# Strategic Behavior, Institutional Change and the Future of Agriculture

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**ABSTRACT**

Policy reforms increasing the roles of markets in agriculture and related institutional changes are occurring worldwide. These are accompanied by and related to rapid technical change, especially for information systems, biotechnology, and organizational mechanisms. Trends in farm size, integration, concentration, environmental sensitivity, organization and funding of research and development, and multinational business organization are among the observable consequences of these changes. With the evolving role of government, new institutions are emerging for shaping the strategic behavior of public and private sector agents. What are the characteristics of these institutions? Where will strategic behavior and interaction of agents have a critical impact on the performance of agriculture? How will they shape the future of agriculture? What are the implications for policy analysis and the development of the capacities of our profession?

Key Words: Agricultural Policy, Game Theory, Mechanism Design, Strategic Behavior

# STRATEGIC BEHAVIOR, INSTITUTIONAL CHANGE AND FUTURE OF AGRICULTURE

## Introduction

Strategic behavior is increasingly important in interactions between economic agents as the number of agents decreases and as agents take on different characteristics. Examples of the latter are different locations of agents, capacities for segmenting markets, and access to alternative information structures. Changes in the agricultural sector due to concentration, product differentiation, market reforms, and a decreasing role of the government are placing increased emphasis on understanding strategic interactions as an ingredient of effective policy analysis. This is true of both public and private agents. And, these changes, if appropriately read, have broad implications for the capacities of agricultural economists and the way that agricultural economists approach policy analysis.

From the early days, agricultural economists were leaders in the use of partial and general equilibrium frameworks in developing policy analysis and in communicating the results of related analyses in ways that influenced both government and the private sector. Often, agriculture was seen as a particularly appropriate arena for applications of the competitive model; undifferentiated products, large numbers of firms, and government interventions aimed at transfers through markets and trade management. In fact, large-scale systems are in place that embody the prior restrictions from the conventional theory and are used for routine policy analysis and projections.

The traditional theory and methods are, however, less appropriate when the number of agents that are interacting is limited and the information that the agents have about each other may differ. Also, there are issues related to the interactions of the agents and the types of rules that govern these interactions. Game theoretic frameworks which have by some been viewed as esoteric and of limited practical applicability provide a strucuture for this kind of analysis. Combined with modern concepts of mechanism design, game theoretic formulations offer an approach to policy analysis and the study of institutional change that is likely to be of increasing value to professionals involved in the economics of agriculture, broadly defined.

This paper provides a brief overview of game theory and mechanism design. The intent is not to be encyclopedic or to deal with the subtleties of the modern theory in either area. Instead, the overview is used as a basis for illustrating the value of the concepts that emerge from these developments for applied policy problems in agricultural economics. The latter is accomplished in the form of three examples. Stylized analytical models are formed as a basis for illustrating the applicability of game theory and mechanism design in routine policy analysis. The applications selected for illustration involve research and development, integration and incomplete contracting, and markets in which the timing of decisions by the agents matters.

## Elements of Modern Game Theory

Game theory[1] is used to analyze situations where each *participant's* fortune depends not only on the actions of that *participant* but also on the actions of other participants involved in the interaction. We choose to organize the overview as described in Figure 1, proceeding from the basic formulation to dynamic games, and differentiating between strategic and extended form games.

### The Basic Formulation

Two nearly equivalent formulations are used for modeling games: the *strategic* or *normal* form and the *extensive* form. First, we introduce the building blocks for both formulations. Then we emphasize the extensive form games. A strategic form of a game has three components; the set of participants or "players"; the sets of pure-strategies available to each player and Bernoulli payoffs for each player as conditioned by the strategies played. In most game theoretic analysis, a crucial assumption of *common knowledge* is employed. It requires that all players know the structure of the game, their opponents know the structure, and that their opponents know that they know, and so on *ad infinitum*.

Having modeled a strategic interaction, the question of the outcome of the game remains open. A Nash equilibrium is a solution vector, consisting of mixed strategies for all players (a strategy profile), such that each player's strategy is an optimal response to the opponents' strategies. One might argue that Nash equilibrium is the "consistent" mode of behavior since for a strategy profile that is not Nash at least one of the players would have an incentive to deviate.

It is assumed that players choose their actions independently and simultaneously when they play strategic form games. Thus, the sequential structure that may arise in interactive decision making is suppressed. Many economic applications have an intrinsic dynamic structure. For instance, models of sequential bargaining, entry deterrence, exit and "time consistency". The concept of a game in extensive form is used for modeling such dynamic situations. An extensive form game is a generalization of a single-agent decision tree to the situation of multiple decision makers. In the extensive form, the order of moves and the information possessed by a player when making each move are explicitly modeled.[2] Thus, participants in an extensive form game choose contingent plans.

We have collected the elements of the extensive form game into five categories. The first is the set of participants or *players*. The second, termed *the physical rules*, describes who moves when and what each player's choices are when it is her turn to move. The third, *the informational rules* describes what each player knows about the actions taken previously in the game when she makes her choices. The fourth, *nature's moves*, is a probability distribution over random events. The last component, *the payoffs*, represents the outcome for each player as a function of strategies played.

We use chess to demonstrate the concepts just introduced. There are two players in chess, white and black. The list of physical rules is too long to present. However, some of the basic rules are that white is always first to move and players take turns alternately moving one piece at a time. Also, movement is required and each type of piece has its own method of movement. The informational rules of chess are very simple. Each player learns the opponent's move before making its own. The payoffs depend on who is playing the game. For instance, there was much at stake in the 1997 match between the World Chess Champion Gary Kasparov and the top-rated chess program Deep Blue. Deep Blue won the sixth and decisive game of the match, and its development team's payoff, besides pride and joy, was $700,000, while Kasparov received $400,000.

**Selected Developments**

The existence of the mixed-strategy Nash equilibrium for an extensive-form game is a direct corollary to Nash's theorem on the existence of equilibrium for strategic form games. However, the uniqueness of the Nash equilibrium is not guaranteed (either for extensive or for strategic form games). There are numerous examples of strategic interactions that posses a plethora of Nash equilibria. This suggests that one might use a more restrictive equilibrium concept to make the theory more useful for prediction.

Selten's (1965) work started the research on *refinements* of the Nash equilibrium. He argued that in extensive form games not all the Nash equilibria are reasonable. A Nash equilibrium does not place restrictions on the behavior of the players at information sets (under contingencies) that are not reached along the equilibrium path. Thus, there is freedom in specifying strategies at these information sets. But, if an out-of-equilibrium contingency arises, then the prescription of a Nash equilibrium for a player may be non-optimal. In other words, an equilibrium may rely on an "empty threat", that will never be carried out if called. Selten introduced the concept of *subgame perfect equilibrium* to rule out equilibria with such non-credible threats.

Economic agents are often repeatedly involved in the same strategic interaction. That is, they play the same game form against the same opponents. For instance, duopolists compete in prices over a time horizon, the same upstream and downstream firms bargain over the price and quality of the intermediate good for more than a single production cycle, the US and the EU change domestic agricultural policies in response to their counterpart's behavior as well as conditions on the world markets. The theory of *repeated games* is useful framework for studying these interactions. In a repeated game the same "stage game" or "constituent game" is played for finitely or infinitely many periods. That is, a "physical environment" of the game in the beginning of each stage (set of players, feasible actions and per-period payoffs) is independent of the history (the sequence of actions chosen in previous periods). In finitely repeated games, all players are completely certain when the game will end, while in infinitely repeated games the players are uncertain of the last period.

Repeated games belong to a class of extensive-form games called *multi-stage games with observed actions*, where the players act simultaneously in each stage of the game and know the actions chosen in all past stages. An example of multi-stage game with observed actions is chess, where in each stage one of the players chooses a legitimate move while the other's choice set is empty. Chess is a game of perfect information with a finite horizon[3] and hence can be solved by backward induction[4], a many-player generalization of the same concept in dynamic programming.  This algorithm can be applied to finite-stage games with observed actions to find subgame-perfect equilibria. But it cannot be used for a game with infinite stages, since there is at least one node with infinite number of successors and hence no last stage from which one can start solving the game backward.

Analysts often utilize a very useful algorithm for verifying that the strategy profile is a subgame perfect equilibrium of a multi-stage game with observed actions. This is so called *one-stage-deviation principle*, an analogue to the principle of optimality in dynamic programming. The one-stage-deviation principle for finite-stage games with observed actions states that a necessary and sufficient condition for a strategy profile to be subgame perfect is that no player can increase her payoff by deviating from her strategy in a single stage and conforming to the strategy afterwards[5].

A repeated relationship opens the opportunity for players to use "punishment" or "reward" strategies to compel opponents to choose certain strategies. It also allows players to establish "trust" and different "reputations." These aspects of long-term relationships can have a substantial effect on the outcome of a strategic interaction, generating significantly different results than the static model.

"Unfortunately, " the set of predictions for infinitely repeated games with observed actions is extremely large. The "*folk theorem*" for repeated games asserts that "almost every" payoff vector can be enforced as an equilibrium. More precisely, it states that if players are sufficiently patient then any feasible and individually rational payoff [6] can be supported as a Nash equilibrium. One might ask the question whether the folk theorem remains true if an equilibrium concept stronger than Nash is used. Fudenberg and Maskin (1986) have shown that the folk theorem applies to the payoffs of a subgame-perfect equilibrium.

**Imperfect Information**

We have considered strategic interactions where all involved participants are completely informed about the game they are playing and, in particular, about the payoffs to their opponents. In many situations players do not know some characteristics of their opponents: competing firms may not know each others' cost functions, an employer may not know the disutility of effort of its employees, local government may not know the value of the public good to the residents in its jurisdiction. In other situations players may know their opponents' characteristics but may be uncertain that the other players are completely informed about them.

The game in which some players do not know some characteristics of the others is said to have *incomplete information*. Harsanyi (1967-68) proposed a formulation to analyze these games. He suggested transforming the game of incomplete information into a game where nature moves first and determines each player's "types", where type corresponds to player's private information relevant to his decision making process. It is also assumed that the probability distribution over nature's moves is common knowledge. Thus, a game of incomplete information is converted into one of *imperfect information*, also called a *Bayesian* game. In a Bayesian game each player, upon receiving his private information (also called signal), uses Bayes' law to update his beliefs about other players' types. A *Bayesian Nash equilibrium* is a Nash equilibrium of the "expanded game" where each player's strategy space is the set of maps from the space of his types to the set of feasible actions.

Games with incomplete information have been used to model many economic situations. For example, signaling in labor markets, provision of public goods, price discrimination by a monopolist, procurement and regulation. Early models with imperfect information exhibited a multiplicity of equilibria even when subgame perfection was applied. Kreps and Wilson's (1982a) *sequential equilibrium* extended subgame perfection to games of incomplete information. Their solution concept makes the belief structure a part of the equilibrium description and imposes certain restrictions on the process of belief updating (in addition to Bayesian inference along the equilibrium path). An extensive-form refinement, that in many situations is easier to apply than sequential equilibrium, is *perfect Bayesian equilibrium* (PBE)[7]. The sequential equilibrium is in general more restrictive than PBE.[8]

If players are involved in the same strategic interaction repeatedly, they may be able to establish and/or maintain a reputation for choosing certain actions. A rough idea of most *reputation models* is that if the same stage game is played finitely or infinitely many times, and if a *player*'s opponents have some prior belief (or initial reputation) that she will be taking same course of action every time the stage game is played, then she may try to preserve and/or to develop this reputation. There are numerous examples in which an economic agent might be willing to commit to take the same action over a number of periods. For instance, the government may always implement its announced agricultural policy to convince farmers that it will keep its promises in the future. Or, a producer may choose a high quality of its product to convince potential buyers to choose its brand. The question is whether with this superior information, the agent will be able to effectively commit to the desired strategy.

Researchers at the forefront (Maschler, Nash, Schelling, Shubik, and Selten) have tried to test game theoretic predictions in controlled environments. This experimental work has yielded important insights and provided tests of actual and predicted behavior. The experimental analyses often suggest outcomes different than the ones predicted by theory. The *theory of learning and evolution* focuses on non-equilibrium explanations of equilibria in games. It views equilibrium as the long-run outcome of an evolutionary or learning process. This theory is a new and promising line of research, and becoming an important constituent part of game theory.[9]

## Mechanism Design

We have argued that game theory can be a very powerful tool in analyzing strategic interactions and in identifying optimal strategies. This type of positive analysis can be accomplished by specifying *all* elements of the five components of a game (players, physical and informational rules, nature's moves and payoffs) and "careful" application of the "relevant" game theoretic solution concept. Economists also conduct normative analysis in the sense of evaluating different policies. *Mechanism design* used in the context of strategic interactions is an effective tool for this analysis.

Mechanism design can be viewed as a complement to game theory. Game theory takes the five characteristics outlined in the previous section as given, while mechanism design asks the consequences of changing some of these characteristics (Brandenburger and Nalebuff (1996)). Altering an element of a game transforms it into a completely new one. Game theory techniques can be used to analyze the transformed game, and compare the outcomes to those of the ongoing game. The result is a policy tool that can be applied in a clearly structured strategic context.

Mechanism design has been successful in formulating schemes for optimal provision of public goods, revenue maximizing auctions, and wage agreements that effectively spread risk while maintaining incentives. The process is one of understanding the strategic interaction, and how the characteristics of the associated game determine the equilibrium outcomes. These outcomes are not always the most desirable, even for the players. Changing the characteristics, using principles of mechanism design (eg., incentive compaibility, contract enforceability) can suggest policies that result in an improvement.

## University Science Policy

The public sector is the major source of research funding for US universities. However, in a world of changing social and private demands, and institutional structures, the private sector share of the university research budget has increased. Both public and private agents allocate funds to universities with objectives or expectations about returns or benefits. Universities in turn try to maximize funding for research. In addition to supporting the cost of high technology research programs, growing and large research budgets make it possible to attract top scholars.

Private investors in university research programs receive the direct benefits according to the contracts they make. As well they may gain early access to results of the publicly funded university research program. Once a private company gets admission to the university research program, “field,” it has an incentive to “graze” the “field, ” and appropriate as many of the results as it can.[10] A possible tactic for accomplishing this goal could be to provide funds to the university departments and to individuals or to hire the university professors as consultants. Universities have variety of instruments to control the appropriation of the publicly funded research results for private benefit. An example is high-powered incentives for scholars to cooperate with the university and license research results before sharing them with other parties. In fact, subsidizing patenting and licensing and sharing of royalties is common practice in major research universities.

Yet another way to discourage private companies from harvesting research results or appropriating the benefits of publicly funded research is to focus university research program on more basic science, less attractive to the private sector due to high potential development costs. In other words, the university can either build a “high wall” around its research program or scientific field and restrict access and appropriation of results by private companies or build a “low wall” and welcome the private sector and its investment.

The public sector, when providing funds to the university, expects research programs that will yield high social returns. Wright and Zilberman (1993) note there is a "danger of distortion of the university research mission by private interests that "free ride" on university research efforts". If this is the case, the public sector may reduce investment in the university research programs. Building the walls "high" enough for maintaining growing public support while low enough to attract private sector investment is a strategic decision for universities. That is, private firms with relatively small funding may influence the direction of scholarly research. More important, the private sector with a small investment in the university research program may find itself in position to appropriate the benefits of a high share of the research funded by the public sector.

**The Game**

We use a stylized game to analyze the strategic interaction between the university and the public and private sector research funders. We address the strategic decision from the university viewpoint. The purpose is to find a strategy for the university to achieve its objectives, given that other participants will behave in their self interest, and optimally. First, we consider a situation in which the university perceives that the flow of public funds will be the same irrespective of its interaction with the private investors.

We model this situation as a game with three players, the university, and two private firms $F_1$ and $F_2$, that provide research funding to the university to gain access to or appropriate publicly funded research results. We will say that a private firm "entered" if it has made a decision to invest in the university research program, and a private firm has "stayed out" if there is no investment. In making this decision the private firms are balancing between contracting with the university and accessing the public research program or doing the research themselves.

Even if a private firm enters the university research program it may not have full access to the results of its publicly funded research. It will still face a "wall" or a combination of different university policies for controlling access and appropriation. For simplicity, we assume (Figure 2) that the university has two options for controlling access to its research program, a "high wall" or a "low wall. " The "high wall" ("low wall") describes a situation in which the university decides to make it hard (easy) for private firms to access the results of its research program.

In the game diagramed in Figure 2, the university moves first and chooses high wall or low wall. After observing the university decision, the two private firms simultaneously and independently decide whether to enter or stay out. These are the physical and informational rules of the game. Now we describe the payoffs to the players for the different strategy decisions. These are depicted in Figure 2, where the first element in a triple at a terminal node is the payoff to the university, the second is firm $F_1$'s payoff and the third is firm $F_2$'s payoff. The university incurs a cost of building the wall. We denote the cost of building a high wall by $\bar{c}$ and the cost of the low wall by $\underline{c}$, with $0 < \underline{c} < \bar{c}$.

If a private firm decides to stay out then it nets a payoff of 0, while if it decides to enter it makes a payment to the university ( $p_i \geq 0$ for firm $F_i$, $i$ = 1, 2). The gross value to firm $F_i$ ($i$ = 1, 2), if it enters is $\underline{v}_i$, if low wall, and $\bar{v}_i$ otherwise. High walls diminish the accessibility to the university research program, 0 < $\bar{v}_i$ < $\underline{v}_i$ for $i$=1, 2. We also assume .$\overline{v_1} - p_1 > 0$ and $\overline{v_2} - p_2 < 0 < \underline{v_2} - p_2$. That is, for firm $F_1$ it is worthwhile to enter no matter what wall is built, while firm $F_2$ will find entry profitable only if the university has a low wall.

Now we solve for the subgame perfect equilibrium (SP equilibrium) of the game described in Figure 2. Note that if the university chooses the high wall, the strictly dominant strategies for firms $F_1$ and $F_2$ are enter and stay out, respectively. While if the university chooses a low wall then both firms enter. Anticipating these responses by the firms, the university chooses between $p_1 - \bar{c}$ for the "high wall" and $p_1 + p_2 - \underline{c}$ for the "low wall". Hence, the university will build a "low wall". Thus, the unique subgame perfect equilibrium outcome of this game is for the university to choose a "low wall". Both firms pay and get an access to the university research program.

**Increasing the Scope**

Will the university administration be acting optimally by choosing the low wall as prescribed by the optimal strategy for the game of Figure 2? The clamor for private sector funding by the land grants may indicate the answer is yes. The condition is that the flow of public funds to the university research program is not altered by the policies that affect private sector access. But if the public prefers that the number of private firms "grazing field" be restricted, increasing the public benefit from its investment, the university will be missing a player and the "low wall" strategy may be flawed.

To illustrate this situation, consider a new game with the public sector as one of the players. The extensive form of this game is depicted in Figure 3. The game has four players: the university, the public sector and the private firms $F_1$ and $F_2$. As in the game described by Figure 2, the university moves first and decides the "height of the wall" around the research "field". After observing the university's choice, the public sector makes a decision on the funding of the university program. It has two options, "high investment" or "low investment". If the public sector chooses high investment then the university receives $I_H$ while if low investment is provided, the university receives $I_L$, where $I_H > I_L > 0$. We also assume that $p_1, p_2 < I_H$, i.e. the high investment from the public sector is more attractive to the university than the funds of any of the private firms.

The public sector investment choice is followed by the decisions of the two firms, enter or stay out, as in the model of Figure 2. The procedure of the private firms gaining access to the university research program (payments in case of entry) as well as the resulting payoffs are the same as in the model of Figure 2. That is, we assume that the payoffs to private firms do not explicitly depend on the level of public funding to the university research program, i.e. they depend only on the height of the wall built by the university and their own decision to enter. Now we describe payoffs to the other players (the university and the public sector) for the different strategic decisions.

These are depicted in Figure 3, where the first element in a quadruple at a terminal node is the payoff to the university, the second is the public sector's payoff, the third is firm $F_1$'s payoff and the fourth is firm $F_2$'s payoff. The public sector nets a payoff of $S_j^H$ (*j*=0, 1, 2), if it has made a high investment and *j* private firms entered. While its payoff is $S_j^L$ (*j*=0, 1, 2), if it has provided a low investment and *j* private firms entered.

The restrictions on the public sector's payoffs are the following: $S_2^H < S_1^H < S_0^H$, $S_2^L < S_1^L < S_0^L$, $S_1^L < S_1^H$ and $S_2^L > S_2^H$. The first two sets of restrictions reflect a situation where the public sector prefers that the number of firms entering the university research field be as small as possible. The third restriction represents a situation in which the public sector considers it to be worthwhile to make a high investment if exactly one private firm will enter. While the fourth restriction reflects the assumption that the public sector will not make a high investment if it expects that the university will be overgrazed.

Now we use backward induction to solve for the SP equilibrium of the game of Figure 3. Note that since the funding decision of the public sector does not affect payoffs to the private firms, the SP equilibrium strategies of firms $F_1$ and $F_2$ are identical to those of the game of Figure 2. That is, firm $F_1$ always enters and firm $F_2$ enters only if there is a low wall. If the university has a high wall, then the public sector, anticipating the responses of private firms, chooses between $S_1^H$, a high investment, and $S_1^L$, a low investment. Alternatively, if a low wall is the choice of the university the public sector chooses between $S_2^H$, a high investment, and $S_2^L$, a low investment. The university's choice to build a high wall will be followed by a high investment of the public sector and the choice of low wall by a low investment.

The university, using this understanding of the game, chooses between $p_1 + I_H - \bar{c}$ and $p_1 + p_2 + I_L - \underline{c}$. The university will select the high wall if $I_H - \bar{c} \geq p_2 + I_L - \underline{c}$.

**Extensions and Observations**

This analysis of strategies can be used by the players to inform changes of mechanisms. In fact, the mechanisms of focus in this simple example are the walls of the university. The implication of the expanded scale game is that these mechanisms are critical to the university research program. But our intent is to be only instructive. The scope of the game can be expanded or the physical and informational rules made more complex; enriching the policy implications or alternatively better informing the decision of the mechanisms relevant to the player of focus. To suggest the possibilities, consider the following:

- Making scholars players, attracted by university research programs that are well funded and from which they can procure high personal benefit of their research effort. This increase of scope might imply even higher walls.
- The university in the game described in Figure 3 may have the option of free riding. If for example, the major public funder of research is federal, a state land grant university may be able to have a low wall but maintain high public funding. This is yet another type of commons problem; perhaps explaining differences in policies toward the private sector by smaller and larger institutions.
- The private sector and/or universities may set in place mechanisms to cooperate in the game. Consortia of universities and private sector firms in major research initiatives are examples.
- Federal agencies may change from formula to grants and contracts as ways of disseminating funds, with the terms of the grants somehow providing a high wall around particular research projects. That is, rules of appropriation may be stipulated as a condition of universities receiving federal funds.
- The private firms' returns to investment in the university research program can be linked to the level of public investment. This may explain why private firms choose to make large investments in relatively well funded university research programs. Alternatively, the public sector may be reluctant to maintain or increase funding of university research programs, if the result is to attract added private sector investors. This suggests that policies tying public and private funding as a condition for added public funding may be misguided.
- Universities and the private sector play this game repeatedly. This suggests the possibility for strategies that involve reputations. Universities may wish to be seen by the public sector as

having high walls, and at the same time attract private investment. The major efforts of universities for private gift funds (resulting in friendly relationships but not entry by direct investment in research programs) may suggest the development of a new mechanism for achieving this result.

With empirical investigation of the payoffs and costs and of the physical and informational rules of game, whichever the scope, informative policy prescriptions can be developed; which amount to the design of mechanisms that permit one player to achieve improved outcomes.

## Industry Structure Policy

Mergers, buyouts and strategic positions are occurring at an increased pace in the industry supporting production agriculture. The recent activity among the biotechnology and chemical firms is an example. For effective agricultural policy, it is important to understand the forces that are driving these mergers and the consequences of alternative interventions. These issues are complicated by the fact that there are few firms in the sectors in which the integration is occurring. Policy interventions must therefore reflect their impacts on the strategic behavior of the firms.

There are three common views of the incentives for integration or increased size of firms. The neoclassical theory justifies the increase in firm size on the basis of technology. This theory neglects the internal organization of the firm. It also fails to provide a rationale for limiting the size of firms. The principal-agent theory provides a framework for investigating the organization of firms and incentives that contribute to capacities for increases in size or integration. Although, this theory has been successful in answering questions about optimal compensation schemes and variety of internal organizational problems, “it does not pin down the boundaries of the firm” (Hart (1994), p. 20). The third view of integration and firm size involves the concept of *incomplete contracts.* This approach appears to have been more successful in explaining tendencies to integrate and firm size.

Unforeseen contingencies, unverifiable terms, costs of enforcement, and a lack of common language all contribute to contracts being incomplete. These characteristics of contracts provide incentives to acquire ownership, since ownership is a source of power when contracts are in dispute and a way of securing residual property rights. In agricultural related industries, eg. biotechnology, complicated contracting relationships among firms have emerged, and have been argued as a cause for the rapid level of integration. Games along with mechanism design can provide a better understanding for the trends in integration and of the role of incomplete contracts.

**The Model**

To examine the implications of incomplete contracts for integration and industry structure, we consider a stylized situation in which there are two firms, $F_1$ and $F_2$, producing "complementary" products. Firms $F_1$ and $F_2$ are operated by manager/owners $M_1$ and $M_2$, respectively. The managers are using the endowments of the firms in producing an output. The outputs are complementary in a sense that increase in the output quality of any one of the firms increases the value of the output produced by the other firm (as well as of its own product) and, hence, that firm's profit.

Each manager can enhance quality of the output by investing his time and energy in product development. We denote this *relationship-specific investment* by $I_i$ for manager $M_i$ (*i*=1, 2). For simplicity, it is additionally assumed that manager $M_i$ (*i*=1, 2) chooses one of the two levels of investment, high investment $\overline{I}_i$ or low investment $\underline{I}_i$, where $\overline{I}_i > \underline{I}_i$. Given the complementarity of the outputs, there is an incentive for the managers to coordinate their investments through a contract between the firms. However, due to the nature of investments, the contract between the firms cannot be complete.

The extensive form of the game used to model the strategic interaction between the two firms is depicted in Figure 4. The window of time for interaction between the firms is two periods. In the first period, the two managers decide on an ownership structure. They choose from a variety of different ownership patterns. One possible structure is a non-integration where manager $M_1$ owns and controls assets of firm $F_1$ and manager $M_2$ owns and controls assets of firm $F_2$ for the duration of the relationship. Another possibility is that manager $M_1$ acquires firm $F_2$ and gains control over its assets. Still another possibility is that the two firms partially exchange assets, creating a *strategic partnership*. We represent the strategic partnership by a share of ownership, where $\alpha_1$ is the percent of $F_2$ owned by $M_1$ and $\alpha_2$ is similarly defined for manager $M_2$.

The payoffs associated with the investment decisions, conditioned on the type of ownership, are expressed as $(1-\alpha_2)B_1(I_1,I_2)+\alpha_1 B_2(I_1,I_2)-I_1$ for manager $M_1$ and $(1-\alpha_1)B_2(I_1,I_2)+\alpha_2 B_2(I_1,I_2)-I_2$ for manager $M_2$, where $B_i(I_1,I_2)$ is the benefit for firm $F_i$ (*i*=1, 2) given investment decisions $I_1$ and $I_2$. To reflect the complementarity assumption both functions $B_1(I_1,I_2)$ and $B_2(I_1,I_2)$ are assumed increasing in $I_1$ and $I_2$. As illustrated in Figure 4, the choice of ownership is followed by the independent and simultaneous choice of investments.

The solution to the game is by backward induction. Note in Figure 4 that there are four types of subgames. For non-integration, we assume that payoffs are such that the optimal strategy is for managers to select low investment (for illustration, the corresponding payoffs are shown in Figure 4). This reflects the fact neither manager is in position to assure that the benefits associated with a high investment can be captured. For the situation where firm $F_1$ or $F_2$ is acquired, the acquiring manager is in position to capture the full benefits of each investment option. The manager of the acquired firm will have no incentive for a high investment. However, it is possible that the high investment strategy is optimal for the manager of the acquiring firm.

The strategic partnership can produce a strategy that involves high investments by both managers. This could occur if, for example, the complementarities are sufficient. The key is to design a strategic partnership (choose $\alpha_1$ and $\alpha_2$) to assure the necessary distribution of payoffs. To emphasize this possibility, the payoff equations are repeated in Figure 4 for a high investment by both managers. The solution to the game is completed by evaluating the total benefit across the different ownership structures. The division of the total ex post payoff, accomplished through the shares of ownership, is negotiated in the first stage of the game according to the bargaining power of the two parties. The transfer between managers is denoted by $P(\alpha_1, \alpha_2)$.

**Anti-monopoly Policy**

It is possible that the payoffs could be augmented by rents associated with the monopoly power that would occur with full or near full integration of the two firms. This could result in an anti-monopoly policy that would restrict the opportunity to integrate, and even strategic partnerships that would place high control with one of the firms. In this case there are two choices. First, the firms could return to operating independently and attempt to contract with each other. Second, more limited forms of strategic partnerships could be undertaken. This type of restriction is represented by the dotted lines in Figure 4, which are in effect restrictions on the shares of ownership.

The trade-off implied by the anti-monopoly policy restriction of the strategic partnership can also be illustrated by the game depicted in Figure 4. For example, the shares of ownership necessary for (high, high) investments could lie outside the dotted lines. Then, the trade-off involves the cost of the distortions that might be due to the monopoly power compared to the increased payoff from high investments.

What could cause the optimal strategy to lie outside the dotted lines that reflect the anti-monopoly policy in Figure 4? If the optimal share acquisition strategy involves a high degree of control by manager $M_2$, then his investment generates a high complementarity compared to investment of manager $M_1$.

Thus, anti-monopoly policy in high-technology (production of outputs with high complementarities) industries could lead to social loss.

**Extensions and Observations**

This analysis can be extended by enriching the treatment of the organization within the firms. In the game, we have not distinguished between the managers and the shareholders. Also, the game can be viewed in a more dynamic context. Managers might be represented as benefiting from establishing token ownership positions as a basis for obtaining added information about the other manager or firm.

If we distinguish between managers and shareholders, a principal-agent dimension is introduced to the game. Depending on the profit sharing arrangement, managers may be less or more aggressive in acquiring shares of the competing firm. In this case, two factors are operative in the formation of the strategic partnership. The first is the incentive package for the manager. The second is the firm-specific incidence of the complementarity. This could explain for example, why high-technology firms that are started with venture capital are often acquired by lower technology firms that have managers with high-powered incentives.

Suppose there is a tough anti-monopoly policy that restricts the ownership strategy that yields the (high, high) investment. The managers might take a token strategic ownership as a basis for acquiring information to support more complete contract. In this case, the (high, high) investment could occur with a level of ownership by one of the managers that is within the tolerance of the tough anti-monopoly policy.

## Timing and Functioning of Markets

Assembly and distribution systems for agricultural commodities are increasingly dominated by both national and private agents that have the potential for exercising market power. State trading enterprises (STE) and large private firms control most of the international trade volume in agricultural commodities. In domestic markets, the emergence of specialty grains and oil seeds has lead to pricing mechanisms and modes of assembly that are more strategic. For agriculture, the seasonal nature of production compared to a relatively constant demand for the commodities coupled with the ability to exercise market power introduce problems of timing in contracting and time consistent behavior.

Issues of time consistency for international trade have been explored by Lapan (1988), Maskin and Newbery (1990) and Staiger and Tabellini (1987). Melkonian and Johnson (1996) developed a model in which a STE, which has monopsony power, cannot credibly commit to a policy or contract. An annual trading cycle was considered. In the sequence of decisions, the STE moves first and announces a planned level of import. Producers in the exporting countries make their decisions on the allocation of the more fixed inputs (e.g., land) based on the related price expectation. However, before they make decisions on the allocation of the more variable inputs (e.g., labor or fertilizer), the STE has the opportunity to revise the announced level of imports. Then, the labor or variable input allocation decisions of the producers are made, given the revised (and predetermined) level of imports and the previous allocation of the more fixed inputs. Finally, trade takes place.

A standard monopsony argument yields the optimal level of import, if the STE is assumed to commit itself to the announced import level. But, when the STE cannot be held to the precommitted or the ex ante optimal level of import, it has an incentive to set a lower ex post level, once the land allocation decision has been made (the STE will face an ex post supply that is less elastic than the ex ante supply). In standard terminology, the ex-ante optimal level of import is not time-consistent. If foreign producers are assumed to know the rule used in setting the ex post level of import, they will use this information when making their land allocation decisions.

It was shown that both the importer (STE) and the exporting countries are worse off as a result of inability of the importer to precommit to the ex ante optimal level of import. Also, it was shown that forward contracting can assure the support of the ex ante optimal level of import as a time-consistent equilibrium (Melkonian and Johnson (1998)). An alternative is to consider the trading strategies in a sequential game context. The implications of signaling and reputation are at issue in the resulting sequential or multi-stage game formulation. The strategies that emerge suggest trade management mechanisms that dominate unregulated outcomes for the sequential trade, even if they involve contracts that are imperfectly enforceable.

Issues of time consistency in the emerging markets for specialty grain and oilseed are similar in nature. Contracts with producers offer a bonus over the spot market price for the undifferentiated ("commodity") grain or oilseed. Contracts with farmers are made at the beginning of the growing season, and are predominantly for acres and not for quantity. Based on the expectations of the credibility of the contracts with the buyers, the farmers plant the specialty grain or oilseed (which have yield lower than for the commodity grain or oilseed), fixing the land allocation. After this point the farmer can only change the variable inputs.

Marketing is at a local elevator after harvest. The farmer receives the commodity grain or oilseed spot price plus the bonus (usually 5 to 25 percent of the spot price). The time consistency problem emerges because of the incentive for the grain or oilseed buyer (there are few such firms) to reinterpret the terms of the contract. The reinterpretation by the buyers can occur through selective enforcement of the "fine print" (content of foreign matter, tolerances of the characteristics of interest, interpretation of the spot price, etc.) of the contracts. If the farmers anticipate this reinterpretation they will apply less than the ex ante optimal level of variable inputs.

The game theoretic formulation that is developed can be adapted to both of the time consistency problems. We emphasize the international trade application. However, it will be apparent that the model and the mechanisms suggested for improving the outcomes can be tailored to analyze and develop improved policies for the emerging markets for specialty grain and oilseed.

**The Perfect Information Game**

For the international trade application, we consider a sequential three period game between two players. The game has three periods. In the first period, player 1 (the STE) announces the policy she intends to implement in the third period. That is, player 1 makes one of two announcements: "benevolent" or "nonbenevolent." This announcement becomes known to player 2 (the STE's trading partner). After either of the two announcements is made, players 1 and 2 play the game depicted in Figure 5 (numbers at the decision nodes of the game tree represent the player whose turn it is to move; the first of the pair of numbers at terminal nodes represents payoff of player 1, and the second the payoff of player 2). As will be clear, the "cheap talk" of player 1 does not affect the future strategic interaction between the players.

Specifically, in the subgame following player 1's initial announcement, player 2 moves and chooses one of two levels of investment, "high" or "low" (**h** and **l** in Figure 5). After observing the level of investment, player 1 makes her choice of the policy to be implemented: "benevolent" or "nonbenevolent" (**b** and **nb** in Figure 5). The complete (with the policy announcement) game form and the payoffs to the players, depending on the history of the game, are shown in Figure 6. Note that the two proper subgames, starting at the nodes where it is player 2's turn to move, are equivalent (the game forms and the payoffs are the same). This reflects the noncredible cheap talk announcement of player 1.

Now, consider the payoffs to the players with different strategy profiles. For both of the possible levels of investment selected by player 2, player 1's payoff is higher if she chooses to implement the nonbenevolent compared to the benevolent policy; $x_1 < 0$ and $x_2 < x_3$. In contrast, player 2's payoff, given that the investment decision has been made, is higher if the benevolent policy is implemented by player 1; $y_1 > 0$ and $y_2 > y_3$. If an investment decision is followed by a benevolent policy, player 2's payoff is higher when he chooses high; $y_2 > y_1$. If an investment decision is followed by a non-benevolent policy, player 2's payoff is higher when he chooses low; $y_3 < 0$. Player 1's payoff is higher when high investment is followed by a benevolent policy than in the case when low is followed by nonbenevolent; $x_2 > 0$. We also assume that $x_3 + x_1 > 0$. With this assumption, the sign restrictions on the payoffs can be easily summarized; $x_1 < 0$, $0 < x_2 < x_3$, and $x_3 + x_1 > 0$; $y_3 < 0$ and $0 < y_1 < y_2$.

Application of backward induction to this game of perfect information yields the result that in any subgame perfect equilibrium (there are two of them) player 1 implements nonbenevolent policy for any history of the game and player 2 chooses low investment no matter what the initial announcement of player 1 was. Thus, the two equilibria only differ by the initial announcement of player 1. The equilibria payoffs of both players are the same for both equilibria. Both yield a payoff of 0.

**Commitment Mechanism**

Suppose that there is a mechanism that allows player 1 to credibly precommit to a policy or announcement. One possibility is as follows: suppose that before the game player 1 signs a perfectly enforceable (binding) agreement saying that she is going to forego *c* ($c > x_3$) if she does not implement the announced policy. An example of such a mechanism in actual trade is the posting of a bond by one of the parties. The tree for this game is presented in Figure 7. Note that the game form is unchanged, and only the payoffs to player 1 at the terminal nodes, corresponding to histories where the announced and implemented policies differ, have been modified. There is also another interpretation of the extensive form game presented in Figure 7. Suppose that player 1 is known for sure to be a "commitment" (or an "honest") type, that is a player who gets a very high negative payoff (*c*) from reneging on her announcement in the first period. In other words, player 1 incurs very high cost from being inconsistent.

Utilization of backward induction yields the unique subgame perfect equilibrium where player 1 announces benevolent in period 1 and at the node following a particular announcement, she implements the policy that was announced; player 2 chooses high if benevolent was announced and low if nonbenevolent. The subgame perfect equilibrium payoffs to the players are $(x_2, y_2)$. Thus, if player 1 has available an option of a commitment mechanism, she will use it and the payoffs of both players will be higher $(x_2 > 0, y_2 > 0)$, compared to when it is not.

**Imperfect Enforceability, Pooling, and Reputation Effects**

Suppose now that commitment is imperfectly enforceable. As before, the commitment mechanism obliges the party (player 1), if she reneges on announcement, to pay a penalty of *c*. We consider a dynamic game in which the announcement of the policy is made followed by *N* repetitions of the investment choice-implementation sequence. As previously, we assume that the game has two players. Before the game is played, player 1 makes a contract with the third party, which obliges her to implement the announced policy. The information, on whether the commitment contract is going to be honored is, however, the private information of player 1. That is, the commitment contract with the third party is "imperfectly enforceable."

We assume that player 2 has prior probability belief $\rho$ that player 1 incurs a cost each time she (player 1) reneges on the announcement. That is, $\rho$ is the probability of player 1's being commitment type. With probability $(1-\rho)$ player 1's payoffs are as in Figure 6. That is, $(1-\rho)$ is the probability of player 1 being a noncommitment type, for whom the policy announcement is a cheap talk (for a noncommitment type it does not cost anything to renege on the announced policy). In other words, player 2 is uncertain about player 1's cost of reneging on her announcement.

This is a game of incomplete information (Harsanyi (1967-68)), which can be transformed into a game of imperfect information. Nature moves first and chooses player 1's payoff structure, player 1 observes nature's move but player 2 does not. The game when there is only one investment choice-policy implementation stage is depicted in Figure 8. We denote by $\theta_c$ the commitment type player 1, and by $\theta_N$ the noncommitment type.

We first analyze the game depicted in Figure 8 and then move on to present the solution for the game with an arbitrary number (finite) of investment choice-policy implementation stages. Note, that no matter what the value of $\rho$ in the interval (0,1), the following strategy profile and beliefs form a sequential equilibrium of the game in Figure 8:

*Strategy profile.*

(i) the commitment type of player 1 announces nonbenevolent policy and at the information sets following the particular announcement acts consistent with this promise; the noncommitment type announces benevolent policy and implements the nonbenevolent policy given either level of investment and either announcement;

(ii) player 2 chooses low investment following either announcement by player 1.

*Belief.*

(i) The probability that player 1 is of commitment type for the information set following announcement of nonbenevolent policy is equal to one.

(ii) The probability that player 1 is of commitment type for the information set following announcement of benevolent policy is equal to zero.

Using the terminology of signaling games, this equilibrium is separating in a sense that the signal (the announcement) sent by player 1 in the first stage reveals her type. Both players net a payoff of zero in this equilibrium. To find all possible equilibria, we consider two cases differentiated by the magnitude of $\rho$ and relative values of player 2's payoffs for different strategy profiles:

(1) $\rho \geq \dfrac{-y_3}{y_2 - y_1 - y_3}$

(the case in which the relative likelihood of player 1's being a commitment type is high)

Consider the strategy of player 1 where both types announce benevolent with probability 1. Then Bayes' updating yields posterior which is equal to prior beliefs about type of player 1. That is, the probability that player 1 is of commitment type, given that both types announce benevolent with probability one, is equal to $\rho$. Then, given updated beliefs and player 1's optimal strategies following the investment decision, player 2's expected payoff from high investment is equal to $\rho\, y_2 + (1-\rho)\, y_3$ and from low investment $\rho\, y_1 + (1-\rho) 0$. Hence, if inequality (1) is satisfied and player 1 uses the strategy described above, player 2 will choose high investment.

Thus, following strategy profiles and beliefs of player 2 about player 1 constitute a sequential equilibrium:

(i) Both player 1 types announce benevolent policy in the first stage; for the information sets following a particular announcement commitment type of player 1 implements the announced policy (implementation of benevolent policy after announcement of benevolence, and similarly for non-benevolent policy), the noncommitment type chooses to implement nonbenevolent strategy at all of her information sets;

(ii) Player 2 chooses low investment for the information set following nonbenevolent announcement, and chooses high investment for the information set following benevolent announcement.

(iii) At the information set following the benevolent announcement, the probability (posterior) that player 1 is of commitment type is equal to the prior (Bayesian updating is invoked using equilibrium strategy of player 1); at the information set following the nonbenevolent announcement the posterior probability that player 1 is of commitment type is equal to q, where q is any real number in the segment [0,1].

It is apparent that the (strategy profile, beliefs) pair is consistent and sequentially rational (requirements of a sequential equilibrium). This is a pooling equilibrium in the sense that both player 1 types choose to send the same signal (announcement of benevolence). The equilibrium payoffs of the noncommitment type of player 1 and of player 2 are $x_3$ and $\rho y_2 + (1-\rho) y_3$ respectively. Payoffs to both players are higher than in the case when player 1 does not have a reputation for being a commitment type (that is, when $\rho = 0$).

Recall, that for the values of $\rho$ satisfying inequality (1) the (strategy profile, beliefs) pair (*) also represents a sequential equilibrium. But, the outcome payoffs of both players for this equilibrium are Pareto dominated by the equilibrium payoffs for the just described pooling equilibrium. We use the coalition-proof Nash equilibrium[3] concept of Bernheim, et al. (1987) to discard the equilibrium (*). We argue that the pooling equilibrium is more likely to be played than separating one, because if preplay communication were possible then both players would have an incentive to agree to play the pooling equilibrium (which is a self-enforcing mode of behavior).

When the initial reputation for credibility is low,

$$(2) \quad \rho < \frac{-y_3}{y_2 - y_1 - y_3}$$

the only sequential equilibrium, which also survives the elimination of dominated (strictly as well as weakly) strategies, is separating where the noncommitment type chooses the benevolent announcement and the commitment type chooses the nonbenevolent announcement (that is, equilibrium (*)). The equilibrium payoffs of both player 1 types and player 2 are equal to zero, i.e. they are the same as in the case when the player does not have a reputation for being commitment type.

Our conclusions can be easily summarized: For the game where there is only one investment choice-policy implementation stage after the policy announcement, if the prior probability of player 1 being a commitment type is not sufficiently large the resulting equilibrium is the one in which the different player 1 types separate in the first stage (announcing different policies) and the equilibrium payoffs of both players are equal to zero (same as when there is no reputation for being a commitment type). When reputation of being commitment type is sufficiently large, the pooling equilibrium is the only one that survives all the criteria that we have imposed and payoffs of both players are higher than in the case where reputation is absent.

Now, we consider a more general game in that we allow the announcement stage be followed by arbitrary but finite number of investment choice-policy implementation stages. Again, there are two players in the game. The game has $N$+1 stages ($N$ is a positive integer). As previously, we index time backward. The first stage of the game is $N$+1, second $N$, etc. At the stage $N$+1 player 1 makes one of two announcements: benevolent or nonbenevolent. After the announcement is made and observed by player 2, the investment choice-policy implementation game form is played $N$ times. The information structure of the game is the same as in Figure 8.

The nature of the equilibrium is the following: for every $\rho > 0$ there is a number $n(\rho)$ such that, if there are more than $n(\rho)$ investment choice-policy implementation sequences remaining to be played, the noncommitment type will implement the benevolent policy and player 2 will choose high investment. The noncommitment type chooses nonbenevolent in the last stage and mixes between benevolent and nonbenevolent in stages $n(\rho)$, … ,2. Accordingly, player 2 mixes between high and low or chooses high with probability, which depends on the relative magnitudes of $\rho$ and the players' payoffs. Thus, in each of the stages $n(\rho)$, … ,1, the reputation breaks down with positive probability.[6] Reputation breaks down in the later stages, since long-run value from having reputation for commitment is outweighed by the (opportunity) cost of pretending to be a commitment type. Note, that for large enough $N$, payoffs of both players converge to $x_3$. For large enough $\rho$ and/or $N$ this equilibrium outcome dominates the separating outcome. Hence, applying the coalition-proof Nash equilibrium concept, we discard the separating equilibrium.

**Extensions and Observations**

There are observable mechanisms in both international trade and in the emerging markets for specialty grain and oilseed that reflect the opportunity to achieve improved outcomes in situations where time consistency is an issue in contracting. These include multi-year trade agreements of the type often negotiated between major trading. In a context of the emerging markets for specialty grain and oilseed, long term relationships with producers are used to establish reputations for generous interpretations of contracts. Uncertainty and concepts of incomplete contracting provide useful extensions. For example, note the following.

- If demand uncertainty is introduced, the commitment mechanisms can become costly. If, for example, the realized import demand exceeds the commitment of the STE, the resulting payoff can be lower than in the case when the STE can revise its announced import level.

- The potential for reinterpretation of contract terms in the case of the grain and oilseed market application can be viewed in the framework of incomplete contracts. This could suggest an advantage of forming farmer supply networks which could take strategic positions with the buyers of the specialty grain and oilseed.

## Conclusions

At risk of overstatement, it is claimed that the issues identified in these illustrative examples cannot be adequately addressed without the aid of analytical approaches that directly incorporate concepts of strategic behavior. Yet these and related issues are at the center of the debate on agricultural policy and the future structure of the agricultural sector. The expanded capacities that are available through the use and adaptation of game theory and mechanism design are therefore critical to the continued success of agricultural economists in providing useful policy prescriptions and predictions.

One of the major benefits of the use of game theory and mechanism design in policy analysis is the structure provided for understanding strategic interactions. Even the stylized treatments in this paper yield a gain in insight on trends for industry development. As well, these insights provide the basis for further analysis and specialization. The latter is possible since the structuring of the games and mechanisms provides an improved basis for collection of empirical information. That is, the understanding of the issues can guide the prudent allocation of research resources used for empirical analysis. For the former, the “observations and extensions” sections of the paper are offered as evidence of opportunity for exploring policy issues that are of broad public and private interest.

Empirical research to support policy analysis and prediction based on game theory and mechanism design can take several forms. First, the assembly of stylized facts, guided by the formalization of the policy issues can yield useful results. Second, these formulations lend themselves to empirical applications that involve experiments. The opportunities for testing of hypotheses and evaluating structures that are offered by the combination of experimental economics and formulations guided by game theory and mechanism design appear underexploited for use in policy analysis.

The implications for the value of empirical analysis using ad hoc or semi-ad hoc econometric analysis are however far less encouraging. Game theory and mechanism design emphasize the importance of information about payoffs, beliefs, physical and informational rules, and options for altering the contexts of the interactions. This suggests that statistical or econometric models for use in policy analysis must be highly specialized and incorporate a substantial amount of prior information. These observations may argue for reduced investments in multi-purpose and applied empirical models that depend for their information content, largely on ex post secondary data.

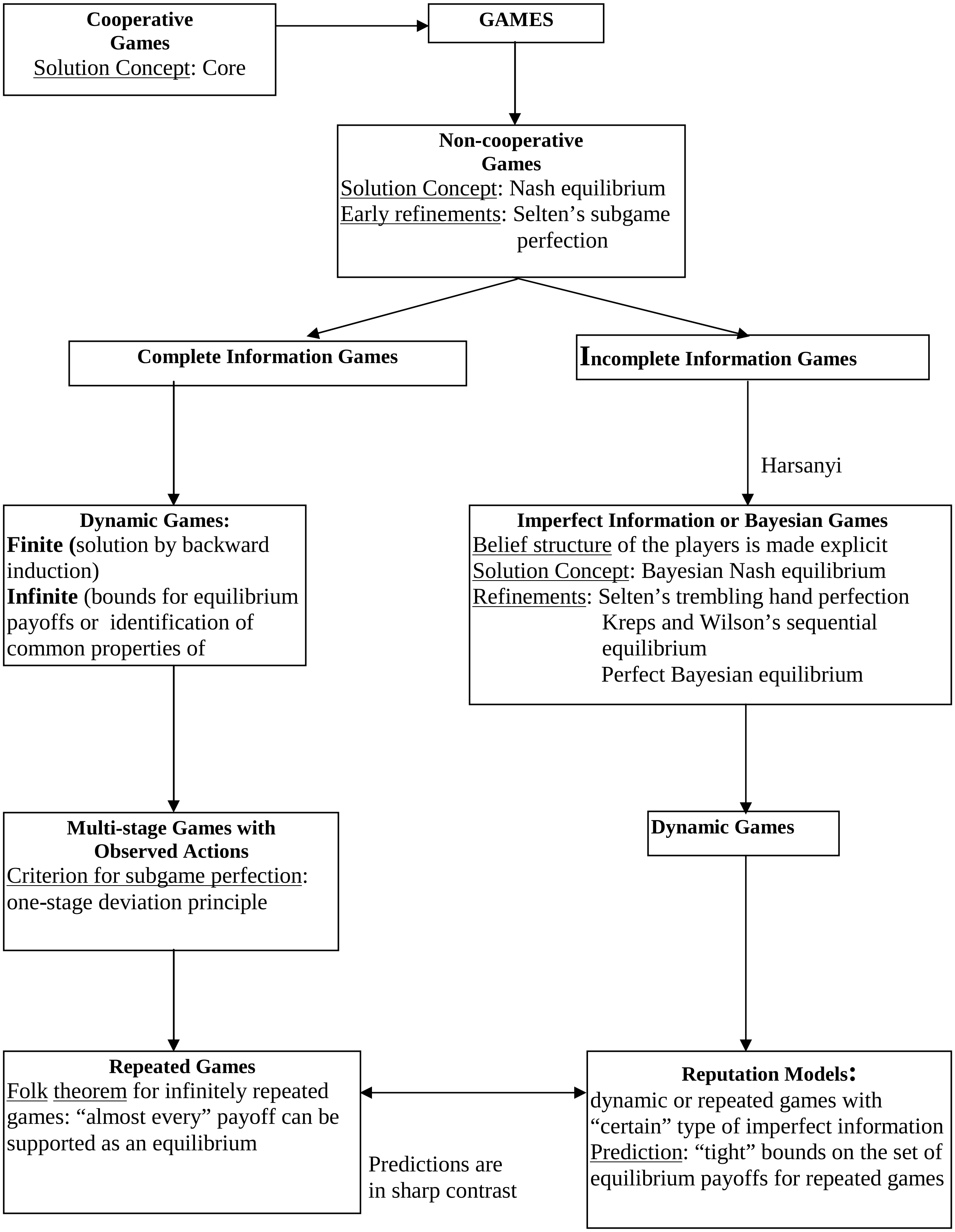


Figure 1. Selected developments in noncooperative game theory.

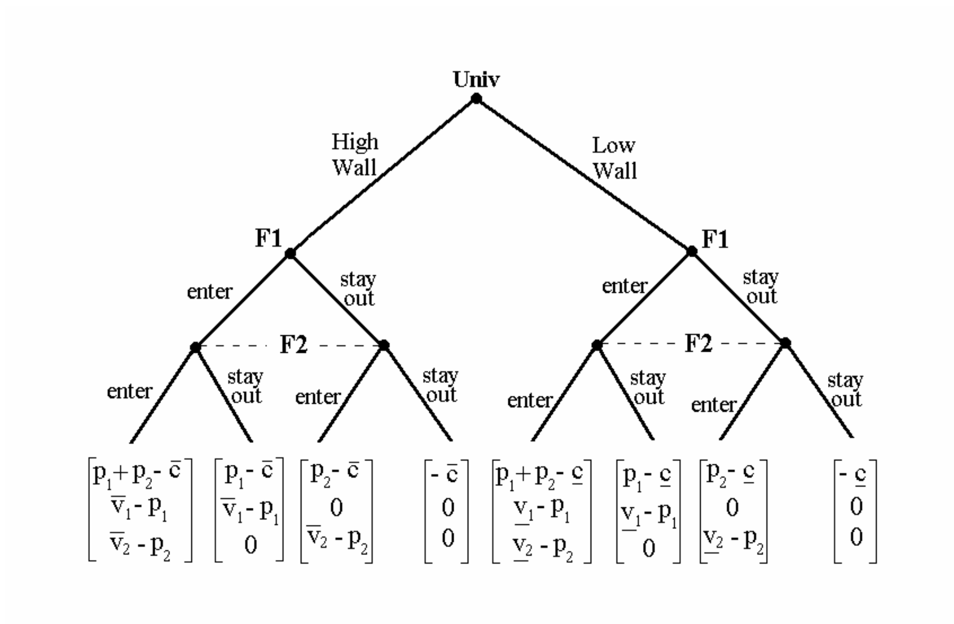


Figure 2. University Science Problem: M 1.

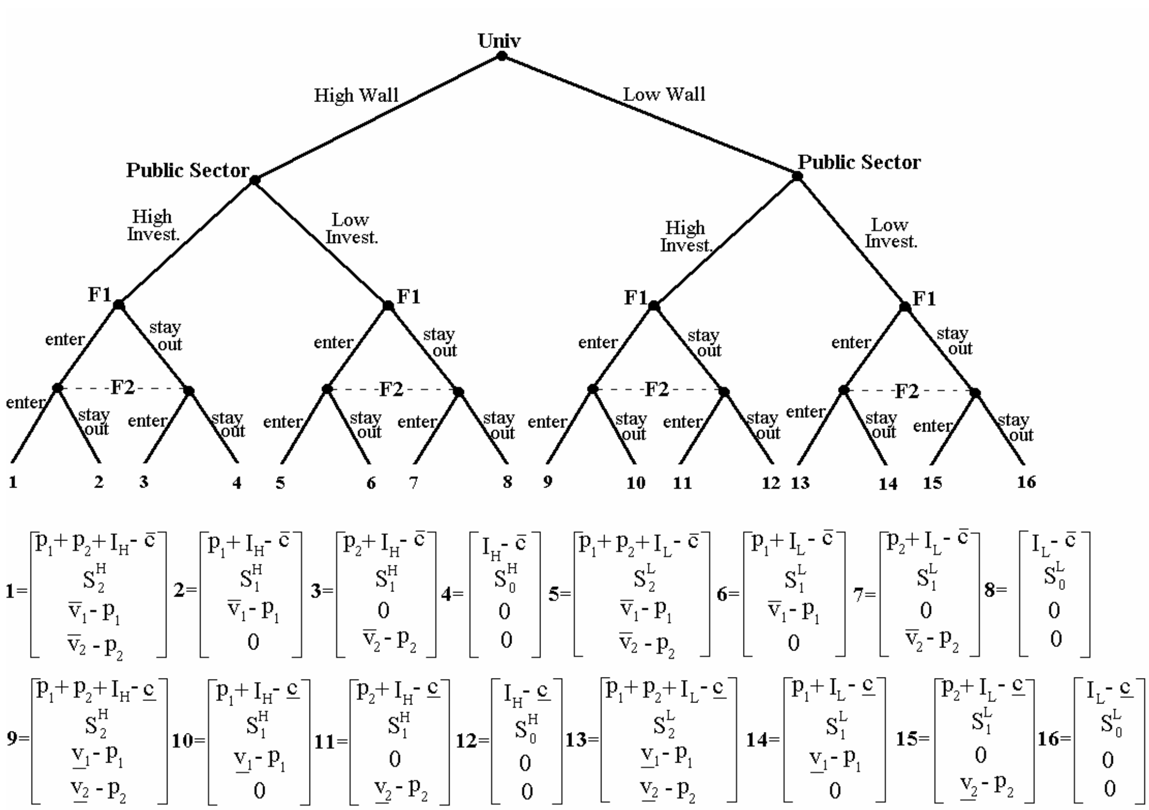


Figure 3. University Science Policy: Model 2.

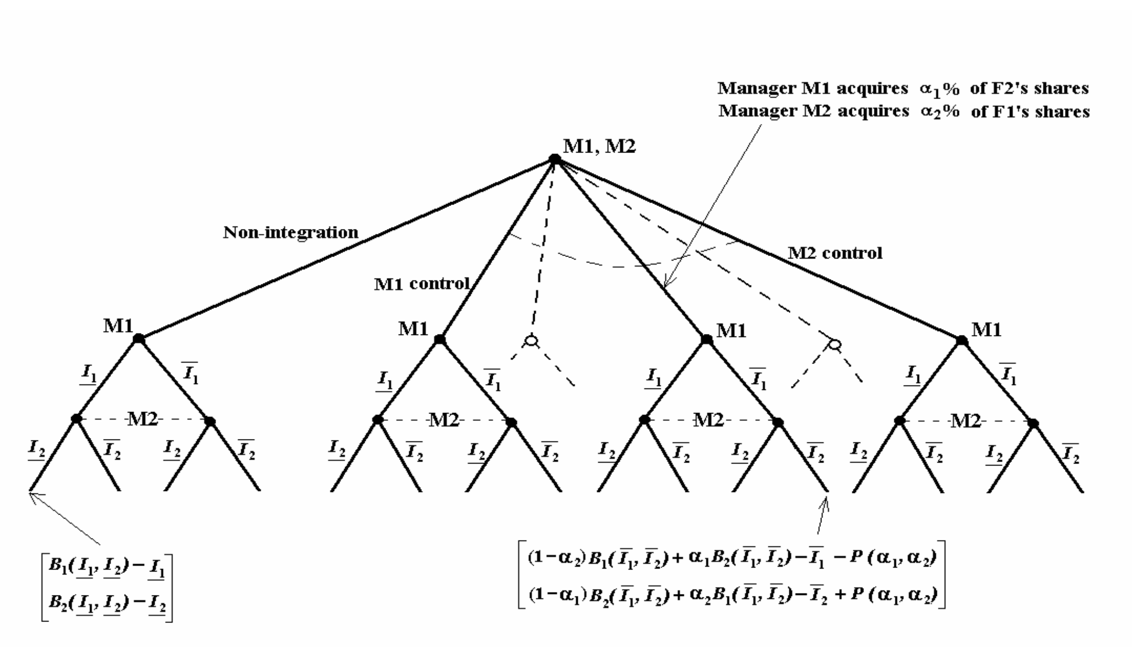


Figure 4. Industry Structure Policy.

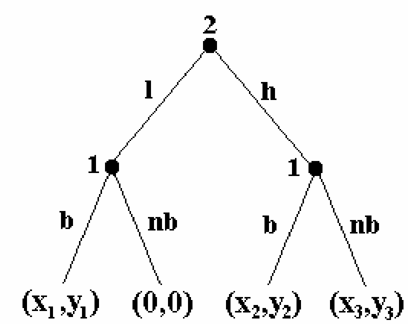


Figure 5. Investment choice–policy implementation sequence.

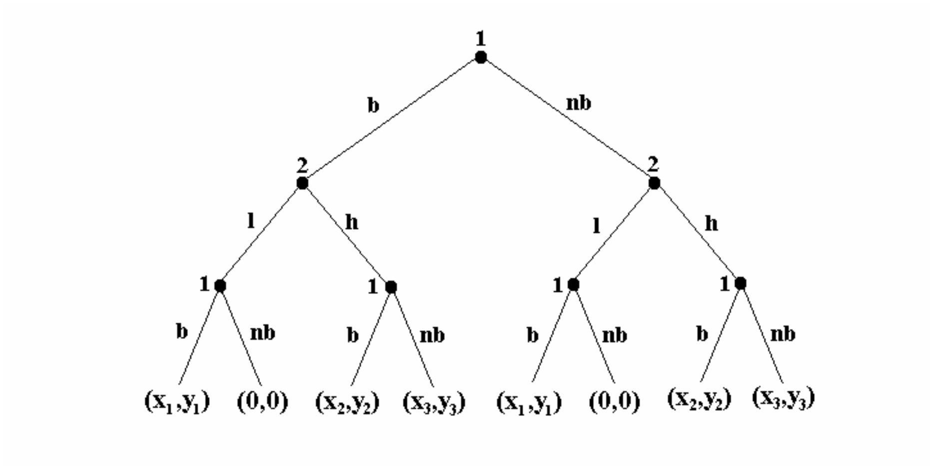


Figure 6. The basic model.

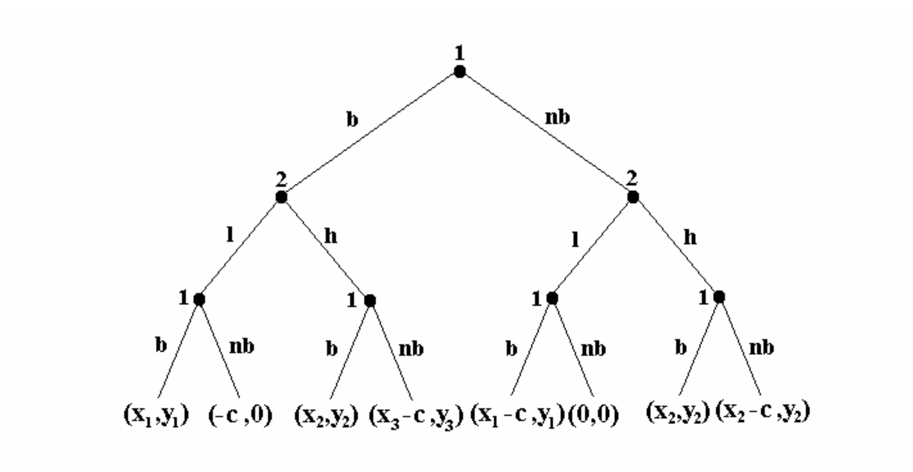


Figure 7. The game with perfectly enforceable commitment mechanism.

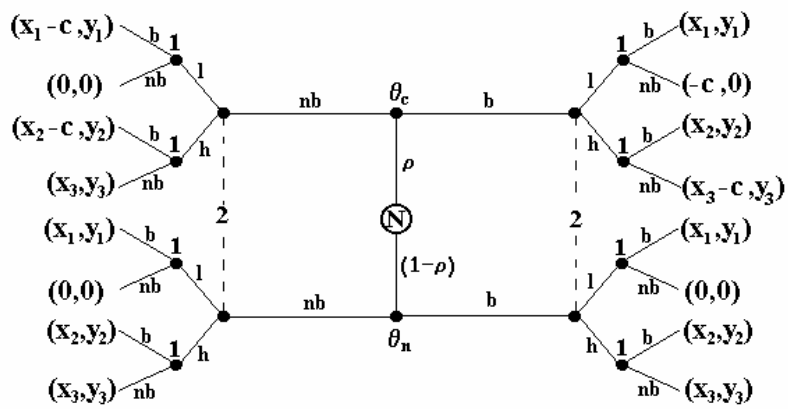


Figure 8. The game with imperfect information.

**ENDNOTES**

1. For more detail, useful references are Fudenberg and Tirole (1991) and Osborne and Rubinstein (1994).

2. Kreps and Wilson (1982a) present a formal definition of extensive form games.

3. Rules of chess prescribe that the game ends as a draw if players repeat the same moves three times in a sequence.

4. In perfect information games, players move sequentially and each player knows all previous moves when making his decision, that is, all information sets are singletons. The backward induction process is to solve for the optimal choice of the last player depending on each possible history of the game, and then solve for the optimal choice of the next to the last mover given that the last mover will make his/her optimal choice, etc.

5. This principle also applies to multi-stage games with infinite horizon under the technical condition of "continuity at infinity", a requirement that payoffs in the distant future are not as important as the ones in the beginning of the game.

6. Payoff of a player is individually rational if it is at least as large as that player's minimax value; payoff vector is feasible if there exists a stage-game mixed strategy profile yielding that payoff.

7. See Fudenberg and Tirole (1991b).

8. Number of strategic-form refinements have been proposed as well. The best known are Selten's (1978) *trembling-hand perfect equilibrium* and Kohlberg and Merten's (1986) *stable equilibrium*.

9. For a very good introduction to the theory and an extensive review of its latest developments see Fudenberg and Levine (1998).

10. The change of terms is to emphasize the analogy between this and the well known commons problem (Bromley (1991)).

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