A Survey of Noncooperative Game Theory with Reference to Agricultural Markets: Part 2. Potential Applications in Agriculture

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This paper is the second of a two-part survey on noncooperative game theory relevant to agricultural markets. Part 1 of the survey focused on important game theory concepts, while this paper 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, auctions, and bargaining.

1. Introduction

Part 1 of this survey reviewed noncooperative game theory concepts that might be relevant to analysis of 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 considering application of noncooperative game theory in agricultural markets, we must then evaluate the importance of imperfect competition in this sector, a topic of some controversy. In terms of potential monopoly power by food handlers, 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 conducted by 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.

Another potentially important dimension of imperfect competition in agricultural markets may be monopsony or oligopsony power exercised by processors and handlers over farmers. Because agricultural products are often bulky and/or perishable, they are costly to transport. Thus, markets for raw agricultural products are spatial markets, an arena where imperfect competition is almost certain.[1]

Imperfect competition is also the norm in the international trade of many agricultural products. 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, p. 2) note, "virtually none of the agricultural trade modelling to date has incorporated these new theoretical developments."[2]

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Review coordinated by John Zeitsch.

[1] 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), Durham and Sexton (1992) and Koontz, Garcia, and Hudson (1993) for discussions in an agricultural markets context.

[2] 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 per cent 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).

Imperfect information and uncertainty also represent important departures from perfect competition in agricultural markets. Uncertainty opens the door to strategic behavior particularly when the uncertainty or lack of information is asymmetric across agents. Such informational asymmetries may be significant 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. Characteristics of the agricultural product itself are an issue in many contexts, opening the door to interesting *adverse selection* problems. Although product characteristics are always important, they become a subject for game theory only when information as to characteristics 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 promising. I focus discussion of potential applications in this review on what might be called *vertical exchange mechanisms*. 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. The three categories of exchange mechanisms discussed in sections 2, 3, and 4 respectively of this paper are: Principal-agent models with asymmetric information, auctions, and collective bargaining. Omitted under this focus is analysis 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).

2. 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/her 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/her production. The agent may have specialized knowledge as to his/her own ability, market conditions, etc. Alternatively, a process/handler may be modelled as the principal who seeks farmers to grow products to his/her 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.[3]

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

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

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/her type to (from) the principal.

2.1 Models with Moral Hazard

I will frame the moral hazard problem in the context of a grower seeking a marketing agent to handle his/her production. This problem was introduced in part 1 of this survey. 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 illustrated in part 1, Figure 1 was that if given the opportunity, the agent accepted a contract and expended low effort, causing the grower to elect to market the product him/herself 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:

$$(1) \quad \pi(E) = R(E) - W(R(E)),$$

and his/her 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

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

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*:

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

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 $R(E,\varepsilon)$ 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 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 1 of this survey 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 (1982) and Milgrom and Roberts (1982). 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.

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.[4] 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.[5]

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 product characteristics and, in turn, on the extent to which these characteristics can be monitored by observation of the product or growers' horticultural practices.

2.2 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 (1970) on "lemons" introduced the problem of adverse selection. Akerlof showed in the context of used automobiles that adverse selection problems may result in low-quality products driving high-quality products from the market, thus inducing a welfare loss. The reason is that if quality cannot be judged costlessly as is the case for used automobiles, risk-neutral buyers' willingness to pay for a car would be a weighted average across perceived quality classes of the product. However, only sellers of low-quality products are willing to sell at this price. Thus, a product's availability for sale at this price is evidence that it is low-quality, and the market equilib-

[4] 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.

[5] 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.

rium is for only low-quality products to be offered at the low-quality market price.

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.

Adverse selection models often will involve signalling of the type discussed in part 1 of this survey. 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 characteristics 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. 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.

2.3 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.

The objective of the manufacturer is to select contractual instruments to maximize his/her 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. Vertical control models have direct application possibilities in agriculture in the area of food retailing.

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. $P^m > c$ introduces a fundamental externality between the manufacturer and dealer because any dealer action that affects consumer demand impacts on the manufacturer's profit, but this impact is not considered by the dealer.

"Double marginalization" (Spengler 1950) occurs when the dealer also has market power and marks price above his/her 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 general, the manufacturer has two objectives: to provide the dealer with correct economic signals and to transfer revenues to him/herself. Charging $P^m = c$ 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.

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 are substitutable downstream, setting $P^m > c$ for one input induces distortions in the input mix (Vernon and Graham 1971), and (2) higher costs borne by the dealer will cause him/her 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 productive inputs, 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.

Important vertical control questions in agriculture arise concerning interactions between processor/handlers and retailers or large food service companies. (Landlord-tenant interactions are another source of agricultural application.) Connor *et al.* (1985) demonstrate 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 role reversal with retailers as principals and food manufacturers as agents may also prove illuminating. For example, an important trend in food retailing has been for the retailer to impose *slotting allowances*--fees charged by the retailer to carry a manufacturer's product.[6]

A recent empirical 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 did not employ game theory, but the process of new product selection they described is very strategic in nature. A prototype model of the process of new product introduction as an extensive form game has the manufacturer moving first (as principal) and offering a contract to the supermarket to carry its product. The supermarket either accepts or rejects the contract. McLaughlin and Rao speculate that slotting allowances may be linked to inferior products and that superior products will be stocked without extra inducements. However, if quality information is asymmetric with the manufacturer informed and the retailer uninformed as seems

[6] 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.

likely, then manufacturers of low quality products have incentive to conceal that fact by *not* offering slotting allowances, i.e., under McLaughlin and Rao's logic, refusal to pay a slotting allowance is a signal that the product is high quality. (Recall that the word "quality" is to be given a very broad interpretation in these contexts - see footnote 4.)

Test markets are another interesting illustration. McLaughlin and Rao's empirical results show a positive relation between acceptance of the product by retailers and the presentation of test market results. Test markets again strike at incompleteness and imperfectness of information in the new product adoption game. Test market results can be used to signal high quality, but a low-quality manufacturer may be able to manipulate these tests to masquerade as high quality.

A manufacturer who knows his/her product is high quality has incentives to incur expenses for test markets and to pay slotting allowances because he/she knows the product will be successful if adopted. By the same logic, a low-quality manufacturer will be unwilling to incur these costs because subsequent expected profits do not justify it. Thus, under a separating equilibrium, manufacturers of high-quality products may incur substantial introductory marketing costs, that otherwise may be wasteful, to signal their high quality.

Turning briefly to grower-handler interactions at the other end of the market chain, we observe a substantial and increasing amount of vertical control exercised by the handler in some sectors. Although monopsony power in these first-handler sectors is a concern, vertical control may also be exercised at these levels to address moral hazard and adverse selection problems.

3. Auctions

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 favoured 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 favouring 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.

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 some mechanisms, such as strategically set reserve price(s), may lead to the highest valuation bidder not receiving the item.

3.1 Auction Theory Basics

The key reason why monopolists/monopsonists sometimes use auctions is asymmetry of information.[7] If a monopolist knew buyers' valuations of the item offered for sale, he/she 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/she 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/her 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/her valuation by raising lower bids by some small amount (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.[8] 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

[7] 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.

[8] 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/her valuation. In this case, he/she pays the second highest bid, an amount greater than his/her valuation.

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,[9] 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/her strategy in consideration of other bidders' strategies.[10] 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.[11]

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 will not 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/her 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).[12] This optimal price is independent of the

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[9] 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.

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

[11] 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 (1987) 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.

[12] 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.

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.

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/she bids his/her 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/her *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, p. 884). A bidder must use "a valuation function whose expectation, conditional upon winning, is an unbiased estimate of the object for sale."

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/she 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 conclu.sion, 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. The discussion of repeated games in part 1 of this survey 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.[13] 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/her 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 consider briefly 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/her 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 one 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.[14] However, a deception effect also exists. If a player knows his/her bid will reveal information about items to be sold subsequently, he/she has incentive to shade his/her bid downward in initial stages of play in hopes of inducing lower bids from his/her rivals in subsequent stages. This result is another application of the signalling model discussed in part 1 of this

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

[14] This result is an illustration of Milgrom and Weber's (1982) point that it is in the seller's interest to reveal information about the product being sold.

survey. 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/she 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.

3.3 An Application to the US Dairy Termination Program

This program was authorized as part of the 1985 US Farm Bill. Participating farmers agreed to slaughter or export their entire dairy herds and not re-enter dairy production for at least five years. A bidding procedure was established to select participating farmers. A base level of production was calculated for each farmer in terms of his/her 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.

Let us 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. 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

1983). It further suggests that a reserve price could have also reduced the cost.[15] 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 guess that some of the "winners" felt cursed.

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.[16]

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 ten years. This work is now examined for what it may offer in terms of understanding cooperative bargaining in agriculture.[17] 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 $\delta_1, \delta_2 < 1$ 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.

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[15] 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.

[16] Economic factors may justify this type of intervention. First, voluntary collective bargaining is subject to a free-rider problem in that nonmembers of the bargaining group 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. Campbell and Fisher (1981) describe the Australian experience in this regard.

[17] 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 this work.

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.[18] 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):

$$(4) \quad \pi_1 = (1 - \delta_2)/(1 - \delta_1\delta_2)$$

$$(5) \quad \pi_2 = \delta_2(1 - \delta_1)/(1 - \delta_1\delta_2)$$

In the simple case of equal discount rates, the payoff to 1 is simply $1/(1 + \delta)$.[19] Examination of the payoffs yields two conclusions about bargaining in this context: It pays to go first,[20] 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/she gets the entire pie. This result illustrates the point noted in part 1 of this survey 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/her 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.[21] Suppose one player's valuation of the product bargained for is known by the player but not his/her 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

[18] 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.

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

[20] As the time delay between periods goes to zero, this advantage disappears.

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

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/her 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.[22] The problem discussed in part 1 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).

4.1 Application to Collective Bargaining in Agriculture

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.[23]

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 per cent 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,[24] shipping to other processors, and relying on fresh product sales. Processors presumably also have outside options through external sourcing or sourcing from nonassociation-

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[22] 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).

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

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

members. Thus, the outside option feature of bargaining models may be important 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 collective bargaining models for agriculture.[25] 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?

5. Conclusions

This paper, presented in two parts, has surveyed noncooperative game theory concepts that might be used to analyze agricultural markets and has outlined applications in the areas of principal-agent models, auctions, and bargaining. In closing I do not want to over-sell noncooperative game theory's potency. Even the leading developers in the field such as Kreps have warned of its over application. Nonetheless, my conclusion is that there is considerable scope for both positive and normative application of game theory to agricultural markets, and it is unlikely that economists outside of agriculture will fully develop these applications. I hope this survey will play at least a small role in integrating game theory into more agricultural economists' tool kits.

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[25] 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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