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## Potential Benefits and Limitations of Game Theory in Agricultural Economics

The 1994 Nobel Prize in Economic Science was awarded to John Harsanyi, John Nash, and Reinhard Selten. Reflection on how game theory has affected or can affect agricultural economics is now worthwhile. Game theory has become a ubiquitous and substantial component of general economics. Does it play a comparable role in Agricultural Economics? Should it?

Game theory is intended for situations where decision-makers are affected by interactions of others' behavior with their own. Harsanyi (p. 10) makes the following distinction between "social settings" where game theory and ethics should be applied and "private settings" where decision theory is applicable: "Individual decision theory deals primarily with rational behavior in situations in which the outcome depends on an individual's own behavior. ... The proposed basic difference between decision-theoretical situations and game situations lies in the fact that the latter involve mutually interdependent reciprocal expectations by the players about each other's behavior; the former do not." Game theory is most immediately applicable to problems involving contracts, cooperation, and public goods which includes nearly all environmental issues. Such situations are important components of agricultural economics, and thus agricultural economics would seem to be fertile ground for game theory applications (Sexton). The alternative decision-theory approach mentioned by Harsanyi appears to remain the appropriate paradigm for most farm-level production decisions.

The main contribution of game theory is that it allows modeling a wider variety of situations than neoclassical theory alone. When a land owner and a potential renter/operator bargain over a rental contract, game theory is needed to capture such real-world concepts as "bargaining power" and "reputation" which have no neoclassical counterpart. When agricultural economists observe cropland rental contracts that involve revenue sharing in some cases and fixed cash payments in others, they need a model which can predict both contract form and benefit shares. Game theory provides such.

Despite this potential contribution, game theory's use in agricultural economics is hard to identify outside of the fields of international trade and political economy which are covered in the other two papers in this session. There are two reasons. First, game theoretic concepts are widely

used only implicitly in much of the literature. For example, the standard moral hazard model used to model contracts is not usually characterized as a game, although it clearly is one, and many papers that analyze it do not include its game theoretic underpinnings (e.g., Horowitz and Lichtenberg). The corollary to this principle is that many interesting models can be analyzed without drawing on the underlying game theory. Cournot models of oligopoly are such an example.

Another likely reason for limited use of game theory is the difficulty of using it as a basis for estimation. Because agricultural economics is by and large an empirical discipline, and because game theory helps in deriving conceptual models but not in specifying empirical models, it tends not to be central to agricultural economics. How game theory might be used to provide better empirical models remains an unexplored research area for our discipline.

An understanding of what game theory is meant to do — help model situations that cannot be modeled without it — helps to evaluate its role. It is not primarily an empirical tool. Its strengths and weaknesses are remarkably similar to the strengths and weaknesses of the rest of economic theory. Like neoclassical theory, game theory is exceptionally general; as with neoclassical economics, the same simple tools and intuition can be used in a wide variety of decision-making contexts. It is not primarily an empirical tool because its extreme generality means that in most situations an alternative hypothesis (for example, to Nash equilibrium) is hard to derive. As with neoclassical theory, the principle activity of game theorists will be to correctly describe the structural form of the model rather than to specify an alternative behavioral theory.

### **Synopsis of Game Theory's (Non-)Appearance in Agricultural Economics Literature**

Game theory has appeared in agricultural economics research primarily in studies of international trade and political economy (see other papers in this session) — problems that inherently deal with collective action. In trade models, countries formulate policies (both domestic production and trade or macro policy) considering other countries' alternative behaviors that affect access to markets or prices received in those markets (e.g., Karp and McCalla). In political-economic models, producer groups formulate and argue for price/production policies and argue against the policies supported by

rival producer and consumer groups; in so doing, they must anticipate demands made by rival groups and actions undertaken by other lawmakers (e.g., Rausser and Zusman).

The rest of this section reviews other agricultural economic problems involving either bilateral contracts or public good characteristics to which game theory is applicable but either has been used only implicitly or not at all. These areas include landlord-tenant contracts, collective action, cooperatives, pesticide use, crop insurance, vertical integration, agricultural research spillovers, product licensing, and many other issues of resource exploitation and environmental regulation. The intent is to suggest areas in agricultural economics where game-theoretic models can broaden understanding of behavior.

The underlying assumptions of game theory are that the decision maker behaves rationally and reasons strategically. The assumptions imply that a decision maker "is aware of his alternatives, forms expectations about any unknowns, has clear preferences, and chooses his action deliberately after some process of optimization" (Osborne and Rubinstein, p. 4). Models of game theory are divided according to three broad categories: strategic games, extensive games with or without perfect information, and coalitional games. The first two categories are often called "non-cooperative" games and the latter are called "cooperative" games. While the framework of strategic games and extensive games is suitable for modeling players' autonomous actions, the framework of coalitional games fits situations in which actions are taken by coalitions. Public good aspects of agricultural problems can be analyzed under each of the above categories depending on the type of interaction among players. We first review some areas in which some applications of game theory have appeared and then suggest areas for which application appears possible but has not been undertaken.

**Landowner-Tenant Contracts.** The landlord-tenant relationship has been an important subject of agricultural economics over most of the discipline's history. Most recent references discuss land tenancy in developing countries, but land tenancy is also important in the United States. Approximately 45% of U.S. farmland is rented (Census of Agriculture, Table 1); approximately 65% of this is rented with a cash lease, 30% with a share lease, and 5% with a mixed cash-share lease

(Census of Agriculture, Table 108). Wage contracts, fixed rent (cash) leases, and crop-share leases have been studied thoroughly. Stiglitz and Reid study incentives and risk-sharing aspects. Newbery and Stiglitz and Hallagan apply the principal-agent framework and consider a screening model as well. Bell compares results derived under the principle-agent model and the bargaining model under both costless and costly monitoring. Eswaran and Kotwal recognize farmland contracting as a two-sided moral hazard problem and use the partnership model to describe players' incentives. Game theory suggests that the terms of such contracts will depend primarily on which party specifies the contract terms rather than on external market forces.

**Collective Action by Farm Organizations.** Davis and Palomba use the non-cooperative prisoner's dilemma game to predict the failure of the National Farmers Organization to drive up farm prices and income by means of "holding" actions or boycotts because of the public good nature of the outcome of the boycott. That is, if the price of an agricultural output is increased because of the boycott, any farmer will be able to enjoy the advantage of the increase regardless of his participation in the boycott. Such 'free rider' behavior is expected from a game-theoretic perspective and induces a non-Pareto optimal outcome for all players.

**Cooperatives.** Most actions taken by cooperatives have public good characteristics. Like collective action, their success hinges on free-rider considerations and benefit distribution. These factors justify a game-theoretic approach to issues such as the stability of cooperatives with respect to market conditions, and the impact of cooperative size on ability to secure member benefits in bargaining with suppliers or customers. Nitzan and Schnytzer apply a game-theoretic model to assess the effect of disutility of labor and distribution schedules of supply in Chinese agricultural teams. Lin uses game theory to explain the failure of Chinese agricultural collectives after 1959. He argues that since supervising agricultural work is difficult, agricultural collectives have to rely on self-enforcing contracts that are effective in a repeated game. In 1958, the right to withdraw from a collective was repealed. That is, the game was changed to a one-time game under which self-enforcement failed. As a result, agricultural productivity collapsed. Kimball considers a repeated game model of a

farmers' cooperative to explore the conditions under which a cooperative, as a substitute for formal insurance markets, is self-enforcing. Game theory provides insights into the extent of insurance provided by a self-enforcing cooperative arrangement.

**Pesticide Use.** Pesticide application can be modeled as a game among farmers. Once a pesticide is applied to an individual farm, its effects spill over onto neighboring farms in the sense that the total pest population is reduced. That is, each farmer (of the same crop) benefits when pesticides are applied, but each would prefer other farmers to incur more of the cost of application. Harsanyi's Bayesian game of incomplete information fits such strategic behavior. Regional pest control programs such as the boll weevil eradication program are examples. Ahouissoussi applies a principal-agent model to analyze the resistance of some farmers to eradication programs operated by the Animal and Plant Health Inspection Service. The potential gain from regional pest control varies across producers and the producers' cost of switching from firm-specific to regional control is unknown to the principal. A game-theoretic framework is also suitable for modeling strategic behavior of farmers with common property stock externalities. For example, declining pest resistance is considered a common property resource problem that calls for collective action to control the buildup of resistance (Regev et al.).

**Crop Insurance.** With crop insurance, contracts are designed by a principal, either a private firm or the government, and offered to agent farmers who have different yield distributions known only to them. Issues related to crop insurance have been analyzed emphasizing the moral hazard problems of input choice and the adverse selection impacts on actuarial performance (e.g., Hueth and Furtan). While game-theoretic language has not been used, these problems clearly involve mechanism design and can be studied as Bayesian games of incomplete information (Fudenberg and Tirole).

**Vertical Integration.** The U.S. food market is becoming increasingly vertically integrated. Factors motivating vertical integration of (food) industries include increasing consumer demand for reputation and product uniformity, transaction costs, price and production risk sharing, and access to credit. Advances in production and processing technology enable food processors to target specific consumers more effectively but require greater coordination among producers, processors and



consumers (Barkema and Kelly; Frank and Henderson). Such mechanisms of coordination can be studied with game theory.

Contracting in vertically integrated agricultural industries appears to be a particularly fertile and largely unexplored area for application of game theory. Typically, an integrator who owns the major inputs and more than one stage of the production process contracts with agents that provide labor and other inputs to a particular stage of the production process. In this setting, contracts between integrators and farmers in the fully integrated broiler industry and the increasingly integrated swine industry can be analyzed as games of mechanism design. A typical problem is that the uninformed integrator needs to condition actions on information that is privately known to the informed agents, the growers. By offering properly structured incentives, the integrator can induce growers to reveal their types or provide optimal effort levels.

**Agricultural Research Spillovers.** Lobbying over R&D funding is a political economy problem that we do not consider in this paper. However, another dimension of R&D funding deals with spillover effects. State governments' decisions to fund state agricultural experiment stations yield both state-specific private benefits and region-wide public benefits (Khanna, Huffman and Sandler). That is, neighboring states that share the same geoclimatic conditions enjoy the fruits of the research without necessarily sharing its cost (Khanna). Alternatively, to avoid the free rider problem, governments can act collectively by agreeing on an aggregate level of research activity and bargaining over the sharing of its cost. In determining shares of the cost of the research activity, each government must consider how the presence of research spillovers will affect the other governments' contributions to the cooperative research effort.

**Product Licensing.** Licensing of patents for pesticides, seeds, and genetic material is another problem for which bargaining holds potential. Firms have different capacities for marketing products. Some specialize in brand-name development, whereas others specialize in generic competition. Thus, dynamic considerations of product development and market exploitation suggest benefits of cooperation. International licensing of branded food products is another example where game theory

can be applied (Sheldon and Henderson).

**Other Possibilities.** As this brief survey suggests, a wide range of problems in agricultural economics have characteristics that seem to call for game-theoretic analysis. Resource exploitation and environmental regulation problems provide a host of other potential applications of interest to agricultural economists. For example, non-cooperative games are often used to model strategic aspects of externalities that result from joint use of the commons or those that result from privately owned resources, and cooperative games provide a framework to discuss issues of fairness in distributing shared resource costs and benefits. (See Mesterton-Gibbons for an excellent survey of applications of both cooperative and non-cooperative games in resource modeling.)

### **Strengths and Weaknesses of Game Theory: The Case of Land Rental Contracts**

To this point, we have outlined several areas for which game theory has produced useful insights and a number of others in which problems seem to call for a game-theoretic framework. With this wide variety of possibilities, it remains to assess the potential magnitude of benefits that can be obtained from these game theory applications. Obviously, an assessment of benefits in each area of application is beyond the scope of a single paper. In the remainder of this paper we focus on a particular problem to illustrate some of the strengths and weaknesses of game theory for agricultural economic problems. For this purpose, we focus on the farm rental contract between a landlord and tenant. Contract choice is particularly appropriate as a game, but its game-theoretic aspects are rarely recognized.

Suppose the landowner can offer one of two contracts. In Contract A, the tenant gives the owner two-thirds of the crop. In Contract B, the tenant gives the owner one-third of the crop and a fixed payment,  $K$ . The tenant can take one of three actions: sign the contract and use a high level of inputs,  $x_H$ ; sign and use a low level of inputs,  $x_L < x_H$ ; or not sign the contract. Crop yields are  $f_H$  and  $f_L$  if the contract is signed, respectively. If the tenant does not sign the contract, the owner gets zero payoff. Output price is normalized to 1 and  $w$  is the input price. Let  $K = \frac{2}{3}f_H - wx_H$ . We assume  $\frac{2}{3}f_H - wx_H > \frac{2}{3}f_L - wx_L$ ;  $\frac{1}{3}f_L - wx_L > \frac{1}{3}f_H - wx_H$ ;  $f_H - wx_H > \frac{2}{3}f_L$ , and that all of these expressions are positive.

Figure 1 shows the extensive form game. With these specifications, the game has four equilibria:

1.  $\{x_L \text{ if A, } x_H \text{ if B; Contract B}\}$
2.  $\{x_L \text{ if A, } x_L \text{ if B; Contract A}\}$
3.  $\{x_L \text{ if A, no contract if B; Contract A}\}$
4.  $\{\text{no contract if A, } x_H \text{ if B; Contract B}\}$

where the first component is the tenant's strategy and the second is the landlord's strategy. Each equilibrium specifies a particular choice of strategy for both players. For example, in equilibrium 1, the tenant's strategy is to choose input level  $x_L$  if the landlord offers contract A and input level  $x_H$  if the landlord offers contract B; the landlord's strategy is to offer contract B.

Equilibrium 1 (and its analog in a variety of games) is the one on which the literature almost invariably focuses, and the predicted contract is B. Agricultural economists have long observed the superior qualities of Contract B. Allowing the tenant to keep a higher proportion of returns leads to higher input use, higher yields, and, if  $f_H - wx_H > f_L - wx_L$ , higher total returns. Contract B occurs in equilibria 1 and 4.

Although not often recognized, this game has two equilibria in which Contract A is chosen. Some equilibria can be ignored by implicitly or explicitly invoking two restrictions: perfection and properness. Perfection requires that the proposed equilibrium be an equilibrium of all subgames. There are two proper subgames of the Figure 1 game in which only the tenant moves. Equilibrium 2 is not perfect because the tenant "threatens" to play  $x_L$  if B, yet the tenant is better off with other actions if B were actually offered. The desire to rule out such non-credible threats led Selten to formalize perfection. Perfection also rules out equilibrium 4. The perfect equilibria are 1 and 3.

The most unusual equilibrium is 3. It arises because Contract B leaves the tenant indifferent between accepting and not accepting the contract; but if he rejects the contract, the owner should choose Contract A. In summary, this game has two perfect, proper equilibria yielding Contract A or B, and no standard procedure is available for predicting one over the other.

Next, generalize this model by giving the landlord a continuous strategy space. Attention is restricted to linear contracts in which the landlord chooses a tenant crop share,  $\alpha$ , and a fixed payment,  $\beta$ , which may be positive or negative. If the contract is accepted, the tenant earns  $\alpha f(x) - wx - \beta$  and the landowner earns  $(1-\alpha)f(x) + \beta$ . Consider a game in which the landlord first chooses a contract and the tenant then chooses whether to accept and, if he accepts, a level of  $x$ .

This game has an infinite number of equilibria. When  $f(x) = \ln(x)$  and  $w = 0.1$ , these equilibria are of the form  $\{x = 10\alpha'$  if  $0 \leq \beta' \leq \alpha'(k + \ln\alpha')$ , no contract otherwise;  $\alpha', \beta'\}$  where  $\alpha'$  ranges from 0 to 1 and  $k \equiv \ln 10 - 1$ . All but one of these equilibria are not perfect. If the landowner were to choose  $\{\alpha \neq \alpha', \beta < \alpha(k + \ln\alpha)\}$ , then the tenant is better off working ( $x = 10\alpha$ ) than refusing the contract, so his threat not to sign the contract is not credible. Just one perfect equilibrium exists in this game:  $\{x = 10\alpha$  if  $0 \leq \alpha(k + \ln\alpha) - \beta$ , no contract otherwise;  $\alpha = 1, \beta = k\}$ . See Eswaran and Kotwal for analysis of this equilibrium. Call this Contract  $B^*$ .

The conclusions that can be drawn from this game show the full range of advantages and disadvantages of game theory. If  $B^*$  is observed, game theory's prediction is validated. But if a contract other than  $B^*$  is observed, say not- $B^*$ , then three related, unanswered questions arise. Is not- $B^*$  observed because perfection is not an operable concept? Or is it because the model is missing an important component such as production uncertainty and tenant risk aversion? Or is the game misspecified? If perfection is not a reasonable restriction, then which non-perfect equilibrium will be observed? On the other hand, if  $B^*$  does occur, then the game theoretic background appears to have been largely unnecessary because  $B^*$  can be derived as the solution to a simple two-stage optimization problem and one need not derive the other equilibria or explain why they are unlikely to occur.

The model can be further expanded to allow bargaining between the landlord and tenant. Game theory provides two reigning models of bargaining named for their founders: Rubinstein-Stahl and Nash. In the Rubinstein-Stahl alternating-offers model, the players take turns making offers to the other party (Rubinstein). For example, the landlord first offers a contract to the tenant, which the tenant can either accept or reject. If the tenant accepts, the contract is entered into. If the tenant

rejects, he can propose his own contract, which the landlord either accepts or rejects. If the landlord rejects, the landlord makes another proposal, which the tenant again either accepts or rejects, and so on. If the players fail to reach an agreement, they get their outside option, which we have normalized to zero in the above example. Let  $\delta$  be the discount factor.

The game has a unique subgame perfection equilibrium that depends on the discount factor and who makes the first offer. If the landlord makes the first offer, the equilibrium is  $\{x = 10\alpha$  if  $\beta \leq k/(1+\delta)$ ;  $\alpha = 1$ ,  $\beta = k/(1+\delta)\}$ . This change from a game in which the landlord makes a single offer to one in which the players make alternating offers changes the equilibrium prediction. If the tenant makes the first offer, the equilibrium contract has  $\alpha = 1$  and  $\beta = \delta k/(1+\delta)$ . As the discount factor goes to one, the equilibrium is independent of who makes the first offer, in which case the result is a cash lease equal to half the farm profits.

Nash bargaining provides an alternative model. Nash bargaining is properly considered a cooperative game, but it may better be regarded as a *reduced form* of the bargaining process (Nash; Binmore, Rubinstein, and Wolinsky). That is, the analyst, either implicitly or explicitly, claims knowledge only of potential payoffs rather than of the bargaining process. In the above model, the Nash Bargaining Solution predicts a fixed payment of  $\beta = k/2$ , the same as the alternating-offers equilibrium when the discount factor is 1. For the specific example presented here, this result turns out to be the average of the two alternating-offers outcomes. Thus, for example, the Nash Bargaining Solution might be used in some cases as an approximation when there is a 50-50 chance for landlords and tenants to make first offers and the data on who made the first offer are missing.

These various games that can be played for the same economic situation illustrate some of the empirical awkwardness of game theory. Even when consideration is restricted to perfect equilibria, at least four equilibria are applicable depending on which game is played (i.e., depending on who initiates the game and how). While the scope of this paper is too limited to do so, similar considerations can be demonstrated for more complicated games with public good characteristics. Thus, for most of the agricultural economic problems to which game theory appears to be applicable,

a tradeoff appears to be imposed on the researcher in which clarity of empirical results must be sacrificed for more general and strategic understanding of economic process. This is a question that can only be answered according to personal tastes and revealed preferences of researchers. Whether game theory or neoclassical theory is employed, we point out that proliferation of numbers with limited understanding of processes is no more a formula for long-term success of the profession than is increased sophistication of models that cannot be communicated to decision makers. The susceptibility of both approaches to such pitfalls depends on the skill and insight of the practitioner.

### **Game Theory Versus Neoclassical Models: Concluding Comments**

An important question that must be addressed in the selection of approach is whether the conceptual understanding and insights of game theory merit sacrificing the empirical tractability of neoclassical models. Factors affecting this choice may not be the same as for studies of other sectors of the economy. To see this, note that a bilateral bargaining model is essentially a model of monopoly-monopsony transactions. Game theory suggests outcomes that can occur in cases where neoclassical models are relatively silent. On the other hand, agriculture traditionally has been viewed as a sector where perfect competition is a better assumption than for other sectors. Thus, the benefits added by refinements of game theory may be relatively less valuable.

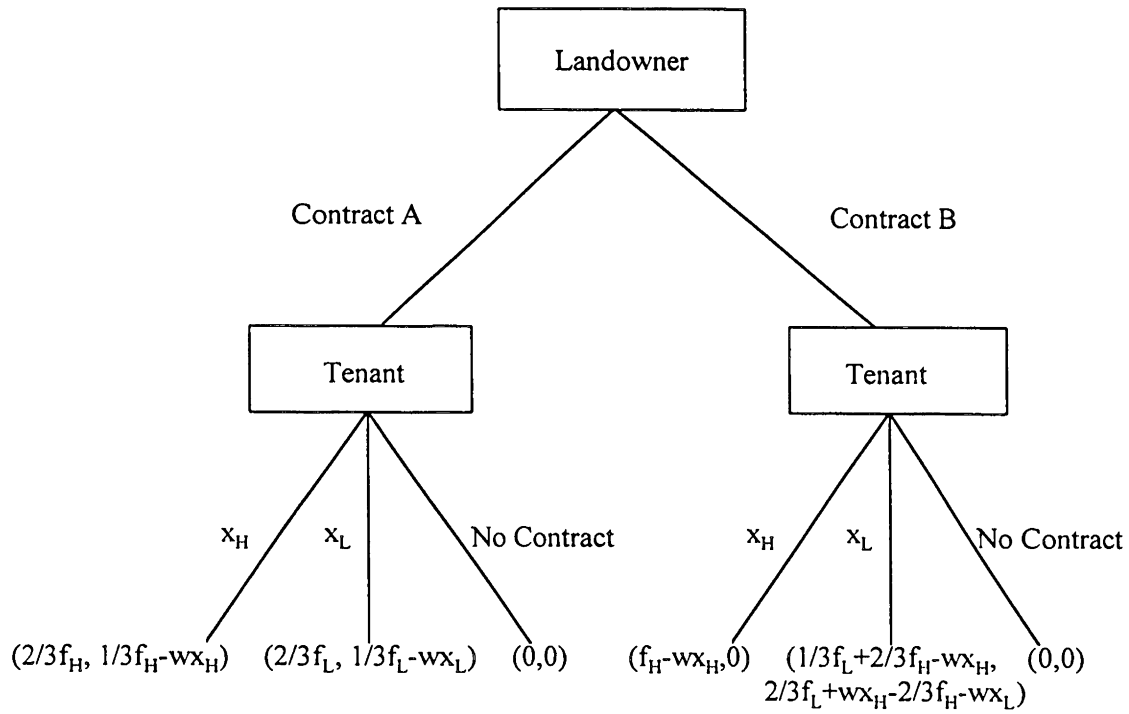
One approach to evaluating the relative benefits of game theory may be to consider the local isolation of transactions. Remote markets may be thin. For example, some landlords may have few potential tenants or some tenants may have few potential landlords because of transportation and coordination costs associated with distance. The extent of these transaction costs may determine the relative benefits of game theory approaches. The model of perfect competition may be applicable as an approximation within the bounds of transportation costs, but game theory may be required to better model individual transactions.

Game theory's emphasis on individual transactions, strategic payoffs, and mutual expectations calls for reconsidering the current predominant mode of empirical analysis of agricultural data. Most empirical analysis is of aggregate data because little panel data on specific transactions have been

developed. For example, if rental contracts follow the alternating-offers game, but some landlords offer first and some tenants offer first, then the average aggregate behavior may follow the Nash Bargaining Solution and may not be empirically distinguishable from Neoclassical competition.

In summary, the various considerations of this paper suggest that game theory is a fruitful ground for conceptualizing micro-level transactions, particularly those that take place in more isolated markets or among cooperating groups. While we have focused our conceptual demonstration on problems of bilateral bargaining, similar implications apply to problems with public good characteristics. However, the contribution to improvement of aggregate models may be illusive and contributions in many applications (not all) may amount to little more than second-order corrections.

Figure 1. The Landowner-Tenant Game





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