and chooses not to enter if it observes $q^*(c_L)$. To complete specification of the PBE, posterior beliefs, $P^*(\ )$ on the part of the entrant for outputs other than $q^*(c_L)$ or $q^M(c_H)$ must be specified that support the proposed equilibrium. These beliefs are arbitrary , so $P^*(\text{HIGH}/q') = 1$ for all $q' \notin \{q^M(c_H), q^*(c_L)\}$ is a valid choice to support the equilibrium.

If the cost of signalling is sufficiently great, a low-cost incumbent will instead choose $q^M(c_L)$ (constraint no. 3 above is violated) and a pooling equilibrium will ensue where the entrant enters if its expected profit is positive, given its priors on the incumbent's type. An important implication of this type of model is that the introduction of just a small probability in the entrant's mind that the incumbent is high cost possibly causes the rational low-cost incumbent to *discretely* increase its period 1 output above its profit-maximizing monopoly level to signal its type.

1.2.4 Reconsidering the Paradoxical Equilibria in Finite-Horizon Games

The preceding observation is key to unraveling the paradoxical equilibria in the iterated prisoners' dilemma, chainstore, and centipede games. The key references are Kreps and Wilson (1982b) and Milgrom and Roberts (1982b) on the chainstore game and Kreps, Wilson, Milgrom, and Roberts on the prisoners' dilemma. The modelling approach is similar in each case. The game is converted to one of incomplete and asymmetric information by introducing the probability that a player's type is not as modelled in the original specifications of the game. For example, Kreps *et al.* consider the possibility that one of the "prisoners" can only play a "tit-for-tat" strategy that calls for him to cooperate at the outset of play and at any subsequent period t if his opponent cooperated at period t-1. Or in the chainstore game, the possibility of a "rapacious" incumbent who enjoys predation is introduced by Kreps and Wilson.

A key facet of these (and any other) games is that the game structure is *common knowledge*. This means that each player knows the configuration of the game tree and the other player(s) know that he knows and so on. This point is important because it means that an informed player has an opportunity to exploit an uninformed player's uncertainty. For example a rational (non tit-for-tat) prisoners' dilemma player can play cooperatively at the outset of the game to give the impression that he is tit for tat. The other player is not fooled by this behavior, but, nonetheless, as long as his partner is playing cooperatively, it may be in his interest to play along by choosing to cooperate also.

Analogously, in the chainstore game, a nonrapacious incumbent has incentive to predate during the early periods of play of this game to perpetuate the possibility in entrants' minds that he is rapacious. Potential entrants, being aware that even a nonrapacious incumbent may fight entry during early periods of play, elect rationally not to enter.

Introducing uncertainty into these models is, thus, seen to rather drastically alter the equilibria from the stark results obtained by applying subgame perfection to the perfect information versions of these games. The new equilibria call for players in the prisoners' dilemma to cooperate in early periods and only fink towards the end of play, or in the chainstore game for the incumbent to fight entry in early periods and accommodate only towards the end of play. These outcomes comport better with intuition and, moreover, with actual play of the games in experimental settings (see, for example, Axelrod 1984 and McKelvey and Palfrey 1992). A further key point is that these new equilibria are obtained even with very modest degrees of uncertainty, e.g., low probabilities that a prisoner is tit for tat or an incumbent is rapacious.

1.2.5 Further Refinements

I turn now to discuss briefly other refinements to Nash equilibrium that have emerged in the literature in recent years. Two equilibrium concepts that were developed contemporaneously with PBE and have similar properties (and, hence, yield similar equilibria) to PBE are Selton's (1975) concept of *trembling-hand perfect equilibrium* and Kreps and Wilson's (1982a) *sequential equilibrium*. The idea behind trembling hand perfection is that players may make mistakes (their hands may tremble) during play of a game. A trembling-hand perfect equilibrium strategy continues to be optimal for a player even if there is a small chance that some other player will pick an out-of-equilibrium action.[16]

The concept of sequential equilibrium is also based upon the specification of strategy profiles that are Nash for the remainder of the game, given the beliefs and strategies of the other players, and updating beliefs using Bayesian inference whenever possible. Kreps and Wilson add a further consistency requirement for sequential equilibrium which for some games limits the range of equilibria relative to perfect Bayesian equilibrium. The consistency requirement, for example, would require that two players observing another player's actions should form the same beliefs as to that player's type. It also imposes consistency of beliefs over time.[17]

The concepts of SPE, PBE, trembling-hand perfect equilibrium, and sequential equilibrium can be related as follows: Every sequential, perfect Bayesian, and trembling-hand perfect equilibrium is also subgame perfect. Every trembling-hand perfect equilibrium is a sequential equilibrium, and every sequential equilibrium is also a perfect Bayesian equilibrium but not vice-versa.

As noted, the problem of multiplicity of PBE due to the arbitrariness of out-of-equilibrium beliefs has stimulated the search for ways to restrict these beliefs and, hence, limit the admissible PBE. This is an area of considerable on-going research, and I will attempt here to only illustrate briefly the spirit of some of the refinements. A book by Van Damme (1987) provides a comprehensive discussion, although some work has been accomplished since its publication date.

A main motivation for the further refinements has been to eliminate out-of-equilibrium beliefs that do not make sense. These refinements are often called *intuitive criteria*. One specific avenue to pursue is the notion that if an action is dominated for some type of player (conditional upon subsequent equilibrium behavior) but not another, then, upon observing that action, posterior beliefs should assign zero probability to the type for which the action is dominated. Milgrom and Roberts (1982a) applied this criterion in their limit pricing game to find a unique separating equilibrium rather than a continuum of such equilibria.[18]

Another criterion due to Cho and Kreps (1987) is to look at strategies dominated by the proposed equilibrium outcome. This intuitive criterion tends to eliminate more strategies than the simple dominance criterion discussed above. Consider a proposed equilibrium with payoff $\pi^*(t_1)$ for a player of type t_1. Now consider that player 1 deviates from his equilibrium strategy and plays the out-of-equilibrium action a'. It is said that a' is *equilibrium weakly dominated* for type t_1 if for any optimal response $\mathbf{a}^+$ to a' by other player(s), the payoff for type t_1 is no greater than $\pi^*(t_1)$ and is strictly less for some $\mathbf{a}^+$. The point is that if players of a certain type have no incentive to take the observed out-of-equilibrium action, then other players should place no probability weight on those types upon observing the action, i.e., the posterior $P^*(t_1/a') = 0$.

Further discussion of refinements is beyond the scope of this paper, but those interested in serious pursuit of the subject can consult papers by McLennan (1985), Kohlberg and Mertens (1986), Grossman and Perry (1986), Banks and Sobel (1987), and Fudenberg, Kreps, and Levine (1988).

1.2.6 Problems in Noncooperative Game Theory

I conclude Part I of this paper by summarizing what are considered to be some of modern game theory's major problems. See Kreps (1990a) and Sutton (1990) for a more complete discussion. A first observation is that game theory requires clear and precise specification of the rules of the game. This means that modes of "free-form" competition are not amenable to game theory analysis. More significant is the problem that the equilibria of games often shift dramatically due to seemingly minor modifications of the rules. This situation is observed most vividly in games of bargaining, a subject of discussion in Part II. Related to this point is Kreps' concern that the rules of the game are specified exogenously by the analyst and taken for granted. Where do the rules come from? Might they be endogenous? It would seem that the only response to these concerns is to reiterate Rubinstein's (1991) point that careful specification of the rules of the game is the essence of game theoretic modelling and why indeed it is an "art."

A problem discussed by both Kreps and Sutton is the multiplicity of equilibria that often emerge and the associated problems of choosing

among them. As Sutton (p. 506) notes, "given any form of behaviour observed in the market, we are now quite likely to have on hand at least one model which. . . [derives] that form of behaviour as the outcome of individually rational decisions." This problem has led to the search for refinements as we have just seen, but Kreps and Sutton are also concerned with the method of most refinements. Most refinements focus upon out-of-equilibrium actions, but Kreps notes that most are "based on the assumption that observing a fact that runs counter to the theory doesn't invalidate the theory in anyone's mind for the rest of the game (p.114)." This concern has led Kreps to focus on so-called *complete theories*, whereby no action is absolutely precluded, but out-of-equilibrium actions are held to be unlikely *a priori* (see Fudenberg, Kreps, and Levine 1988).

Kreps' final concern is with the mode of equilibrium analysis itself. Again, to quote:

> Equilibrium analysis is based formally on the presumptions that every player maximizes perfectly and completely against the strategies of his opponents, that the character of those opponents and their strategies are perfectly known (or any uncertainty on the part of one player about another player is fully appreciated by all the players and the strategy as a function of the other player's character is also known), and that players are able to evaluate all their options (p.139).

The point is that none of these conditions are met fully in reality, and the approximation may be appropriate in some cases but not others.

Part II: Applications to Agricultural Markets

Noncooperative game theory as applied to analysis of markets is fundamentally a theory of imperfect competition. If the tenets of classical competition are met, there is no scope for strategic behavior. In assessing this statement recall that imperfect competition can be caused by either small numbers of players, imperfect information, or both.

In considering applying noncooperative game theory in agricultural markets, we must first evaluate the importance of imperfect competition in this sector, a topic of some controversy. For example, Wohlgenant (1989) and Holloway (1991) were unable to reject a hypothesis of no market power for US food manufacturing in most aggregate product categories. Other studies, though, offer quite different conclusions.

The comprehensive analysis of the US food marketing system contained in Connor, Rogers, Marion, and Mueller (1985) and Marion (1986) suggests that seller market power may be important at most levels of the food chain, except the raw product (farm) level. Econometric studies of single sectors in the food industry such as meat (Schroeter 1988, Schroeter and Azzam 1990, and Azzam and Pagoulatos 1990), fruit (Wann and Sexton 1992), and dairy (Haller 1992) support this conclusion.

Traditional seller concentration is only one dimension of imperfect competition in agricultural markets. Another potentially important dimension may be the exercise of monopsony or oligopsony power by processors and handlers over farmers. Because agricultural products are often bulky and/or perishable, they are costly to transport. This observation implies that markets for raw agricultural products are spatial markets, an arena where imperfect competition is almost certain.[19]

Finally, imperfect competition in the international trade of many agricultural products seems to be the norm. In large part this condition is caused by the intervention of marketing boards and state trading companies to govern export trade and centralized import authorities to control purchases of food products. An extensive game-theory-based strategic trade literature has arisen to analyze imperfect competition in trade (see Krishna and Thursby 1990 for a survey), although, as Carter and McCalla (1990) note, "virtually none of the agricultural trade modelling to date has incorporated these new theoretical developments (p. 2)."[20]

A characteristic of agricultural markets upon which there is probably general agreement is that imperfect information and uncertainty are often important. The analysis in Part I demonstrated that uncertainty opens the door to strategic behavior particularly when the uncertainty or lack of information is asymmetric across agents. Such informational asymmetries are important in agricultural markets. For example, processors are probably often better informed about market demand conditions than are farmers. Processors may have incentives to exploit these informational advantages, whereas farmers have incentives to encourage processors to reveal truthfully their knowledge of market conditions.

By the same token, farmers in many cases will have informational advantages over processor-handlers concerning their characteristics as growers. In the simplest signalling model context, a grower might be HIGH or LOW quality, with HIGH-quality growers' problem being to signal their type to processors, while LOW-quality types try to masquerade. Quality of the agricultural product itself is an issue in

many contexts, opening the door to interesting *adverse selection* problems. Although product quality is always important, it becomes a subject for game theory only when information as to quality is asymmetric, e.g., the handler knows whether the produce is fresh, but the retailer does not and verification is costly.

Thus, the scope for application of game theory methods to questions in agricultural marketing appears to be rather promising. In discussing potential applications I will restrict analysis to what might be called *vertical exchange mechanisms*. Indeed exchange in agricultural markets takes place under a great variety of mechanisms, and, with the exception of classical competitive exchange, most are amenable to analysis through the methods of noncooperative game theory. Omitted under this focus is consideration of the horizontal coordination that comprises modern oligopoly/oligopsony theory. Arguably this class of applications is more familiar than those I will discuss here, and they are already lucidly compiled, although with no special reference to agriculture, in Tirole (1988) and the *Handbook of Industrial Organization* (Schmalensee and Willig 1989).

The four categories of exchange mechanisms discussed in this paper include: Principal-agent models with asymmetric information, the economics of vertical control, auctions, and collective bargaining. The distinction between the first and second topics is artificial because vertical control problems are essentially principal-agent problems. I separate out the topic because it has a well-established literature in its own right.

2.1 *Principal-Agent Models*

The *principal* is the entity who hires the *agent* to perform some task. In almost all cases, the agent acquires an informational advantage at some point in the game as to his type, actions, or other states of the world. Contexts for application of this basic model in agricultural markets may be several. Some applications may involve the farmer or grower as the principal seeking to contract with a marketing firm as agent to sell his production. The agent may have specialized knowledge as to his own ability, market conditions, etc. Alternatively, a process/handler may be modelled as the principal who seeks farmers to grow products to his specifications. Growers may have specialized knowledge as to their types, production costs, etc.

Potential applications of the model need not be limited to the first-handler level either. It may be useful, for example, to model the behavior of a large retail food chain seeking manufacturers of private-label products as a principal and the manufacturer as an agent. Or in some contexts it may be useful to consider a manufacturer as the principal and retailing firms as the agents.[21]

Key references on principal-agent models are Arrow (1985) and Hart and Holmstrom (1987). The models can be partitioned according to the nature of the information asymmetry. Models where the agent takes actions unobserved by the principal are known as *moral hazard models*. Models where the agent has hidden knowledge prior to contracting with the principal are known as *adverse selection models*. Adverse selection models may involve signalling, with the agent taking actions to signal (or conceal) his type to (from) the principal.

2.1.1 Models with Moral Hazard

I will frame the moral hazard problem in the context of a grower seeking a marketing agent to handle his production. This problem was introduced in Figure 1. In most principal-agent models with moral hazard the unobserved action is referred to as the agent's *effort*. This term must be interpreted broadly. In the context of a marketing firm, effort could refer to speed of transit to market for sake of freshness, proper refrigeration to retard spoilage, advertising and promotion activities, diligence in processing, etc.

The essence of the moral hazard problem is indicated by the SPE to the Figure 1 game, where, if given the opportunity, the agent accepts a contract and expends low effort, causing the grower to elect to market the product himself at a cost in terms of inefficiency. The problem arose because the grower could not observe the agent's level of effort (i.e., the action was hidden). A more sophisticated version of the moral-hazard model is obtained by assuming that, although effort is unobservable, a variable related to effort is observable. This variable may be profits, the level of output, or the per unit price that the grower receives net of any marketing costs.

In this case the problem is to design a contract based on the observed variable to elicit the optimal expenditure of the unobserved variable—effort. To model this problem, assume that the effort choice is not dichotomous but, rather, is distributed along the interval $[E_1, E_2]$. Suppose the grower cannot observe effort but can observe the revenue received for the product $R(E)$, $R'(E) > 0$. Given that production has already taken place, the grower's profit function is simply:

$$\pi(E) = R(E) - W(R(E)), \tag{1}$$

and his problem is to choose a payment schedule, $W(R(E))$, for the marketing agent as a function of revenues received so as to maximize profit.

The formulation of this problem is completed by specifying a utility function for the agent, $U(W,E)$, which is increasing in W and decreasing in E, and a reservation level, U_1, of utility that specifies the agent's opportunity cost. Any contract that the grower offers must satisfy the *individual rationality* or *participation constraint* that

$$\max\{E\}\ U(W(R(E)),E) \geq U_1. \tag{2}$$

Secondly, the grower wishes the marketing agent to voluntarily expend the level of effort, E^*, that maximizes $\pi(E)$. This condition is known as the *incentive compatibility constraint*:

$$E^* = \operatorname{argmax}\{E\}\ U(W(R(E)),E). \tag{3}$$

The payment scheme that maximizes (1) subject to (2) and (3) is known as a *forcing contract* because it forces the agent to choose the level of E that maximizes the grower's profits.

An important complication is added to this basic moral hazard problem when the observable variable, revenues in our illustration, is observable only with noise. This complication is a very realistic consideration for agricultural contexts where markets are often rather volatile. To depict this problem, let ϵ represent a random variable that affects revenue so that now $R(E,\epsilon)$ is the revenue function. A low observed revenue can now be due either to poor market conditions or shirking by the agent.

Specification of this more realistic problem is the same fundamentally as the nonstochastic problem depicted in (1), (2), and (3) except that expected values over possible realizations of ϵ must be taken for π and U. Solution of the modified problem has proven to be exceedingly difficult unless restrictions are placed on the problem. Discussion of these issues is beyond the scope of this paper; the crucial references are Grossman and Hart (1983) and Rogerson (1985).

Repeated play and agent reputation may be ways of mitigating moral hazard problems, but some of the lessons from Part I are instructive here. In a finite horizon setting, the subgame perfect equilibrium will unravel to reveal an agent producing low quality or low effort at every opportunity, if that is the optimal response for any single iteration of the game. For reputation to have its effect, the model must be specified with incomplete information as in Kreps and Wilson (1982b) and Milgrom and Roberts (1982b). For example, if the principal entertains even a slight probability that the agent is predisposed to produce high quality or effort, the agent has incentive to actually produce high quality or effort to perpetuate that perception at least until the latter plays of the game.

As noted, this framework may yield valuable insights regarding contract structure in agriculture when the processor/handler is modelled as the principal and the grower as the agent. For example, product quality dimensions are increasingly important in today's food market.[22] Raw product quality can be influenced by farmers horticultural practices (effort), but it is also influenced by random factors that cannot be observed perfectly by the processor. Depending upon the raw product and the nature of the harvest technology, aspects of product quality may be discerned directly through grading. The processors' job in these cases is to specify contracts with growers that solicit the processor's desired quality level subject to incentive compatibility with growers and also their financial viability. Imperfect monitoring may involve inability to observe directly either farmers' horticultural practices or the characteristics of the harvested product.[23]

Contractual practices vary widely across raw agricultural product markets, and much of the variation in contracts may deal with differences across markets in the importance of and the variability in quality and, in turn, on the extent to which quality can be monitored by observation of the product or growers' horticultural practices.

2.1.2 Models with Adverse Selection

Adverse selection models differ from moral hazard models in that the former has hidden knowledge rather than hidden actions. In the principal-agent context, the principal's job is to sort out agents of alternative characteristics. These situations are modelled as games of incomplete information, where Nature selects the agent's type, and the choice is unobserved by the principal. The principal then offers one or more contracts to the agent who may accept one or reject them all.

Akerlof's seminal work on lemons (1970) introduced the problem of adverse selection. Rasmusen offers a simplified game description of the problem. In this model cars are either of two quality types (HIGH or LOW). Both buyer and seller value HIGH = 6000 and LOW = 2000, so payoffs for a buyer are either 6000 - P or 2000 - P, depending upon whether HIGH or LOW quality is purchased, and similarly for the seller we have either P - 6000 or P - 2000. Nature chooses between the two states of the world with equal probability, and the buyer cannot distinguish between the states. In this model if all cars were put on the market, the expected value of a car is 4000. But the owner of a high-quality car would not sell for this price. Hence any car priced at 4000 or any other price less than 6000 must be low quality, so the buyer will refuse to pay more than 2000. Perfect equilibrium in this model is for only low-quality cars to be placed on the market and sold for 2000.

In this prototype model with identical buyer and seller valuations,

there is no social loss from the absence of a high-quality car market. With a little more work, however, the same result can be derived when buyers' valuations exceed sellers' valuations, so trade is socially desirable, or when quality is distributed along an interval rather than dichotomously.

A number of conditions may attenuate adverse selection problems. Contracts may specify dimensions of product quality, products may be tested, and sellers may offer warranties. Adverse selection also provides a rationale for government intervention in the form of quality standards, licenses, and certification.

Another important feature of adverse selection models is that they often will involve signalling of the type discussed in Part I. For example, high-quality sellers can provide a warranty more cheaply than low-quality sellers and have incentive to do so as a means of establishing their type. Whether low-quality types will also offer warranties and induce a pooling equilibrium hinges on the cost of providing a warranty versus the costs of being pinpointed as low quality. Price itself may be used as a signal, and, depending on the model specification, the high-quality firm may use either a high price or a low price as its signal. Advertising provides another mechanism to signal quality. The reason is that the likelihood of repeat sales is greater for high-quality sellers than low-quality counterparts. Thus, advertising is relatively more valuable for high-quality sellers.

There also appears to be considerable scope for application of models of adverse selection to the agricultural sector. As noted in the prior subsection, consumers' emphasis on product quality places a premium on the sector's collective ability to provide the desired product attributes. A direct response to product quality concerns is to write contracts that specify quality standards or provide premiums or discounts for departures from a benchmark quality. Writing these contracts and monitoring them for compliance is, of course, an expensive process. Some dimensions of quality can be monitored only at considerable cost, if at all.

If the marketing sector at its various stages is unable to recognize and reward quality, the message of the adverse selection models is that high-quality will be driven out. Again, the pooling practices of cooperatives are especially worrisome in this regard. If cooperatives are less able to reward quality than other organizational forms, the equilibrium configuration across organizations calls for predominantly low-quality producers to patronize cooperatives.

In agriculture, the various quality provisions mandated by marketing orders and marketing boards may be justified as a response to adverse selection. If not for adverse selection, quality standards that proscribe products with certain characteristics merely limit consumers' choices. With asymmetric information, however, failure to impose quality standards also limits consumer choice by driving out high quality.

2.2 *Vertical Control*

Vertical control refers to the contractual practices whereby an upstream entity, usually the manufacturer, restricts the behavior of a downstream entity, usually a dealer or retailer. Vertical restraints include such contractual arrangements as franchise fees, bundling of distinct goods into a single package, quantity fixing, royalties, exclusive sales arrangements (requirements contracts), exclusive sales territories, and resale price maintenance.

In the hierarchy of vertical control, these contractual arrangements may be considered intermediate modes of control, ranging between the extremes of simple arm's length transacting with uniform prices and full vertical integration. Models of vertical control are essentially principal-agent models with the manufacturer as principal and a retailer as agent, so these interactions are well suited to modelling via the analytical devices considered so far.

The objective of the manufacturer is to select contractual instruments to maximize his profit. In modelling this interaction as a game the manufacturer moves first and offers one or more contracts. The dealer can either accept a contract or reject them all. To be accepted, a contract must insure the agent's financial viability. The dealer may take actions that cannot be monitored fully by the manufacturer or may possess private information, so much of the concern with vertical control is inspired by moral hazard or adverse selection problems.

In the absence of sophisticated contracts, a manufacturer's price, P^m, to a retailer must be in excess of marginal costs, c, to obtain profit. This deviation of price from cost introduces a fundamental externality between the manufacturer and dealer in that any dealer action that affects consumer demand impacts on the manufacturer's profit, but this impact is not considered by the dealer.

The prototypical example of this externality is the "double marginalization" (Spengler 1950) that occurs when the dealer also has market power and marks price above his cost, P^m. Double marginalization reduces the manufacturer's profits. In a simple perfect information setting, this externality can be overcome by the manufacturer setting $P^m = c$ and using a franchise fee to extract profit from the dealer or setting price at the monopoly level and imposing a resale price ceiling to prevent the dealer from implementing a further price markup. In more complex settings involving uncertainty and dealer risk aversion these contracts may no longer be desirable.[24]

2.2.1 A Single Manufacturer and Dealer

The following general framework for analyzing vertical control is due to Katz (1989). Consider a game between an manufacturer and a dealer. Revenues in the downstream industry are denoted as $R(X,Y,E,\theta)$, where X is the upstream good produced by the manufacturer at constant marginal cost, c, Y is an input used by the dealer which is purchased competitively, E denotes dealer "effort," and θ is a parameter that may represent a dealer characteristic or a realization of market demand.

The dealer's utility is expressed as $U(M,E;\theta)$, where M is income or profits; the reservation utility is U_1. The payment made by the dealer to the manufacturer is $W(X,Y,E,\theta)$. The manufacturer's objective is to implement a contract that maximizes profit to the two production levels and transfers all profit to him. As noted, the prototype solution to this problem is for W to take the following form:

$$W(X) = F(\theta) + cX,$$

where F is a franchise fee set to achieve $U = U_1$.

In essence, the manufacturer has two objectives: to provide the dealer with correct economic signals and to transfer revenues to himself. Charging price equal to marginal cost accomplishes the first objective, and the franchise fee accomplishes the second.

Simple two-part tariffs are no longer optimal in the presence of uncertainty and risk aversion. Suppose there is asymmetric information concerning the realization of θ, and, specifically, that the manufacturer is the uninformed party. An interesting possibility is that $X(\theta)$ and $X' > 0$. In this case it is optimal for the manufacturer to set $P^m > c$ to allow dealers to signal their value of θ. The manufacturer extracts profits based on the deviation of price from c but does not drive out low-θ agents, as would be the case if franchise fees were used, because F cannot be set conditional upon θ.

The converse case is that the manufacturer is informed about θ. The manufacturer can then use the contract specification to signal his value of θ to dealers. If, for example, θ refers to the sales potential of the product, high-θ types can signal by setting per unit price in excess of c. By tying his profits to the level of sales, the manufacturer credibly signals that the product has high sales potential.

A further reason for the manufacturer-dealer contract to specify price in excess of c is to prevent manufacturer moral hazard. For example, a manufacturer may commit to provide promotional support for a dealer, but if $P^m = c$, the manufacturer has no incentive to carry out the promise, and the rational dealer will not believe it.[25]

The preceding illustrations indicate that as the contractual environment becomes complex, departures from marginal cost pricing may be desirable. In these cases, further complexity in contract specification is called for to ameliorate the distortions caused by $P^m > c$. The distortions are twofold: (1) if inputs (X and Y in our formulation) are substitutable downstream, setting $P^m > c$ induces distortions in the input mix (Vernon and Graham 1971), and (2) higher costs borne by the dealer will cause him to restrict output. Alternative solutions to the first problem are for the manufacturer to invoke a royalty scheme, where the manufacturer receives a fraction of the dealers' final revenues, or a tie, where the manufacturer forces the dealer to jointly purchase both X and Y, setting their relative prices to achieve the efficient input mix. Finally, a retail price ceiling may be used to prevent a price mark up and, hence, output contraction at retail.

2.2.2 Multiple Manufacturers and/or Dealers

Several dealers competing to sell a single manufacturer's product succeeds in eliminating the double marginalization problem, but creates other problems. The manufacturer can no longer set $P^m = c$ and use a franchise fee to extract monopoly profits because the competing dealers will be unable to jointly establish the monopoly price downstream. Setting $P^m > c$, of course, encounters the distortion problems just discussed. A further problem is that competing dealers may provide suboptimal promotion of the product because of free riding among themselves. A contractual solution to this problem is to eliminate dealer competition through imposing exclusive territories. Resale price maintenance may also preserve dealer incentives by eliminating price cutting (Matthewson and Winter 1984).

A new set of issues come to the forefront in the realistic setting of multiple manufacturers. Just as multiple dealers could free ride on each other's promotional efforts, so may multiple manufacturers. When dealers carry multiple brands, the manufacturer whose advertisements attract consumers to the store may not end up getting the sale. Exclusive dealerships address this problem at a probable cost of reduced efficiency of the retail operation.

When dealers can choose from among multiple manufacturers, opportunism on the dealers' parts is a concern. In a rational-agent setting a propensity on the part of one player to behave opportunistically can be mutually detrimental because the affected party will anticipate the behavior and respond accordingly. Opportunism becomes a problem when a party has sunk assets, i.e., assets that are

dedicated to a particular task and cannot be recovered in the short term. One response to the threat of opportunism is to underinvest in dedicated assets.

The threat of opportunism is reduced if parties expect to interact over multiple periods. The asymmetric information story of Kreps and Wilson (1982b) and Milgrom and Roberts (1982b) is once again instructive in this context. An innovative response to the threat of opportunism is for the party prone to opportunism (the dealer in our context) to also invest in dedicated assets that would not be recoverable if the contracting parties failed to reach agreement (Williamson 1983). These investments, called "hostages" are a way for a player to commit credibly to not behave opportunistically.

A final way for manufacturers to overcome free ridership among themselves is to delegate decision making authority to a common marketing agent who internalizes the externalities among dealers and maximizes joint industry profits. This possibility is considered by Bernheim and Whinston (1985) and by Katz (1989), who establishes the preceding result as a subgame perfect equilibrium of a multistage game. The analogy to marketing orders and marketing boards in agriculture is clear.

2.2.3 Application to Vertical Control in Food Marketing

It would appear that the interactions where most of the important vertical control questions in agriculture arise are between processor/handlers and retailers or large food service companies. The information summarized in Connor *et al.* (1985) demonstrates that many food manufacturing industries are structural oligopolies, and the manners of control they employ in dealings with retailers have important implications for the performance of the sector and the welfare of farmers and consumers.

These games would be modelled in the usual mode with manufacturers as principals and retailers as agents. However, the emerging power of large retail food chains suggests that some role reversal with retailers as principals and food manufacturers as agents may prove illuminating. For example, an important trend in food retailing is for the retailer to impose *slotting allowances*--fees charged by the retailer to carry a manufacturer's product.[26]

The recent paper by McLaughlin and Rao (1990) on new product selection by supermarkets illustrates the potential application of noncooperative game theory to interactions at this stage of the food marketing chain. McLaughlin and Rao's study is empirical and does not employ game theory, but the process of new product selection they describe is very strategic in nature. A prototype model of the process for a dealer, but if $P^m = c$, the manufacturer has no incentive to carry out the promise, and the rational dealer will not believe it.[25]

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However, this type of multipart pricing scheme is not common at the first handler level. One reason may be that farmers could negate such a scheme through arbitrage in some cases.

"Market basket" pricing by processors is being observed in some industries. Here the grower's price is determined based on an index of the processor's price for the various processed products produced from the farm input. This arrangement is analogous to a royalty scheme but has the curious effect of shifting risk to growers.

2.3 Auctions

McAfee and McMillan (1987, p. 701) define an auction as "a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants." The strategic nature of auctions makes them a prime candidate for the application of noncooperative game theory. In particular, a seller must consider buyers' behavior in selecting the type of auction format to implement. Given an auction format, buyers' bidding strategies must incorporate an optimal response to the format and also consider the strategies employed by rival bidders. Sosnick (1963) gives an interesting, non-game-theoretic discussion of the strategic issues involved in bidding at an agricultural auction.

Auctions are a favored exchange mechanism when market prices are highly volatile and posted prices work poorly. These markets may involve many traders on both sides of the market so that the primary purpose of the auction is to facilitate discovery of the competitive market price. Examples in agriculture include fresh fish, eggs, and some fresh fruits and vegetables. Another market condition favoring auction exchange is variable quality of the good being sold. Again, posted prices work poorly and bidding is an efficient means to establish value. Livestock, wool (Whan and Richardson 1969), and used farm equipment are often sold via auction for this reason. In other instances spatial factors or other impediments to efficient marketing create "thin markets" with few sellers. Electronic auctions can be used to increase the number of bidders and improve market efficiency (Rhodus, Baldwin, and Henderson 1989).

In contrast to these "competitive market" auctions, monopoly or monopsony structures can also favor auction exchange, and most of auction theory is concerned with these types of auctions. Examples include sales of one-of-a-kind items such as antiques or art. Governments assume the role of monopsonist when they solicit bids for construction projects or the provision of public services. Government is equally comfortable in the role of monopolist auctioning off oil or mineral exploration rights. Even rights to receive government subsidies may be bid. For example, grain exporters submit bids for bonuses on sales of grain to targeted countries under both the US and EC export enhancement programs (Ackerman and Smith 1990). To complete the cycle, importing countries such as Japan auction quotas to import grain. The US recently tried to handle its surplus dairy production by having farmers bid for a subsidy payment to shut their operation down.

2.3.1 Auction Theory Basics

The key reason why monopolists/monopsonists sometimes use auctions is asymmetry of information.[27] If a monopolist knew buyers' valuations of the item offered for sale, he could simply post a take-it-or-leave-it price or prices to extract the maximum value as in the textbook analyses. The nature of this asymmetry offers a convenient classification of auctions. If potential buyers' valuations of the item are independent as in the case of antique or art auctions among collectors, not dealers, then the auction involves *independent private values*. In turn, private-value auctions can be categorized according to whether the seller recognizes differences among the bidders or whether he perceives their bids to be drawn from a common distribution--the *symmetric* bidders case. Asymmetry may arise for a number of reasons including systematic cost differences among the bidding firms.

At the other extreme is the sale of mineral rights or government securities, where the item to be sold has a *common value*, although no one knows the value with certainty. Between these two polar cases are situations where bidders' valuations are *correlated*, although they may differ. Correlation or *affiliation* of bids captures the idea that as one bidder's estimate of an item's value rises so does his expectation of the other bidders' estimates.

Participating in an auction is a risky undertaking, and players' attitudes toward risk can affect auction outcomes. Most models assume risk neutrality. Risk aversion generally works to a seller's benefit because raising one's bid is a form of insurance. That is, it decreases the probability of losing and getting a zero payoff at the cost of a reduced payoff from winning.

Although a wide variety of auction mechanisms may be considered, four types are most commonly studied. The *English* auction involves open outcry of ascending bids, with the item going to the highest bidder. In this auction a bidder's dominant strategy is to bid up to his valuation by raising lower bids by some small amount ϵ (i.e., this strategy is optimal regardless of other players' strategies). The same dominant strategy exists for a *sealed-bid, second-price* auction, where the item goes to the highest bidder who pays a price equal to the highest unsuccessful bid.[28] The English auction is, of course, widely

used, whereas the sealed-bid, second-price auction is little used, but has proven useful in modelling. When players have independent private valuations, English and sealed-bid, second-price auctions produce the same price and allocation. When values are correlated, the open outcry feature of the English auction differentiates it from the second-price auction and causes higher prices under the English format (Milgrom and Weber 1982).

A *first-price, sealed-bid* auction awards the item to the highest bidder, who pays the bid price. This auction format is strategically equivalent to the *Dutch* or descending form of open outcry auction where the auctioneer announces an initial high bid and then lowers the bid by equal increments until someone claims the item by agreeing to pay the bid price. Strategic equivalence of the two formats, both of which are used in practice,[29] follows from the fact that bidders pay their bid value in either case and have no opportunity in the case of correlated values to learn about other bidders' valuations.

Dominant strategies do not exist for these types of auctions. Rather, a player must formulate his strategy in consideration of other bidders' strategies.[30] The strategy combinations to these games comprise a Nash equilibrium when each player's strategy is optimal, given the optimal strategies of every other player.

Among the most famous results in auction theory is Vickrey's (1961) *revenue equivalence theorem* which states that all four of these auction types yield the seller the same expected revenue in the case where bidders are risk neutral and have symmetric, private independent valuations. Each auction format is efficient in this environment because the item goes to the player with the highest valuation.[31]

An important strategic feature of auction theory is the assumption that the monopoly seller or monopsony buyer can commit to the form of auction to be used. This condition raises the question as to which type of auction format is optimal for the monopolist/monopsonist under alternative game structures? A large literature on optimal auctions has arisen in response to this question. The revenue equivalence theorem provides an answer for a specific set of circumstances and auction mechanisms.

In general though, these basic auction forms can be extended in many ways by, for example, (i) specifying a reserve price below which a monopolist won't sell, (ii) charging "entry" fees to bidders for the right to participate, (iii) specifying fees or bonuses for low or high bids, etc. Analysis of optimal auctions has been simplified by the *revelation principle* (Myerson 1981) which states that, in searching for an optimal selling mechanism, it is sufficient to consider only mechanisms that induce participants to directly reveal their valuation.

Sellers' problems are thus reduced to constrained optimization problems whereby the seller chooses functions in terms of players' (truthful) valuations that assign probabilities of winning and payments to be made by each player subject to (i) participation constraints--each player earns nonnegative expected revenue, and (ii) incentive compatibility--each player is induced to reveal his valuation. See equations (1)-(3) for application of these same principles to the moral hazard problem.

In the prototype auction model with risk neutrality, symmetric bidders, and independent private values, this prescription indicates that any of the four basic auction formats is optimal *provided* it is supplemented by a reserve price that *exceeds* the seller's own valuation (Riley and Samuelson 1981).[32] This optimal price is independent of the number of potential buyers. A reserve price set above the sellers' own value is also optimal in the common values case, although the level of the reserve now varies with the type of auction and the number of bidders (Milgrom and Weber).

Bulow and Roberts (1989) simplify the optimal auction problem for the private values case by showing that it is fundamentally the same as the monopolist's problem in devising a third degree price discrimination scheme. An example of this analogy is the result that reserve prices are optimally set in a discriminatory fashion when bidders are asymmetric, with discrimination favoring low-valuation bidders.

2.3.2 Topics in Auction Theory

Common- or correlated-value auctions and the winner's curse. In bidding for some items like government securities or mineral exploration rights, it is reasonable to assume that the asset to be auctioned has an identical but unknown true value to each bidder. Similarly in bidding for construction or service contracts, equally efficient firms will face the same, unknown costs of completing the project. These types of auctions are usually conducted with sealed bids. Each bidder must estimate the true value of the item to be auctioned. The winner is the bidder who makes the highest estimate. The question is what bidding strategy should be employed in these auction settings?

A strategy of bidding up to one's *ex ante* valuation on average causes the "winner" to fall victim to the *winner's curse*. The reason is that the winner is the one who made the largest (positive) error in estimating the value of the item. Undervaluing the item results in losing the auction, but the loser's payoff is constrained to zero. Thus, although all bidders' valuations may be unbiased, the winner, if he bids his valuation, is likely to lose money. An alternative statement of the

winner's curse is that the winner's *ex post* valuation conditional upon winning is lower than his *ex ante* valuation.

The implication of the winner's curse is that bidders in these settings must shade their bids to avoid being "cursed." The manner in which bids must be scaled down is described by Thiel (1988). A bidder must use "a valuation function whose expectation, conditional upon winning, is an unbiased estimate of the object for sale (p. 884)."

A corollary to this analysis is that relatively poorly informed bidders are particularly vulnerable to the winner's curse in the sense that, upon winning, their *ex post* valuation may be considerably less than their *ex ante* valuation. In fact, players with uniformly poorer information should not bid at all. Thus, for example, a farmer who "wins" a machinery auction in which experienced dealers were also bidding has reason for concern that he overbid. Another corollary is that it is in a seller's interest to reveal private information prior to the auction and thereby mitigate bidders' uncertainty and need to shade their bids to account for the winner's curse.

Are winners in these auction settings really cursed, or do they rationally adjust their bids in accord with statistical theory? Both real-world and experimental evidence has been gathered to shed light on this question. Much of this literature is summarized by Thaler (1988), who concludes that both experimental and field evidence supports a winner's curse phenomenon. A recent empirical study of highway construction by Thiel (1988) disputes that conclusion, however.

Collusion among bidders. Our discussion of auctions thus far has assumed that bidders behave noncooperatively, i.e., they do not coordinate their bids. Bidder cartels, however, are a genuine concern in many auction settings. The question then concerns methods the seller may utilize to decrease the effectiveness of cartels. Our discussion of repeated games in Part I is instructive in this regard. Recall that the folk theorem establishes that cooperative (cartel) solutions can be achieved in infinitely repeated games. The key feature is that players who deviate from the cartel agreement can be punished by other players during subsequent play, thereby enforcing the original agreement. Thus, cartels among bidders are more likely when the bidders (such as art dealers, oil companies, and food brokers) interact repeatedly in similar auction settings.

Bidding cartels usually operate by cartel members designating one of their group, say the bidder with the highest valuation, to bid for the group.[33] Afterwards the group can reauction the item among themselves. Among the prototype auction mechanisms, Robinson (1985) shows that sealed-bid, first-price or Dutch auctions are less vulnerable to bidder cartels than is the English auction. In game theory parlance the cartel solution is a Nash equilibrium in the latter auction but not the former. To see this point, note that in the English auction cheating on the agreement by bidding against the cartel's representative only serves to cause that player to bid up to his valuation, resulting in a zero payoff to the defecting bidder. Thus, the cartel strategy is self enforcing (i.e., Nash) in that, given the proposed cartel strategy, no one has incentive to deviate. In contrast with the sealed-bid, first-price auction, a cheater can secretly bid above the cartel bidder's price and "steal" the item. Thus, the cartel agreement is not self enforcing in any *single* play of the sealed-bid first-price auction.

This observation helps explain the use of sealed-bid, first-price auctions by governments. Another tool to mitigate cartel effectiveness is the reserve price, which can be set strategically to counteract bidder cartels as a function of the number in the cartel and the members' valuation functions (Graham and Marshall 1987).

Multiple object auctions. The prototype auction model assumes a single indivisible object is being sold but in reality auctions often involve multiple items such as the sale of government securities, import quotas, or export subsidies. Two broad classes of multiple object auctions can be established: those in which the quantity to be exchanged is exogenous, as in the case of the items just mentioned, and those where the quantity is endogenous in the case of a buyer soliciting bids on a purchase contract. We briefly consider each case.

The exogenous quantities case can be further decomposed according to whether the items are to be sold *sequentially* or *simultaneously*. In many cases the seller may make this decision, raising the question as to which procedure is preferred for the seller. The choice is important because of information that might be revealed through the stages of play in a sequential auction. However, this factor does not come into play in the prototype case with independent private values. Here the seller's main choice is the type of auction format--specifically whether to charge a discriminatory price (each buyer pays his bid price) or uniform price (each buyer pays the amount of the highest unsuccessful bid). Assume k items are for sale and each of n buyers desires only 1 item. Weber (1983) establishes a revenue equivalence result for this model: under either discriminatory or uniform pricing, the seller's expected revenue equals the number of items to be sold times the expected value of k + 1 highest bid. Revenue equivalence breaks down under buyer risk aversion or correlated values among buyers with the former effect favoring a discriminatory auction and the latter effect favoring a uniform auction.

Hausch (1986) considers the case of simultaneous vs. sequential auctions when bidders have common valuations. The following

tradeoff is shown to exist: A sequential auction can cause buyers to reveal their private information which reduces the impact of the winner's curse and, in turn, causes bidders to raise their offers.[34] However, a deception effect also exists. If a player knows his bid will reveal information about items to be sold subsequently, he has incentive to shade his bid downward in initial stages of play in hopes of inducing lower bids from his rivals in subsequent stages. Readers will recognize this result as another application of the signalling model discussed in Part I. Thus, which format the seller should prefer is, in general, unclear, although the tendency will be to prefer sequential auctions as the number of items to be sold increases.

The endogenous quantities case is best thought of as a manufacturer soliciting bids for the procurement of an input, wherein the manufacturer can purchase whatever amount of the input he desires at the agreed upon price. This environment introduces one key complicating factor (Hanson 1988): because demand is elastic, bidders in the typical first-price, sealed-bid auction have incentives to reduce their bid sales price from what it would be in the exogenous quantity case to reflect that the buyer's demand is elastic. Conversely, in a second-price auction bidding one's marginal cost remains the dominant strategy. The first-price auction results in a lower selling price, but both the buyer and successful seller are made better off relative to the second-price auction because a greater volume of product is exchanged. This feature of the sealed-bid, first-price auction coupled with its comparative invulnerability to collusion may help explain its frequency of use.

2.3.3 An Application to Agricultural Markets.

Auction theory suggests two types of applications. Positive applications concern understanding the array of auction mechanisms in practice and comparing auction exchange with other pricing mechanisms. Normative applications concern use of the theory to aid in designing "better" auction mechanisms in either the sense of maximizing seller revenue, enhancing the efficiency of the auction (i.e., does the bidder with the highest valuation necessarily get the item), or developing optimal bidding strategies. The first two objectives are not necessarily compatible as mechanisms, such as strategically set reserve price(s), may lead to the highest valuation bidder not receiving the item. Because I have tried to mention agricultural applications throughout this analysis of auctions, I will illustrate application with a normative discussion of a single auction: the US Dairy Termination Program.

This program was authorized as part of the 1985 Farm Bill.

Participating farmers agreed to slaughter or export their entire dairy herds and not re-enter dairy production for at least 5 years. A bidding procedure was established to select participating farmers. A base level of production was calculated for each farmer in terms of his production from July 1984 through December 1985. Farmers then bid a dollar amount to be paid for each hundredweight in their base. Nearly 40,000 farmers submitted bids, and about 14,000 were selected, with selected bids ranging from $3.40 to $22.50 per hundredweight. My discussion concerns not the overall efficacy of this program, but, rather the government's bidding scheme and farmers' bidding strategies.

Lets begin by characterizing the auction. The government wished to reduce production capacity by 12 billion lbs. annually. Thus, we had a multiple object auction with an exogenous quantity. In considering bids farmers needed to forecast future dairy prices, slaughter cattle prices, interest rates, tax rates, nondairy employment opportunities (both farm and nonfarm), etc. These elements would effect the profitability of participation for any farmer. Thus, valuations were correlated, but they were not common because opportunity costs surely differed among farmers.

Participating in the auction was a risky venture but so is dairy farming, making it unclear how risk and risk aversion would have entered the calculus. As we shall soon discuss, the announcement of the program stimulated a barrage of discussions of the program and suggestions of bidding strategies from farm publications and university extension personnel, so it is quite reasonable to assume that bidders were symmetrically informed.

Given these auction parameters, what can be said *ex post* about both the government's choice of auction mechanism and, given the mechanism, the nature of advice offered to farmers? Beginning with the government, a reasonable goal in establishing the auction would have been to minimize cost to the treasury subject to soliciting bids for 12 billion lbs. of milk. It chose to implement a discriminatory first-price auction (winning bidders received their bid amounts) and set no reserve price (maximum acceptable bid), although it did reserve the right to cut off acceptances short of 12 billion lbs. if bids were deemed too high.

Because of uncertainty over some parameters of the auction such as the effect of risk, it is difficult to make a firm evaluation of the government's choice. However, questions can be raised about both the choice of a discriminatory first-price auction and the failure to set an explicit reserve. Auction theory indicates that a uniform second-price auction (each successful bidder receives the price of the highest unsuccessful bidder) could have achieved the diversion at a lower cost

to the treasury (Weber). It further suggests that a reserve price could have also reduced the cost.[35] A further advantage of the second-price auction is that it would have simplified farmers' bidding decisions, because bidding one's valuation would have become the dominant bidding strategy.

What about the bidding advice proffered to farmers, given the auction format chosen? I examined several, although by no means all, publications that discussed bidding strategy for this auction. The common theme in these articles was preparing "breakeven" bids. This was good advice because the breakeven bid provides an estimate of a farmer's valuation of the auction. Translating these valuations into a bidding strategy was a daunting task, given the auction format chosen, because the optimal bid would have depended on others' bids, i.e., there was no dominant strategy.

An obvious point is that farmers needed to shade their bids up from their valuations. Otherwise, their expected payoff was zero, win or lose. Most experts recognized this point, although some offered no advice beyond calculating breakeven bids and at least one suggested that bids below the breakeven might be rational. This auction format was ripe for selected bidders to fall victim to the winner's curse, unless they shaded their bids for both a profit margin and to account for the winner's curse. None of the publications I examined advised farmers about this effect. Given the range of accepted bids, it is safe to say guess that some of the "winners" felt cursed.

2.4 Collective Bargaining

Collective bargaining in agricultural markets occurs under two distinct sets of circumstances. In the first case a bargaining association arises from the voluntary initiative of growers. US fruit, vegetable, and dairy markets typify this process (Iskow and Sexton 1991). The second instance is when collective bargaining results from government fiat. This is the marketing board case that is common, for example, in Australia and Canada. Here the law compels farmers to pool their production and market it collectively.[36]

The notable attempt to date to develop a conceptual model of the cooperative bargaining process in agriculture has been by Helmberger and Hoos (1965), who employed a bilateral monopoly model. Bargaining, however, has been an important area of application for noncooperative game theory in the last 10 years. This work is now examined for what it may offer in terms of understanding cooperative bargaining in agriculture.[37] The fundamental problem in bargaining is the division of a fixed pie between two parties. The value of the pie can be set at 1.0. To obtain a solution, players must have incentive to come to an agreement. This is accomplished by discounting. Let δ_1, $\delta_2 < 1$ denote the discount rates for players 1 and 2, respectively. Another important feature in modelling the prototype bargaining problem is to specify the order of play. The usual possibilities are seller offer with buyer acceptance or refusal, buyer bid with seller acceptance or refusal, or alternating offers. Not surprisingly, the bargaining equilibrium is affected by the set up of play.

The key paper on noncooperative game theory analysis of bargaining is Rubinstein (1982), who studied a game with alternating offers between players and an infinite horizon with discounting. In other words, players may alternate offers forever unless they come to an agreement.[38] Rubinstein showed that there was a unique subgame perfect equilibrium to this game in which the players reach agreement immediately, and the payoffs are as follows (assuming player 1 moves first):

$$\pi_1 = (1 - \delta_2)/(1-\delta_1\delta_2), \tag{4}$$

$$\pi_2 = \delta_2(1 - \delta_1)/(1 - \delta_1\delta_2). \tag{5}$$

In the simple case of equal discount rates, the payoff to 1 is simply $1/(1 + \delta)$.[39] Examination of the payoffs yields two conclusions about bargaining in this context: It pays to go first,[40] and it hurts to be impatient (have a low δ) relative to your rival. What if the costs from failure to reach agreement were a fixed amount c_1, $c_2 > 0$ per period, rather than a proportional discount rate? If $c_1 = c_2 = c$, any division that guarantees each player at least c can be supported as a perfect equilibrium. If $c_2 > c_1$, delay hurts 2 more than 1. In this case if 1 moves first he gets the entire pie. This result illustrates the point noted in Part I that equilibria in bargaining games may be very sensitive to what seem to be modest changes in the specification of the model.

Much of the work on bargaining subsequent to Rubinstein has involved specifying richer bargaining environments and examining their impact on the bargaining equilibria. One realistic generalization is to consider that parties may have options to the bargaining process. For example, in agriculture growers may be able to dispose of their product in export markets, if they cannot reach agreement with domestic processors. By the same token, processors may be able to source product externally. Let $s_1, s_2 \geq 0$ denote the value of the *outside option* for players 1 and 2, respectively, and otherwise maintain the same structure of play as in Rubinstein's model ($s_1 + s_2 < 1$ is also needed to make agreement beneficial).

It can be shown (see Shaked and Sutton 1984 or Sutton 1986) that if the outside options are voluntary and $s_i \leq \pi_i$, $i = 1,2$ where the π_i are defined in (4) and (5), then the presence of the outside options does not matter. The unique perfect equilibrium remains as specified in (4) and (5). Thus, for example, threats on the part of processors to procure production from outside a bargaining association are meaningless to the bargaining process unless the value of this option exceeds what the processor would otherwise obtain in dealing with the association.

What if the threat to take an outside option is not voluntary? For example, what if an outside force can elect to randomly terminate bargaining? In this case it can be shown that as the likelihood of breakdown becomes large, the equilibrium payoffs converge to a "split the difference" solution where each player gets the value of his outside option and one-half of anything that is left over. The puzzling issue this result presents for potential bargainers is how to make the threat of the outside option credible.

Another mode of enrichment to the noncooperative bargaining model has been to incorporate incomplete and imperfect information.[41] Suppose one player's valuation of the product bargained for is known by the player but not his rival. For example, a buyer may have a HIGH or a LOW reservation price. Assume a game structure where the seller makes offers and the buyer accepts or rejects the offer. A LOW-reservation buyer will be unwilling to accept certain seller offers that a HIGH-reservation buyer would accept.

This game environment offers the LOW buyer the opportunity to signal his reservation price by rejecting some of the seller's initial offers. Of course, a HIGH buyer may also reject otherwise acceptable offers to mimic the LOW buyer in hopes of generating a pooling equilibrium. An attractive feature of these models is that delays in obtaining agreement (e.g., strikes) can emerge in a perfect Bayesian equilibrium.[42] The problem discussed in Part I of a multiplicity of equilibria is encountered in bargaining models of asymmetric information. The multiplicity-of-equilibria problem is exacerbated if there is two-sided uncertainty (Fudenberg and Tirole 1983).

Almost all of bargaining theory is bilateral. If Rubinstein's model is recast in an n-person bargaining context, there is no longer a unique subgame perfect equilibrium (Sutton 1986).

2.4.1 Application to Cooperative Bargaining in Agriculture[43]

The noncooperative game theory approach to bargaining has generated some useful insights. The more impatient players do worse. Outside options do not matter if they are small relative to the equilibrium bargaining outcome, and if they are voluntary. Even modest outside options matter, if the choice to pursue the outside option is involuntary. There may be an advantage to moving first in an alternating-offers bargaining environment. Costly delays in failure to reach agreement may be the consequence of imperfect information, as players attempt to use the bargaining process to either obtain or convey information.

In considering the relevance of these highly stylized models to agricultural bargaining, we should consider how the structure of the bargaining models compares to the agricultural bargaining environment. Surprisingly perhaps, there is a rather good fit in many US agricultural industries (Iskow and Sexton 1991), and a number of general principles can be distilled. Nearly all bargaining associations negotiate for price and other factors related to pricing, such as division of costs for first-handler services and quality premiums and discounts. In most instances quantity to be sold is fixed prior to bargaining, either because the crop is a perennial or because individual growers have standing sales contracts with processor/handlers. This point is important because it establishes that in many cases quantity sold is not a function of the bargaining outcome, i.e., bargaining's fixed pie assumption holds.[44]

The percentage of output in the relevant market area controlled by the bargaining association varies across industry. In most cases in the US the association controls in excess of 50% of production in the market, but does not have exclusive control. Associations usually interact with multiple processors, but the bargaining environment is often structured so that the association bargains initially with a single handler, often the dominant firm in the industry, and agreements with other handlers closely parallel the initial agreement. This structure, thus, is roughly bilateral in nature and also conforms to the framework of bargaining theory.

Most of the associations in the Iskow-Sexton survey indicated having some outside options if bargaining broke down. Most common among these were taking legal action,[45] shipping to other processors, and relying on fresh product sales. Processors presumably also have outside options through external sourcing or sourcing from nonassociation members. Thus, the outside option feature of bargaining models may be an important feature to understanding bargaining in agriculture.

In the realm of information, the asymmetry tends to favor processors. Given a volume of crop, R^*, to be bargained for, the key items of information needed to determine its value are processors' costs and demand conditions for the processed product. Processors are apt to have superior knowledge of both items. Growers' costs, conversely, don't matter.

The recent progress in analyzing bargaining using noncooperative games thus offers useful guidelines in constructing bargaining models

for agriculture.[46] Two key questions to be addressed are (1) What are the key factors determining the division of benefits between growers and processors? Clearly, the bargaining theory results give us some initial insights in this regard, and (2) When is cooperative bargaining desirable for farmers? The market structure in which bargaining emerges is generally oligopsony, not monopsony (Iskow and Sexton 1991), but the advent of bargaining often converts the environment to one approximating bilateral monopoly. Under what conditions is this shift in market environment good or bad for farmers?

Conclusions

This paper has surveyed noncooperative game theory concepts that might be used to analyze agricultural markets. To date, these methods have been utilized infrequently by agricultural economists. Agricultural economics is an applied field and game theory is a tool of economic theory, so perhaps the infrequency of usage is not surprising. Another factor may be that agricultural markets are regarded prototypical competitive markets, and game theory is a tool of imperfect competition.

I reject this latter argument for the infrequency of use of game theory in agricultural economics and will not repeat the bases for this rejection given at the outset of Part II of this paper. I agree, though, that agricultural economics is and should remain an applied field. However, most would accept theory's fundamental importance in guiding application, and it is my opinion that agriculture as an industry is sufficiently unique that we cannot necessarily rely upon theory developed without consideration of these distinctive features of agricultural markets.

For example, concerns over monopsony or oligopsony power are relatively unique to agriculture, given the typical immobility of the raw product and fewness of processors. The fact that the marketing process for agricultural products is initiated by the production and sale of a particular raw product that is relatively nonsubstitutable for other inputs is also unique. Third, at the retail level, the emerging power of the large food chains is important and relatively distinctive. Given that manufacturers are also often powerful, this consideration raises important bilateral monopoly/oligopoly issues. Fourth, agriculture is quite unique among industries in that producers are allowed, even encouraged or forced, to form coalitions for the purposes of procuring inputs and marketing production.

In closing I do not want to over sell noncooperative game theory's potency. Although the subject is certainly in vogue among economists and probably will become even more popular as it integrates fully into graduate curricula, the intellectual giants of the field such as Kreps warn of its over application. Nonetheless, my conclusion is that there is considerable scope for both positive and normative application of game theory tools to agricultural markets, and it is unlikely that economists outside of agriculture will fully develop these applications.

Endnotes

1. These include Kreps' microeconomic theory text (1990a), a second book by Kreps (1990b) that is not concept oriented, but, rather, is a thoughtful discussion of noncooperative game theory's successes, failures, and future prospects by one of its leading scholars. Rasmusen (1989) is an excellent, modern introduction to noncooperative game theory. Tirole's recent text (1988) in industrial organization is a masterful presentation of noncooperative game theory applications. The *Handbook of Industrial Organization* (Schmalensee and Willig 1989) focuses heavily on noncooperative game theory applications and includes a chapter on noncooperative game theory methods by Fudenberg and Tirole, who also recently published a book on the subject (Fudenberg and Tirole 1991).

Books that treat both cooperative and noncooperative games include Friedman (1986–a rather mathematical orientation) and the two volume treatise by Shubik (1982, 1984). For readers primarily interested in cooperative game theory, Luce and Raiffa remains an excellent reference.

2. Everyone is familiar with the two prisoners whose finking on each other produces long prison terms for each. However, the term "prisoners' dilemma" is applied broadly to contexts where cooperation is in players' mutual interests, but individually each has incentive to behave noncooperatively. Examples are duopolists setting prices or output levels, nations choosing trade policies, or communities competing for industry through tax breaks. A stimulating book by Axelrod (1984) is devoted to the study of prisoners' dilemma situations.

3. Most often economists are interested in pure strategy equilibria because mixed strategies are often difficult to interpret from an economic perspective. Many games may have both pure and mixed strategy equilibria, and the modeler will emphasize the pure strategy equilibria. See Fudenberg and Tirole (1989) and Sutton (1991) for discussion of alternative interpretations of mixed strategy equilibria. Rubinstein expresses the view that nonexistence of equilibrium in pure strategies should not necessarily cause the modeler to turn to analysis of mixed strategies. Rather, nonexistence of a solution should alert the modeler to possible deficiencies in the game description or assumptions underlying the solution concept.

4. In the case of Bertrand's equilibrium, absent binding capacity constraints, even duopolists earn zero profit.

5. This solution algorithm is effective so long as the game tree isn't too big or complicated. Circumstances where players are indifferent among alternatives can also create problems because the manner in which ties are resolved likely will effect play of the game. Usually the analyst is given leeway to resolve ties, and some justification from theory can often be given for a particular resolution. Figure 1 illustrates this point. In a great many games one type of player will be assumed to behave competitively and earn just some reservation level of payoff, usually normalized to zero. The agent in Figure 1 earns zero from accepting a contract and expending high effort and from staying out of the market under grower integration. Any payoff to the agent strictly above his reservation payoff cannot be an equilibrium because another payoff that paid him slightly less could be proposed and would be accepted.

6. Consider, for example, the following analysis due to Friedman (1971). Oligopolists adopt strategies that call for collusion in the initial period and all subsequent periods provided no cheating has *ever* been detected. If cheating is detected, the players punish it by playing their single period Nash strategies (e.g., Cournot) forever. Some reflection should reveal that these strategies comprise a SPE, provided players do not discount the future so heavily that the single-period gain to cheating outweighs the future discounted losses from earning Cournot rather than collusive profits. The "perfect" folk theorems indicate that an essentially unlimited number of other payoffs can be enforced as SPE, including the Stackelberg equilibrium. Again, the key is that discount rates are not too high. Once a critical discount value is exceeded, the only SPE is to play the single-period Nash equilibrium strategies forever. See Fudenberg and Tirole (1989 pp. 279-82) for further discussion and folk theorem references.

7. If $\gamma \leq 1$ is the discount parameter and $\theta \leq 1$ is the probability that play continues at each period, then players should merely use the factor $\gamma\theta$ to discount the future.

8. An important example in this tradition is the "trigger pricing" model of Green and Porter. In the prototypical repeated game players observe perfectly the outcomes from each period's play, and, hence, are in a position to punish deviations. Green and Porter consider an oligopoly model with demand uncertainty. Therefore, price decreases can be due either to cheating or to low demand. Since players cannot distinguish between the two signals, they must respond by playing noncooperatively whenever price falls below some trigger threshold. However, punishment has a finite duration and cooperation can ensue, unlike in Friedman's model (note 8). Thus, Green and Porter's model explains the episodic price wars that are common to cartels.

9. In technical terms private information means that some player's information partition is *finer* than some other player's partition. Games of asymmetric information are necessarily games of imperfect information because if the players' information partitions differ, the information sets cannot all be singletons. Games can have asymmetric information without having incomplete information. For example, players may undertake moves at the outset of a game that are not revealed to other players but which influence the way they

play subsequently in the game.

10. Notice that this happens not to be the case in the Figure 6(b) game because A has the dominant strategy of EARLY regardless of B's type.

11. Credit for the development of perfect Bayesian equilibrium is somewhat hard to pinpoint. The concept is aligned with Selton's work (1975) on perfection and Kreps and Wilson's work (1982a) on *sequential equilibrium.* Early signalling models such as Akerlof (1970) and Spence (1973) implicitly use the concept. The first explicit application is Milgrom and Roberts (1982a). Kreps (1990b) credits Fudenberg and Tirole (1988) with formalizing the concept.

12. The following example illustrates using Bayes rule to calculate posterior probabilities. It is bad form and perhaps illegal to inquire about the marital status of an applicant for a faculty position. Still, however, inquiring minds want to know. Suppose an interviewer's prior probability that an applicant is married (M) is

$$P(M) = 0.4.$$

The data observed by the interviewer is that the applicant is a homeowner, a fact revealed in casual conversation. The interviewer knows the conditional probabilities of observing this information for a married or unmarried (UM) person of the applicant's age:

$$P(H/M) = 0.6$$
$$P(H/UM) = 0.2.$$

The marginal probability of observing home ownership among this applicant's age cohort is

$$P(H) = [P(H/M) \times P(M)] + [P(H/UM) \times P(UM)]$$
$$0.36 = (0.6 \times 0.4) + (0.2 \times 0.6).$$

In other words, homeowners are twice as likely to be married as not. Thus, the posterior probability that the applicant is married is

$$P(M/H) = P(H/M) \times P(M)]/P(H) = 2/3.$$

Because the interviewer observed data more consistent with M than UM, it is intuitive that the prior on M should be revised upward. Bayes rule provides the vehicle to do so. Although Bayes rule is most intuitive in the context of an example, the above equations can be converted to general formulae by replacing H with "data," M with "event," and UM with "not the event."

13. In addition, a third type of equilibrium may exist, where, in the context of the education model, the low-ability worker randomizes between obtaining and not obtaining education.

14. The fact that education is more expensive for low-ability workers is the key feature in meeting this constraint.

15. A low-cost incumbent will produce more in a Cournot equilibrium than will a high-cost version, and, thus, post-entry profits will be lower if the incumbent is low cost.

16. For an example of how trembling-hand perfection refines equilibrium consider the coordination game between farmers in Figure 4(b). One Nash equilibrium involves A, who moves first, playing EARLY and B playing (if EARLY then LATE; if LATE then LATE). As long as A plays EARLY, B's strategy is a best reply, but if there is a chance that A will tremble and play LATE, then it is certainly not optimal for B to respond with LATE, i.e., this Nash equilibrium is not trembling-hand perfect. The equilibrium where A plays LATE and B plays (if EARLY then EARLY, if LATE then EARLY) can be eliminated by the same argument.

17. The additional restrictions on equilibrium imposed by sequential equilibrium relative to PBE imply a mechanical check of the PBE to see whether they satisfy the consistency requirement of sequential equilibrium.

18. Milgrom and Roberts defined a range of separating equilibria, say $[q^*, q^{**}]$, with q^* identifying the smallest output such that a high-cost incumbent prefers not to masquerade as low cost and, rather, accept his period 1 monopoly profit and invite entry in period 2. Conversely, q^{**} is the maximum output that a low-cost incumbent is willing to produce to signal its type rather than accept a pooling equilibrium payoff. Therefore, if the entrant observes any $q' \in [q^*, q^{**}]$, he should put zero probability on the event that the incumbent is high cost and, hence, should not enter (i.e., outputs in this interval are dominated for the high cost entrant by his simple profit-maximizing monopoly output). Thus, the low-cost incumbent need not produce above q^* to deter entry, and all other outputs in the interval are eliminated from consideration as equilibria.

19. High transportation costs generally limit the number of processor/handlers a farmer can access. The fewness of buyers within a market area, in turn, leads to market power. See Greenhut, Norman, and Hung (1987) for the general theory of spatial imperfect competition and Sexton (1990) and Durham and Sexton (1992)for discussions in an agricultural markets context.

20. Wheat trade provides a notable exception to this general conclusion. Thursby (1988) has estimated that about one-third of wheat exports are by state traders (see Ryan (1984) and Veeman (1987), respectively, for discussions of the roles of Australian and Canadian wheat boards) and over 90% of imports are by state traders. Recent applications of strategic trade theory to wheat trade have been made by Thursby (1988) and Thursby and Thursby (1990).

21. This relationship is usually the implicit context of the literature on vertical controls to be discussed shortly.

22. I intend a very broad interpretation of the word "quality" here, much in the same way "effort" should be interpreted broadly. For example, quality may refer to the physical characteristics of the product itself, or it may refer to the specific time that the product is available for harvest.

23. Although modelling and solving optimal contract problems in the presence of moral hazard is a difficult problem without considering it, one would be remiss to not mention the matter of risk aversion in this context. In agriculture it is very realistic to consider that growers (as agents) are risk averse and a processor (as principal) is risk neutral, due, perhaps, to having diversified stockholders (obviously not the case if the processor is a cooperative). The processor has incentive in these cases to specify contracts to shift risk away from growers (i.e., they have to be compensated, *ceteris paribus*, to bear risk). A price schedule that is constant across realizations of

random variables accomplishes this objective but will not yield growers' optimal incentives in the presence of moral hazard.

24. In the presence of multiple dealers discriminatory fixed fees may be considered illegal price discrimination.

25. An implicit point in discussions of vertical control is that some aspects of principal-agent interactions are simply not contractible because a court would be unable to enforce the provision. This would be true, for example, if the court could not verify whether an action at issue had been undertaken. Some aspects of manufacturer or dealer commitment to provide promotional support undoubtedly fit into this category.

26. Negative franchise fees (the analytical equivalent of slotting allowances) may be compatible with manufacturer control in some cases. The casual empirics of slotting allowances suggests, however, that the fees are charged most often to smaller food manufacturers who lack power in their own right. Thus, they seem to be a manifestation of the retailer's power.

27. In what follows we will generally discuss the monopoly selling case, recognizing that most of the results apply in a straightforward fashion to the monopsony buying case.

28. The reason bidding one's valuation is a dominant strategy in these auction formats is that the price paid upon winning is not one's bid price. Thus, bidding below one's valuation only reduces the chance of winning without affecting the payment, and bidding above the valuation affects the outcome only in the case where the bidder "wins" because of bidding in excess of his valuation. In this case, he pays the second highest bid, an amount greater than his valuation.

29. Sealed-bid first-price auctions are a primary bidding mechanism for government contracts. The Dutch auction is used to sell a number of different agricultural and aquacultural products including flowers and produce in Holland, tobacco in Canada, and fish in Israel and the UK. Most applications of the Dutch auction involve an "electronic clock" with a moving pointer that signals gradually declining prices. Buyers can stop the clock and claim the item by pressing a button.

30. A pure strategy specifies the amount of the player's bid as a function of the bidder's information.

31. Bidders in first-price, sealed-bid or Dutch auctions must "shade" their bids below their valuations to capture economic surplus. Intuitively a bidder trades off declining probabilities of winning with the increased payoff from winning with a lower bid. It turns out that the optimal bidding strategy in these auctions is for players to bid their expectation of the *second highest* valuation conditional upon their own valuation being the highest. This result leads directly to revenue equivalence. See McAfee and McMillan or Milgrom (1989) for more details. Revenue equivalence breaks down when bidders are asymmetric, although no general result can be stated on which format yields more revenue. See Milgrom and Weber (1982) for revenue equivalence results when auctions are not private value.

32. This result follows because it is optimal for the seller to trade off some probability of the good not selling if the reserve is set too high with the increased revenues that the reserve may otherwise generate.

33. Gruen (1960), for example, describes the operation of buyer cartels or "pies" at Australian wool auctions.

34. This result is an illustration of Milgrom and Weber's point that it is in the seller's interest to reveal information about the product being sold.

35. A further caveat to these conclusions is that the underlying auction theory assumes that bidders are behaving rationally, a questionable assumption in this case as the succeeding discussion indicates.

36. Economic factors may justify this type of intervention. First, voluntary bargaining is subject to a free-rider problem in that nonmembers usually receive the same sales terms as members. Second, processors may be able to deter voluntary associations from forming by implementing discriminatory "divide-and-conquer" pricing schemes (Innes and Sexton 1993). Indeed, centralized marketing boards may arise in response to the failure of voluntary cooperation initiatives. Cambell and Fisher (1981) describe the Australian experience in this regard.

37. My focus here will be exclusively on noncooperative game theory models of bargaining. A cooperative game theory literature on the subject also exists that was inaugurated by Nash's seminal paper (1950). The cooperative game theory approach is axiomatic in character, specifying features that a solution should entail and then determining the types of solutions, if any, that satisfy the axioms. Roth (1979) summarizes work conducted under this framework.

38. Notice that this specification is not a repeated game because play ends if the players ever reach agreement. Thus the folk theorem does not apply.

39. Rubinstein's proof of this result is rather difficult, but a simple, elegant proof was subsequently given by Shaked and Sutton (1984).

40. As the time delay between periods goes to zero, this advantage disappears.

41. Key papers that develop imperfect information models of bargaining are Fudenberg and Tirole (1983) and Sobel and Takahashi (1983).

42. This strand of the bargaining literature can dovetail with games of adverse selection by assuming that the seller knows the value of the good but the buyer does not. The buyer can attempt to infer value, however, based on the seller's bids (Evans 1989, Vincent 1989).

43. Much of this subsection is based on the on-going Ph.D. thesis work being conducted by Julie Iskow.

44. This conclusion must be qualified by the observation that the quantity available in future periods may depend upon today's bargaining outcome.

45. Legal action becomes a viable outside option in states that have adopted fair bargaining legislation.

46. One example of a possible agricultural bargaining outcome is provided by Sexton and Sexton (1987), who consider as an outside option that an association of farmers may integrate into the market and operate their own cooperative manufacturing facility. It was shown that the incumbent would in

most cases deter this type of entry by issuing the association a take-it-or-leave-it price offer that dissipates any benefits to the coalition from integrating into production. This result can be interpreted as a bargaining outcome, where the monopsonist just offers the coalition the value of its outside option (to actually integrate into production) and retains the remainder of its monopsony profits.

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