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# Playing Games with the Law

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# REVIEW ESSAYS

# Playing Games with the Law

## Ian Ayres*

In the last two decades, the theory of games has increasingly dominated microeconomic theory. Frank Fisher recently asserted that game theory has become "the premier fashionable tool of microtheorists":

> That ascendancy appears fairly complete. Bright young theorists today tend to think of every problem in game-theoretic terms . . . . Every department feels it needs at least one game theorist or at least one theorist who thinks in game-theoretic terms. . . . The field appears to be in an exciting stage of ferment.[1]

Seminars, economic journals, and Ph.D. dissertations are awash with game-theoretic models of economic phenomena.[2] The marginalist revolution of Samuelson[3] is quickly being supplanted by the strategic models of a new breed of game theorists.[4]

This dramatic change in methodology stems from a series of break-

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1. Franklin M. Fisher, *Games Economists Play: A Noncooperative View*, 20 RAND J. ECON. 113, 113 (1989). Fisher's description of the "ascendancy" is echoed by other economists. *See, e.g.*, Carl Shapiro, *The Theory of Business Strategy*, 20 RAND J. ECON. 125, 125 (1989) ("This new wave of [industrial organization] research consists almost exclusively of game-theoretic studies of behavior and performance in imperfectly competitive markets.").

2. A casual glance at any issue of the leading microeconomic journals such as *Rand Journal of Economics* or *Review of Economic Studies* will reveal several game theory articles. *See, e.g.*, Joseph Farrell & Garth Saloner, *Standardization, Compatibility, and Innovation*, 16 RAND J. ECON. 70 (1985); Drew Fudenberg & Jean Tirole, *Sequential Bargaining with Incomplete Information*, 50 REV. ECON. STUD. 221 (1983).

3. Nobel Prize winning economist Paul Anthony Samuelson formalized the marginalist method of utility and profit maximization. *See* PAUL ANTHONY SAMUELSON, FOUNDATIONS OF ECONOMIC ANALYSIS (1947).

4. The new game theory is dominated by a closely knit group of co-authors which includes David Kreps, Eric Maskin, Roger Myerson, Garth Saloner, Jean Tirole, and Robert Wilson. These theorists often collaborate, and the history of game-theoretic advances turns on the axes of their academic institutions: Stanford, M.I.T., Northwestern, and Harvard. *See, e.g.*, David M. Kreps, Paul Milgrom, John Roberts & Robert Wilson, *Rational Cooperation in the Finitely Repeated Prisoners' Dilemma*, 27 J. ECON. THEORY 245 (1982); Eric Maskin & Jean Tirole, *Correlated Equilibria and Sunspots*, 43 J. ECON. THEORY 364 (1987).

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throughs in the ability to model dynamic games with asymmetric and incomplete information.[5] Economists can now tractably analyze complicated models (or "games") in which individuals ("players") are uncertain or uninformed. These advances have enabled economists to apply the "new" game theory to strategic aspects of everything from bankruptcy to plea bargaining and patent "races."[6] The reality of today's economic academy is that one cannot "do" microeconomic theory without being able to model and solve economic games: Game-theoretic literacy is simply a prerequisite.[7]

It is time that both friend and foe of law and economics take notice of these developments. If history repeats itself, the dominant paradigm of economics today will likely influence the legal scholarship of tomorrow.[8] Just as the efficient capital markets hypothesis has come to influence our current conceptions of corporate law—demonstrated, for example, by the Supreme Court's recent acceptance of the "Fraud on the Market" theory for securities standing[9]—the "new" game theory may very well seep into future law and economics scholarship.

So far, however, the advances of game theory have been slower to diffuse into legal reasoning than other economic contributions. For example, the capital asset pricing model, developed in the mid-sixties, has gained much wider acceptance in the legal community than has game-theoretic modelling.[10] One explanation for this slow diffusion is that new game theory techniques in a sense represent a research technology with high barriers to entry. Even legal academics well-schooled in law and economics have found it intimidating to master new concepts such as "perfect Bayesian equilibria."[11] The exclusionary aspects of learning the new modelling techniques have also been felt within the economics profession. The economists who pioneered and mastered these new modelling tools were simply too busy applying them to take the

5. These terms are defined below. *See* text accompanying notes 47-50 *infra*.

6. *See, e.g.*, Jeremy I. Bulow & John B. Shoven, *The Bankruptcy Decision*, 9 BELL J. ECON. 437 (1978); Jennifer F. Reinganum, *Innovation and Industry Evolution*, 100 Q.J. ECON. 81 (1985); Jennifer F. Reinganum, *Plea Bargaining and Prosecutorial Discretion*, 78 AM. ECON. REV. 713 (1988); Robert Gertner & David Scharfstein, The Effects of Reorganization Law on Investment Efficiency (May 1989) (unpublished manuscript) (on file with the *Stanford Law Review*).

7. It should be noted that economists are not unanimously in favor of this ascendancy. For a recent debate on whether the game theory approach is fruitful, compare Fisher, *supra* note 1, at 123 (game theorists have concentrated "on the analytically interesting questions rather than on the ones that really matter for the study of real-life industries") with Shapiro, *supra* note 1, at 134 ("the introduction of game-theoretic tools into the study of oligopolistic competition has made it possible to analyze carefully a whole range of questions that were not previously amenable to economic analysis").

8. For example, evolving economic theories of competition have affected antitrust analysis. *See* Herbert Hovenkamp, *Antitrust Policy After Chicago*, 84 MICH. L. REV. 213 (1985).

9. Basic, Inc. v. Levinson, 485 U.S. 224 (1988); *see* Daniel F. Fischel, *Use of Modern Finance Theory in Securities Fraud Cases Involving Actively Traded Securities*, 38 BUS. LAW. 1 (1982).

10. *See, e.g.*, RICHARD BREALEY & STEWART MYERS, PRINCIPLES OF CORPORATE FINANCE (2d ed. 1984); Ronald J. Gilson & Reinier H. Kraakman, *The Mechanisms of Market Efficiency*, 70 VA. L. REV. 549 (1984).

11. *See* p. 110.

time to write systematically about *how* to apply them.[12]

Into this pedagogical void comes Eric Rasmusen's new book, *Games and Information: An Introduction to Game Theory*. Rasmusen succeeds not only in making game theory more comprehensible but also in enabling readers actually to use these new techniques. In the jargon of economics, Rasmusen succeeds in lowering the costs for academics who wish to enter the field. The book is sure to become the standard reference in game theory and may by itself be responsible for significantly increasing the diffusion rate of this new modelling "technology." If Johnston's textbook has been responsible for teaching a generation of students how to run econometric regressions,[13] Rasmusen's text is likely to teach the next generation of students how to model games with asymmetric and imperfect information.[14]

With surprising clarity, *Games and Information* lays out the new contributions of game theory in language that will be accessible to a large proportion of the legal community.[15] The book's contribution is threefold: It synthetically organizes and catalogs the sprawling literature on games with imperfect information; it simplifies the games and distills the insights of the path-breaking articles; and, more abstractly, it introduces readers to the process of writing down and solving games. The first two contributions respond to a well-defined need. The clarified versions of important articles will make it easier to read and understand the originals.[16] But it is in achieving the final goal that the book

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12. The situation has strong parallels to the recent development of cloning techniques in biology. The few insiders with applied knowledge of recombinant DNA theory were so busy doing their own research that outsiders had difficulty learning the details of genetic sequencing and the like. The first comprehensive guide to cloning did not appear until 1982. *See* TOM MANIATIS, E.F. FRITSCH & J. SANBROOKE, MOLECULAR CLONING (1982).

13. JOHN JOHNSTON, ECONOMETRIC METHODS (2d ed. 1972).

14. I echo Roger B. Myerson's comment on the back of the hardcover edition:
[Rasmusen's] book . . . will do much to bring game theory into the mainstream of economics education. There has been an explosion of applications of game theory in economics, especially in the area of information economics over the past decade. . . .
Rasmusen's book is well-positioned to be the key text in such courses.

15. Although Rasmusen cautions in his preface that readers who "do not know the terms 'risk averse,' 'first order condition,' 'utility function,' 'probability density,' and 'discount rate' . . . will not fully understand this book," p. 11, those with an undergraduate background in economics or familiar with the law and economics literature will often have the requisite level of sophistication. Indeed, because game theory is in some ways a more self-contained discipline than other aspects of economics, even those innocent of economic training may find the book a rewarding reference. And Rasmusen's lively style is "user friendly." For example, he often includes tips for proper syntax in the game theory community. In exhorting readers to attend game theory seminars, he waxes, "[T]here is a real thrill in hearing someone attack the speaker with 'Are you sure that equilibrium is perfect?' after just learning the previous week what 'perfect' means." P. 10.

16. The author explains:
Journal articles are more complicated and less clear than seems necessary in retrospect; precisely because it is original, even the discoverer rarely understands a truly novel idea. After a few dozen successor articles have appeared, we all understand it and marvel at its simplicity. But journal editors are unreceptive to new articles that admit to containing exactly the same idea as old articles, just presented more clearly. . . . This book tries to present an alternative.

succeeds in truly becoming a *user's* manual. In his introduction, Rasmusen declares that "[t]he efficient way to learn how to do research is to start doing it, not to read about it."[17] Throughout, Rasmusen's "let us go then, you and I" approach invites the reader to join in the creative process of applying the techniques of game theory to real world problems.[18]

The simple thesis of this review is that legal academics can profit from mastering the insights of the new informational approach to game theory and that *Games and Information* is an excellent vehicle for achieving this mastery. Throughout the fifties and sixties, economics remained largely resistant to the virus of game theory.[19] But the resistance was broken by the new informational game theory of the seventies—to the point that game theory now "seems to be swallowing up microeconomics."[20]

The advances in modelling imperfect and asymmetric information that have made game theory a dominant methodology in microeconomics are even more central to the analysis of legal issues. Asymmetric information and strategic behavior are at the core of a large number of legal policy issues. For example, Rasmusen notes that "[g]ame theory is well suited to modelling takeovers because the takeover process depends crucially on information and includes a number of sharply delineated actions and events."[21] This point applies to a large class of legal issues. The law abounds with instances in which small numbers of players who have private information adopt strategies to further their well-defined interests, and in which the substantive and procedural legal rules specify to a highly detailed degree the "rules of the game."[22] It is not surprising, then, that Rasmusen's book is littered with a wide variety of legal games, including, for example, his models of litigation and settlement, agency, predatory pricing, and regulatory enforcement.[23]

Yet legal scholarship has remained largely ignorant of these advances. Law review articles continue to be mindlessly mired in the game theory "technology" of the fifties. Countless articles rearticulate

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P. 10.
    17. P. 17.
    18. Rasmusen explains that his references to newspaper and magazine articles are "reminders that models ought eventually to be applied to specific facts, and that a great many interesting situations are waiting for our analysis." P. 16.
    19. With a few notable exceptions, game theory was stagnant throughout this period. Rasmusen notes that "[b]y 1953 virtually all the game theory that was to be used by economists for the next 20 years had been developed." P. 13.
    20. P. 13.
    21. P. 301.
    22. For example, game theory models of bargaining often need to adopt *ad hoc* assumptions about whether the buyer or the seller makes the first offer (and whether the other party has an option of making a counteroffer). *See* pp. 227-43. In contrast, the procedural rules governing Chapter 11 reorganizations clearly specify that the debtor in possession may submit the first "offer" in bargaining over corporate reorganization. 11 U.S.C. § 1121 (1988).
    23. *See, e.g.,* pp. 60-65, 133-36, 302-06.

the Prisoner's Dilemma,[24] but few even proceed to other bi-matrix games.[25] A LEXIS search of law review articles reveals very few instances in which authors make reference to the Nash equilibrium concept[26]—a prerequisite for solving even the simplest game.

While many academics may ultimately reject a game-theoretic approach to legal issues, it seems safe to predict that the approach will increasingly find its way into legal analysis.[27] Informed criticism will require at least a rudimentary mastery of its techniques. Eric Rasmusen's book is well positioned to fill this need.

This review begins by sketching the method of using game theory to model legal problems. The following sections summarize the central insights of game theory regarding "credible" threats and asymmetric information—especially playing out game theory's implications for informing legal policy debates. I conclude by assessing the strengths and weaknesses of the game-theoretic approach.

## I. THE RULES OF THE GAME

### A. *The Modeller's Art*

The applied thrust of Rasmusen's pedagogy is nowhere clearer than in his first chapter:

> Game theory as it will be presented in this book is a modelling tool, not an axiomatic system. The presentation in this chapter is unconventional. Rather than starting with mathematical definitions, . . . we will start with a situation to be modelled, and build a game from it step by step.[28]

Rasmusen then proceeds to lay out the types of choices that need to be made in modelling. To establish "the rules of the game," modellers need to define clearly:

1) the *players*—the individuals who make decisions;

2) the *order of play* and the *actions* available to each player at each point in the game;

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24. *See, e.g.,* Jonathan R. Macey & Fred S. McChesney, *A Theoretical Analysis of Corporate Greenmail,* 95 YALE L.J. 13, 22 (1985); Peter Huber, *Competition, Conglomerates, and the Evolution of Cooperation* (Book Review), 93 YALE L.J. 1147, 1150-51 (1984).

25. *See, e.g.,* Kenneth W. Abbott, *Modern International Relations Theory: A Prospectus for International Lawyers,* 14 YALE J. INT'L L. 335, 368-75 (1989).

26. Three such articles are Ian Ayres, *How Cartels Punish: A Structural Theory of Self-Enforcing Collusion,* 87 COLUM. L. REV. 295 (1987); Robert L. Birmingham, *Legal and Moral Duty in Game Theory: Common Law Contract and Chinese Analogies,* 18 BUFFALO L. REV. 99 (1969); and John Shepard Wiley, Jr., *Antitrust and Core Theory,* 54 U. CHI. L. REV. 556 (1987). I would like to thank Avery Katz for pointing out this fact. Katz has himself written an important introduction to and application of game theory. Avery Katz, The Strategic Structure of Offer and Acceptance: Game Theory and the Law of Contract Formation (Oct. 19, 1989) (unpublished manuscript) (on file with the *Stanford Law Review*).

27. Possible forerunners of this trend include Alan Schwartz, *A Theory of Loan Priorities,* 18 J. LEGAL STUD. 209 (1989), and Ian Ayres & Robert Gertner, *Filling Gaps in Incomplete Contracts: An Economic Theory of Default Rules,* 99 YALE L.J. 87 (1989).

28. P. 22.

3) the *information* available to players at the time they make decisions; and

4) the *outcome* and *payoffs* for the players that result from different combinations of actions.[29]

By walking the reader through a myriad of models, Rasmusen instills a sense of the process of game-theoretic modelling and shows how to define systematically the essential elements of any game.

To construct a simple model of settlement in civil litigation,[30] for example, one can follow the checklist to define the essential elements of the game. A simple model of tort settlement at a minimum would answer the following questions:

Who are the players? Does the game consist of one potential defendant and one potential plaintiff, or are there multiple plaintiffs that might bring suit (against multiple defendants)? What are the actions and the order of play? Does the game begin with the plaintiff's decision whether to sue (or should the defendant's decision whether to take care be modelled)?

If the plaintiff brings suit, who should make the first settlement offer? Should we allow the other party to propose a counteroffer? How should we model the court's decisionmaking process if the case goes to trial? What information do the players have? Does each player know the likelihood of winning at trial? Does each player know what the other player knows? What are the outcomes and payoffs?[31] How are damages determined? What are the parties' legal fees, and at what stage of the game are they incurred? Are the parties risk averse?

As this example illustrates, even the simplest games can present modellers with a host of alternatives. Rasmusen conveys a sense of the prevailing "tastes" in selecting from among these alternatives. In modelling litigation settlement, for example, modellers could define in detail different trial strategies (if the case goes to trial). But Rasmusen argues for " 'blackboxing': treating unimportant subcomponents of a model in a cursory way."[32] Thus, in modelling games of settlement it may be useful to simplify the litigation process by focussing only on interesting pretrial aspects. Blackboxing is one aspect of what Rasmusen calls "no-fat modelling"—in which the modeller seeks "to dis-

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29. Pp. 22-25.

30. Game-theoretic treatments of the settlement process can be found in I.P.L. P'ng, *Strategic Behavior in Suit, Settlement, and Trial,* 14 BELL J. ECON. 539 (1983), and Robert D. Cooter & Daniel L. Rubinfeld, *Economic Analysis of Legal Disputes and Their Resolution,* 27 J. ECON. LITERATURE 1067 (1989); *see also* pp. 60-65.

31. The "payoff" of a game refers to the expected utility that players receive from playing the game. In contrast, the "outcome" of the game refers to nonutility variables affected by the playing of the game. For example, in a tort settlement game the payoffs of the individual players refer to their out-of-pocket losses or gains, while the outcome of the game would refer to whether a suit was filed, whether the suit settled, or whether the suit went to trial. *See* pp. 24-25.

32. P. 15.

cover the simplest assumptions needed to generate an interesting conclusion; the starkest, barest, model that has the desired result."[33]

## B.  *"Solving" the Game*

Game-theoretic modelling consists of defining the rules of the game and then "solving" the game—deriving the best strategies for each player and the equilibrium that will result if each player undertakes her best strategy. To solve the game, a modeller must decide what constitutes an equilibrium of "best strateg[ies]."[34] The modeller must choose an *equilibrium or solution concept.*[35] The most commonly used solution concept is the *Nash equilibrium.*[36] A set of strategies is a Nash equilibrium if no player has an incentive to deviate from her strategy given that the other players do not deviate.[37] A set of Nash strategies will be resilient against deviance—and therefore constitute an equilibrium—because each player can do no better if the other players conform.

Rasmusen attempts throughout the book to convey a sense of the art of game modelling. The art appears not only in defining the game but also in "solving" the game. Often, the modeller must propose a set of strategies and then check to see if they constitute a Nash equilibrium of best responses. In contrast to methods for solving traditional microeconomic models (of constrained maximization), game-theoretic methodology is not mechanical:

> [T]he modeller must make a guess that some strategy combination is an equilibrium before he tests it [to see if it is Nash]. Some economists are quite frustrated when they learn there is no general way to make the initial guess. The [traditional microeconomics] maximization approach is so straightforward, on the other hand, that we could let a trained ape do it. Just set up a payoff function with some constraints, take derivatives, and solve the first order conditions. That approach is less appropriate to game theory . . . .[38]

Since there can be a multitude of possible strategies, game theorists need to develop an intuition about what set of strategies are likely to be

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33. Pp. 14-15.
34. P. 27.
35. *Id.*
36. Alternative equilibrium concepts include *dominant strategy* and *iterated dominant strategy* equilibria. Pp. 28-32. For example, a set of strategies constitutes a dominant strategy equilibrium if each player's strategy is a best response to *any* strategies of other players. By contrast, the less demanding Nash equilibrium solution concept requires that each player's strategy be a best response only to the other players' Nash equilibrium strategies.

In the famous Prisoner's Dilemma Game, each player has a dominant strategy of finking, because it is the best response regardless of whether the other player finks or cooperates. A dominant strategy equilibrium is a more robust solution concept, but there are many games for which dominant strategies do not exist. Note that all dominant strategy equilibria are also Nash equilibria, but not vice-versa. P. 33.

37. P. 33.
38. P. 140.

Nash. For example, if the players are identical in the sense of having identical information and having identical available actions, then it is often sensible to search for a symmetric equilibrium consisting of identical strategies.[39]

## II. THE INFORMATION REVOLUTION

### A. *Modelling Dynamic Games of Imperfect Information*

The new technology for modelling games is apparent even in the method of representation. The older game theory of the fifties and sixties used the *normal form* representation, while the game theory models of the seventies and eighties have increasingly represented games by using the *extensive form*. The normal form representation of a game uses a matrix to relate players' strategies to the payoffs of the game. For example, consider a coordination game in which two players can increase their individual payoffs if they match strategies. Such a game would apply, for example, to cumulative voting for corporate directors in which two minority shareholders may wish to vote for the same candidates to insure their election.[40] Assume that two minority shareholders, Smith and Jones, must each vote either for herself or for the other.[41] Smith votes first. If Smith and Jones split their votes, they lose the election, and each receives a payoff of -1; if they can coordinate, they win representation on the board and receive a payoff of +1. Since Smith moves first, she has to choose one of two strategies [vote Smith] or [vote Jones]. Because Jones votes second, her strategies are contingent on all information available to her—particularly on the candidate for whom Smith voted. Accordingly, Jones has to choose among four possible strategies:

[if Smith votes Smith, vote Smith; if Smith votes Jones, vote Smith]
[if Smith votes Smith, vote Smith; if Smith votes Jones, vote Jones]
[if Smith votes Smith, vote Jones; if Smith votes Jones, vote Smith]
[if Smith votes Smith, vote Jones; if Smith votes Jones, vote Jones].

This simple game can now be depicted using the normal form by constructing a matrix which relates the possible strategies of the players to specific payoffs:

39. This intuition has been formalized into a proof of existence. Partha Dasgupta & Eric Maskin, *The Existence of Equilibrium in Discontinuous Economic Games, I: Theory*, 53 REV. ECON. STUD. 1 (1986); *see* p. 127.

40. This example is based upon the "Pure Coordination" game that Rasmusen describes at pp. 43-47.

41. Even in this simple example, the voting of the majority shareholder, say Mr. Trump, and the possibility that the minority shareholders could vote for him are suppressed or "blackboxed."

TABLE 1
SHAREHOLDER VOTING GAME I[42]
NORMAL FORM

Jones

| | | [Smith, Smith] | [Smith, Jones] | [Jones, Smith] | [Jones, Jones] |
|---|---|---|---|---|---|
| Smith | [Smith] | (1, 1) | (1, 1) | (-1, -1) | (-1, -1) |
| | [Jones] | (-1, -1) | (1, 1) | (-1, -1) | (1, 1) |

Payoffs to (Smith, Jones)

The same game can be represented using the extensive form by constructing a game tree that details the sequence of play. A game tree consists of a series of *nodes* which are the points in the game at which a player takes an action. The different possible actions are represented as lines radiating from each node. The action of the game is usually represented from left to right and the payoffs are represented at the far right end points.

FIGURE 1
SHAREHOLDER VOTING GAME I
EXTENSIVE FORM



$S_i$ = Smith Node

$J_i$ = Jones Node

· Payoffs to (Smith, Jones)
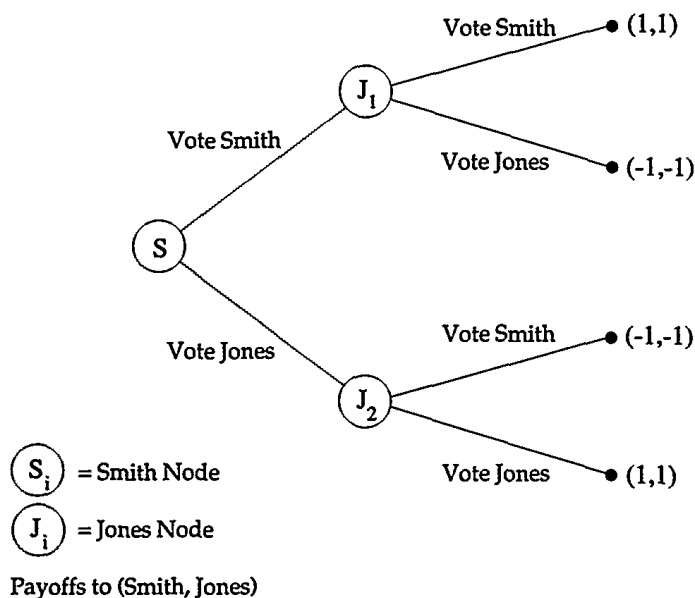
The extensive form representation is superior to the matrix representation of the normal form because it is much easier to represent the

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42. Jones's strategies are abbreviated. For example,
[if Smith votes Smith, vote Smith; if Smith votes Jones, vote Smith]
is represented as [Smith, Smith].

information available to the players at specific nodes—that is, at the time they make their decisions. This superiority of the extensive form representation can be seen by comparing the preceding formulations of the Shareholder Voting Game. Analyzing the normal form matrix, one can see that the strategies

Smith plays [Jones] and Jones plays [Jones, Jones]

represent a Nash equilibrium.[43] However, by exploring the extensive form representation, we can see an important weakness of the Nash equilibrium concept in games with sequential action. Jones's equilibrium strategy mandates that Jones vote "Jones" even if Smith votes "Smith" beforehand. In extensive form terminology, this strategy dictates that Jones should vote "Jones" regardless of whether Jones finds herself at node $J_1$ or $J_2$. In the proposed equilibrium, Jones always finds herself at $J_2$, so her choice of matching Smith's vote by also voting "Jones" is Nash. This equilibrium is weak, however, because if Jones found herself at $J_1$, she would want to deviate from the proposed equilibrium strategy of voting "Jones" (she would prefer to match Smith's vote of "Smith"). This weakness has caused game theorists to strengthen (and to refine) the Nash solution concept with the alluring notion of "perfection," to which we will return below.[44]

Normal form (matrix) representation suppresses the dynamic nature of the game and the information that is revealed as the game is played. In the Shareholder Voting Game, the normal form representation makes it more difficult to analyze how Jones's knowledge of Smith's vote affects the equilibrium. More importantly, the extensive form representation can easily diagram when players have imperfect information. For example, if we changed the foregoing voting game so that Jones continued to vote second but did not know for whom Smith voted, the extensive form representation would become:

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43. One can also see that
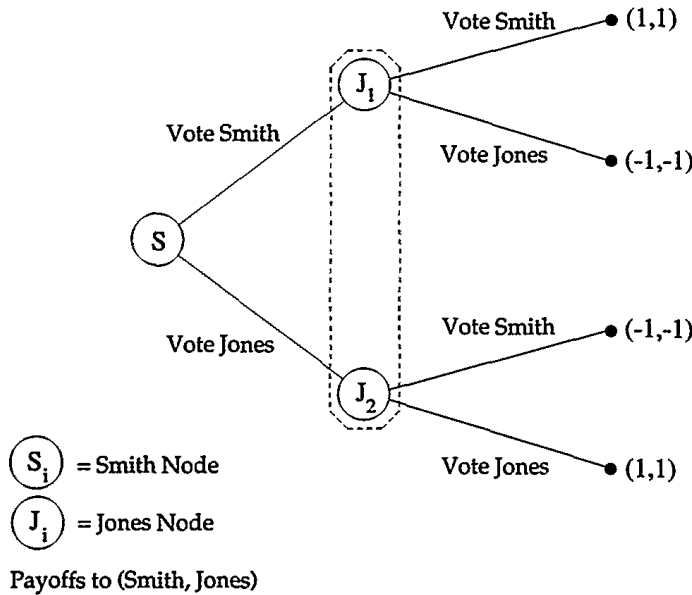Smith plays [Smith], Jones plays [Smith, Smith]
and
Smith plays [Smith], Jones plays [Smith, Jones]
are Nash equilibria.
44. *See* text accompanying notes 54-64 *infra*.

FIGURE 2
SHAREHOLDER VOTING GAME II
EXTENSIVE FORM



$\left(\begin{array}{c}S_i\end{array}\right)$ = Smith Node

$\left(\begin{array}{c}J_i\end{array}\right)$ = Jones Node

Payoffs to (Smith, Jones)

The dotted line surrounding nodes $J_1$ and $J_2$ represents Jones's *information set* at the time when Jones must decide for whom to vote. A player's information set for a particular point in the game "is the set of different nodes in the game tree that he knows might be the actual node, but between which he cannot distinguish by direct observation."[45] Because Jones does not know how Smith voted, she does not know when she votes whether she is at $J_1$ or $J_2$. This reformulation of the voting game also represents a game in which Jones and Smith vote simultaneously—since with simultaneous voting both Jones and Smith cast their ballots without knowing the choice of the other.[46]

Extensive form representation is especially appropriate for games with *asymmetric* or *incomplete* information. In games with asymmetric information, some player has useful private information—that is, information that is not directly observable by other players.[47] Thus, in the Tort Settlement Game,[48] we could assume that only the potential defendant originally knows whether due care was taken. In a game of incomplete information, at least one player is unsure about any or all of the different constitutive parts of a game: players, strategies, or payoffs.[49] Games of incomplete information are often modelled with

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45. P. 48.
46. A simultaneous voting game could also be cast with Jones having the first nodal choice and Smith's subsequent nodes included in a single information set.
47. P. 53.
48. *See* text accompanying notes 30-31 *supra*.
49. Pp. 53-55.

*Nature* moving first by randomly choosing among *different states of the world.*[50]

For example, return to the Shareholder Voting Game, but assume that there are two types of Joneses in the world: cooperative and perverse. The cooperative Joneses of the world have the same preference as before, but perverse Joneses have noncooperative preferences, such that matched voting *reduces* their welfare to a payoff of -1 and mismatched voting *increases* their welfare to a payoff of +1. If Smith knows that 10 percent of the Joneses in the world are "perverse" but not which type of Jones she is facing, then the voting game can be reformulated as a game of incomplete information. If we further assume that Jones does know her own type, then it is also a game of asymmetric information:

FIGURE 3
SHAREHOLDER VOTING GAME III
EXTENSIVE FORM



$N$ = Nature Node

$S_i$ = Smith Node

$J_i$ = Jones Node

Payoffs to (Smith, Jones)
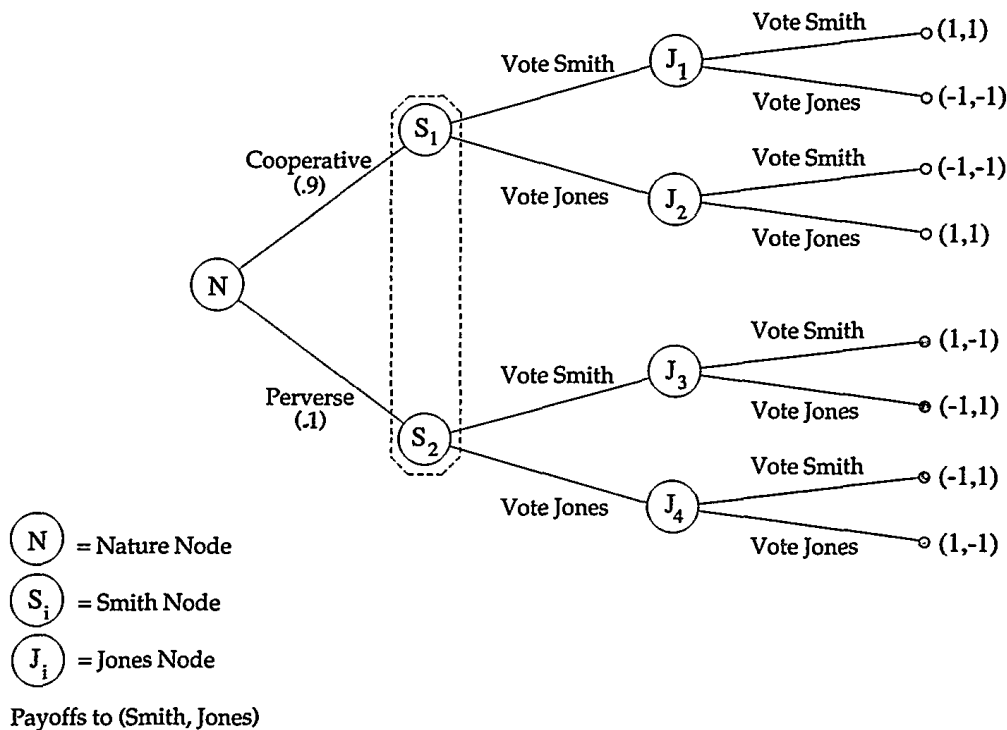
As depicted in Figure 3, Nature moves first and, unbeknownst to Smith, chooses Jones's type, cooperative or perverse. Smith must then vote without knowing which type of Jones she is facing. Jones, however, knows what type she is, and her information sets are therefore individ-

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50. *See* p. 55. Using "Nature" as a player is a convenient way of modelling the origin of individual players' incomplete knowledge.

ual nodes.[51] Node $S_1$ and the action that branches from it is a *subgame* that is identical to Voting Game I.[52]

Alternatively, if we assume symmetric information so that neither Smith nor Jones knew Jones's type at the time of voting, then the game tree would be:

FIGURE 4
SHAREHOLDER VOTING GAME IV
EXTENSIVE FORM



( N ) = Nature Node

( $S_i$ ) = Smith Node

( $J_i$ ) = Jones Node
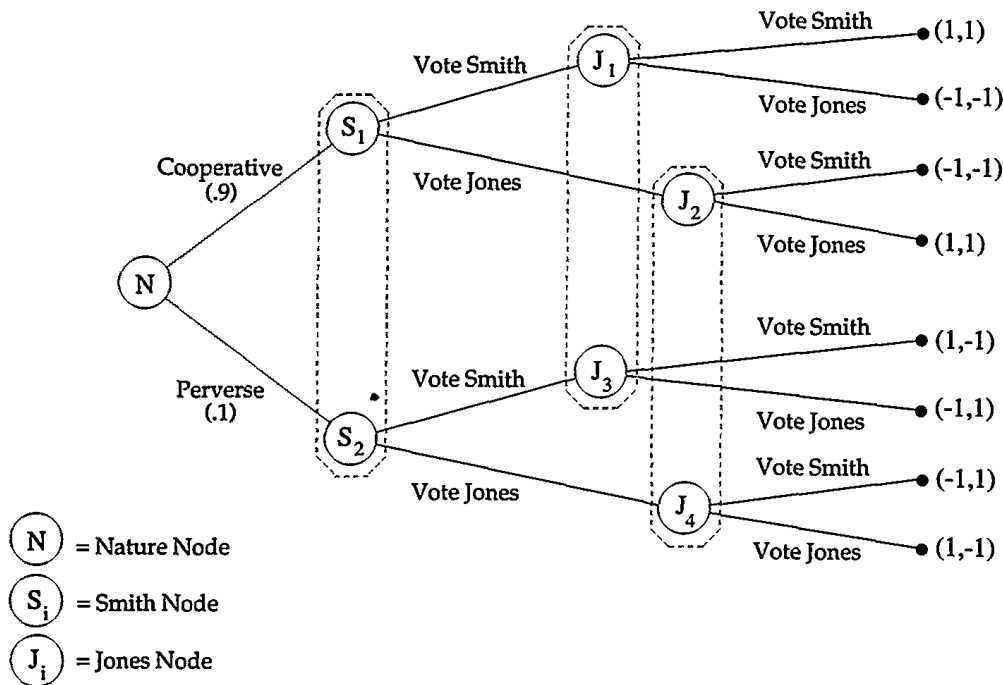
Payoffs to (Smith, Jones)

Jones, by moving second, knows for whom Smith voted. But because she does not know her own type, she cannot distinguish between either nodes $J_1$ and $J_3$ or $J_2$ and $J_4$.

Extensive form representation has as yet rarely been employed in legal periodicals, but it allows modellers to visualize the sequential nature of games and to define with greater precision the information available to decisionmakers at the time a decision is made. These techniques for representing dynamic games with imperfect information[53]

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51. *Singleton* is the term of art for information sets consisting of individual nodes. P. 50.

52. The subgame beginning with node $S_2$ is a *discoordination game* similar to the game of "matching pennies," in which one player wins if the pennies match and the other player wins if they do not. *See* p. 40.

53. Imperfect information is a term of art that encompasses games that have incomplete information or asymmetric information or both. P. 51. In a game of perfect information, on the other hand, all information sets are singletons. *Id.*

are the methodological building blocks for the substantive innovations to which we now turn.

## B. *Perfectness and Precommitment*

In dynamic games, the Nash solution concept is weak in an important sense because it does not test the stability of deviations from the equilibrium path. This was the reason, for example, for the criticism of the Nash equilibrium concept in connection with Voting Game I.[54] That game is one of pure coordination in which each player strives to cooperate and to match each other's action. In games where the players' interests are opposed, however, off-equilibrium responses can be very important to decisions on the equilibrium path. A player may feel the need, for example, to issue a threat, which "is a promise to carry out a certain action if another player deviates from his equilibrium actions."[55]

The unadorned Nash solution concept fails to restrict players from making noncredible threats. To illustrate this phenomenon, consider a simple model of entry deterrence. A potential entrant moves first and decides whether to enter a market. An incumbent responds by deciding whether to fight the entry by lowering its price. Assume that (a) without entry, the incumbent earns monopoly profits of 100; (b) if the incumbent fights entry, the incumbent breaks even and the entrant loses 10; and (c) if the incumbent does not fight entry, they split the monopoly profits. Under these conditions, the extensive form representation of the game is:

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54. The Nash equilibrium in that game which consisted of

Smith plays [Jones] and Jones plays [Jones, Jones]

would not be stable if, for some reason, Smith played [Smith], because Jones in that case would want to deviate from her equilibrium strategy to match the earlier vote. *See* note 36 *supra* and accompanying text.

55. P. 83.

FIGURE 5
ENTRY DETERRENCE GAME



Payoffs to (Entrant, Incumbent)
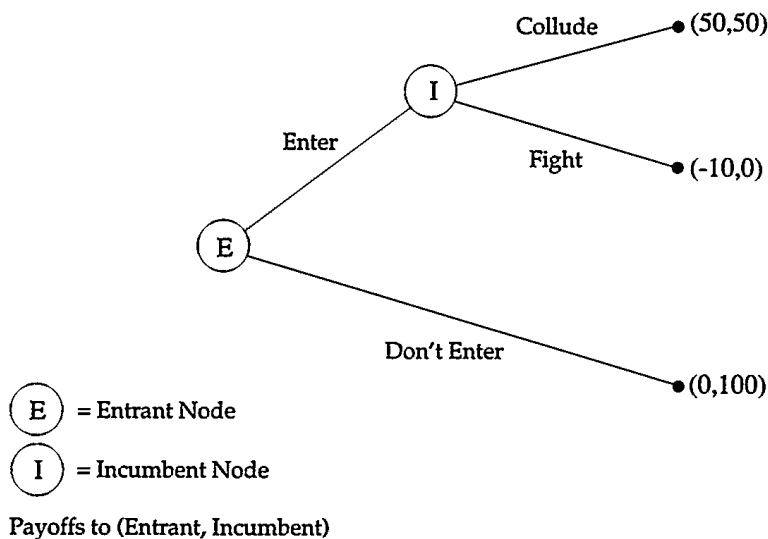
The strategy combination of [Don't Enter], [Fight Entry] is a Nash equilibrium[56] that generates an equilibrium outcome of no entry. But this equilibrium depends crucially on the incumbent's threat of how it will respond to the potential entrant's out-of-equilibrium behavior (entry). In this example, the incumbent's threat is very hollow. If entry occurs, the incumbent would no longer have an incentive to follow through on its threat. In game-theoretic terms, if an incumbent ever finds itself at node $I_1$, it will no longer have an incentive to fight. The incumbent thus faces a dynamic inconsistency. Even though *ex ante* it would like to threaten a fight, *ex post* it prefers to collude with the new entrant.

Game theorists have refined the Nash solution concepts to admit only equilibria that are dynamically consistent. The additional requirement of *perfectness* (or subgame perfection) guarantees this result. A combination of strategies is a perfect Nash equilibrium if the strategies satisfy the Nash requirements for every subgame.[57] In the entry deterrence game, the strategies [Don't Enter], [Fight] are not "perfect," because the strategy [Fight] is not a Nash equilibrium for the subgame starting at node $I_1$.

Refining the Nash equilibrium with the notion of perfection rigorously distinguishes credible from noncredible threats. Simply put, "[p]erfectness rules out threats that are not credible."[58] In many legal contexts, adversaries will wish to precommit to particular types of strat-

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56. If the incumbent is going to fight, the potential entrant will not enter; and if there is no entry, the incumbent doesn't have an opportunity to deviate. This establishes that the strategies are Nash. Pp. 86-87; *see also* text accompanying note 36 *supra*.

57. P. 85.

58. P. 87.

egies. The concept of perfection clarifies the prerequisites for precommitment. A threat will be credible only if the strategy remains an equilibrium on all possible paths, both on the equilibrium path and on any other path which branches off into other subgames.[59]

Players can precommit to threatening strategies by taking actions *ex ante* which restrict or discourage *ex post* deviation from executing the threat. An important form of precommitment is the elimination of subsequent unstable subgames. This in a sense is what Ulysses accomplished by having himself tied to the mast as his ship sailed past the Sirens. But credible precommitment can also occur when a player alters the payoffs on what would otherwise be an unstable subgame. For example, if two people need to bargain over how to divide $1,000 in gains from a certain trade, one party might be able to strengthen her bargaining position by promising to pay a charity $1,000 if she receives less than a specified percentage of the surplus.[60] Poison pills which contingently destroy a target corporation's value unless removed by the target management serve a similar function.[61]

Perfection also clarifies why finitely repeated games tend to "unravel." Rasmusen, for example, considers whether a chainstore repeating the Entry Deterrence Game in twenty separate markets could add credibility to its threat of fighting "because the chainstore would fight the first entrant to deter the next 19."[62] The restriction of subgame perfection leads game theorists to begin by analyzing the last repetition of the game because it is the simplest subgame. From the foregoing analysis, the threat of fighting entry *in the last repetition* is not credible—so rational incumbents will accommodate entry in the final period. The process of backward induction can then be used to analyze preceding periods. Given that the incumbent will accommodate entry in the last period, what will happen in the next to last period? As Rasmusen notes: "The chainstore can gain nothing from building a reputation for ferocity" in the next to last period "because it is common knowledge that he will *Collude* with the last entrant anyway. So he might as well *Collude* in the 19th market."[63]

This process of backward induction (in combination with the requirement of subgame perfection) leads to an unraveling.[64] The chain-

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59. *Id.*

60. *See* ROBERT FRANK, PASSIONS WITHIN REASON 48-49 (1988).

61. *See* ROBERT CLARK, CORPORATIONS 114 (1984).

62. P. 88. This possibility has been embraced by, among others, Richard Posner: If . . . a firm operates in [a] number of markets and faces actual or potential competitors each of whom is limited to one of its markets, it may find it worthwhile to expend considerable resources in crushing a single competitor in order to develop a reputation (for willingness to use predatory pricing).
*Quoted in* George A. Hay, *A Confused Lawyer's Guide to the Predatory Pricing Literature,* in STRATEGY, PREDATION, AND ANTITRUST ANALYSIS 155, 161 (S. Salop ed. 1981).

63. P. 88.

64. This unraveling is at the heart of Selten's Chainstore Paradox. Reinhard Selten, *The Chain Store Paradox,* 9 THEORY & DECISION 127 (1978); *see also* p. 88.

store owner faces the paradox of dynamic inconsistency. It would like to commit to a tough strategy of fighting entry, but even in a repeated game its threats are not credible: In the end it will have no incentive to fight.

## C.  *Learning from the Game: "The Play's the Thing"*

In games with asymmetric information, the uninformed players may have opportunities to deduce the private information of their rivals by watching how their rivals behave. In terms of Bayesian statistics, a player may be able to update her prior beliefs by taking account of how the knowledgeable players behave.[65] For example, in certain games of tort settlement, one player's offer, or another player's rejection, can convey information.[66]

This process of learning from another player's actions is captured in the notion of a *separating* equilibrium. In a separating equilibrium, different type players' choices of different equilibrium strategies reveal their types to the previously uninformed player. In a *pooling* equilibrium, the different types of informed players choose the same strategy in equilibrium, preventing the uninformed players from deducing their opponents' types.[67] The concept of separating equilibria is especially relevant for games of asymmetric information in which Nature chooses one player's type, but in which Nature's choice is not observable by other players.

For example, Alan Schwartz recently presented a model of loan priorities in which an uninformed lender seeks to deduce the default risk of two different types of debtors: debt-free firms and firms with prior debt.[68] If these two types of debtors do not distinguish themselves, then in the pooling equilibrium that ensues the lender will charge all debtors an interest rate that represents a weighted average of the higher rate (appropriate for firms with prior debt) and the lower rate (appropriate for debt-free firms).[69] This pooling equilibrium benefits the high-risk debtors because they receive a subsidized interest rate. The low-risk debtors, however, have an incentive to reveal their identity to the lenders so that they can receive the lower, nonpooled interest rate.[70]

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65. Bayes's Rule is a probabilistic formula for updating a prior belief given new information. *See* p. 58. The concept of a perfect Nash equilibrium can be further refined for dynamic games of asymmetric information. A "Perfect Bayesian Equilibrium" is that perfect equilibrium in which the information sets are rational—that is, conform with Bayes's Rule. *See* p. 110.

66. *See* Barry Nalebuff, *Credible Pretrial Negotiation*, 18 RAND J. ECON. 198 (1987).

67. Some games engender intermediate degrees of pooling or separation.

68. Schwartz, *supra* note 27.

69. That is, $r^* = pr_f + (1\text{-}p)r_d$, where $r^*$ is the pooled interest rate, $p$ is the probability that the potential debtor is currently debt-free, and $r_f$ and $r_d$ are the competitive interest rates that the lender would charge debt-free and indebted firms, respectively, if their types were known. *See id.* at 225.

70. *See also* Joseph Farrell & Carl Shapiro, *Optimal Contracts with Lock-in*, 79 AM. ECON.

If the cost of revealing the information to the lender is sufficiently small, a separating equilibrium will exist in which the low-risk debtors reveal their status and pay the lower interest rate. In this equilibrium, the high-risk debtors do not reveal their status, but still pay an interest rate higher than the pooled rate, because the low-risk debtors have dropped out of the pool. In many instances, the uninformed players can undertake strategies that will induce separation and its concomitant information revelation. In many contractual settings, the uninformed party may propose a *menu* of contracts that induces different types of parties to *self select* different contracts.[71]

Game-theoretic models of asymmetric information are especially apt for depicting issues of agency which pertain to many legal arenas.[72] Indeed, principal-agent models have come to represent a major component of the new game theory literature.[73] Because principals often are uninformed of an agent's ability or effort, principal-agent relationships can easily fall prey to *adverse selection* and *moral hazard.*

Adverse selection occurs when the players have asymmetric information about a player's type. For example, a life insurer may not know the actual health of individual insureds although the insureds themselves would know. Adverse selection would result if only the unhealthy opted for insurance.[74] Moral hazard occurs when an agent can take actions that are not directly observable by the principal—so-called hidden actions. In the principal-agent model, the agent may have a personal preference for shirking. If the principal cannot directly observe the agent's effort, it may be difficult to deduce whether lower profits in a given period derive from shirking or from a random decrease in demand.

It is especially important for legal scholars to note that moral hazard may be possible even when the principal can directly observe an agent's behavior. If the principal cannot prove in court that an agent is shirking, then the agent's effort is *noncontractible* in that a binding contract cannot be conditioned on effort.[75] The presence of noncontractible terms can have a dramatic effect on the remaining terms in a contract. The principal-agent literature attempts to discover contract mechanisms that mitigate the otherwise debilitating effects of moral hazard and other forms of contractual opportunism. Joseph Farrell and Carl

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REV. 51 (1989); Michael Rothschild & Joseph Stiglitz, *Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information,* 90 Q.J. ECON. 629 (1976).

71. *See* pp. 160-61.

72. For example, corporate directors are the agents of their shareholders; lawyers are the agents of their clients.

73. *See, e.g.,* Sanford J. Grossman & Oliver D. Hart, *An Analysis of the Principal-Agent Problem,* 51 ECONOMETRICA 7 (1983); Carl Shapiro & Joseph E. Stiglitz, *Equilibrium Unemployment as a Worker Discipline Device,* 74 AM. ECON. REV. 433 (1984).

74. *See* pp. 133-36.

75. P. 140. In some situations, a principal may be able to emulate state enforcement of noncontractible (but principal observable) terms by entering into a self-enforcing agreement. *See* Ayres, *supra* note 26, at 298.

Shapiro have recently shown, for example, that when product quality is noncontractible, both the length and structure of the contractible provisions will be dramatically affected.[76]

### D.   *Strategic Choice of Legal Rules*

Substantive legal rules can play an important role in the context of asymmetric information. The "shadow of the law" itself constitutes part of the rules of the game.[77] Strategic choice of legal rules may mitigate the inefficiencies of adverse selection or moral hazard. For example, Rasmusen notes that "Holmes conjectured in *The Common Law* that the reason why sailors at one time received no wages if their ship was wrecked was to discourage them from taking to the lifeboats too early to save it."[78] Holmes thus sees this law as an attempt to limit the moral hazard of sailors during storms by changing the terms of their wage contract. Rasmusen, however, rejects the appropriateness of this legal rule because it makes risk averse sailors bear an inefficiently large risk: "If sailors are more risk averse than ship owners, and pecuniary advantage would not add much to their effort during storms, then the owner ought to provide insurance to the sailors by guaranteeing them wages whether the voyage succeeds or not."[79]

A substantive legal rule on whether to pay shipwrecked sailors will obviously have effects when it is immutable—that is, cannot be changed by prior contract. But even the choice of "default" rules, which can be set aside by contract,[80] can affect the equilibrium outcome. Indeed, Rasmusen's analysis ignores the possibility of contracting around this common law standard. Surely, if guaranteeing sailors' wages was efficient, the ship owners and sailors could have expressly contracted for it. The possibility of contracting around the shipwreck default of no salary suggests that Rasmusen's criticism should be directed to the inefficiency of additional contracting costs.

Informational asymmetries are at the center of many legal interactions, especially those involving bargaining. In the coming years, attempts to formalize how legal rules affect strategies and equilibria will become increasingly prevalent. For example, Rob Gertner and I have recently argued that lawmakers should sometimes choose default rules that do not simply minimize transaction costs.[81] Strategic choice of default rules can at times give players with private information incentives to reveal their information by bargaining around the undesirable rule. In the reorganization context, immutable procedural rules can reduce

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76. Farrell & Shapiro, *supra* note 70.
77. *See* Robert H. Mnookin & Lewis A. Kornhauser, *Bargaining in the Shadow of the Law: The Case of Divorce*, 88 YALE L.J. 950 (1979).
78. P. 152 (citation omitted).
79. *Id.*
80. *See* Ayres & Gertner, *supra* note 27, at 87.
81. *Id.* at 92-95, 127.

opportunities for inefficient separation or pooling at inefficient equilibria.[82] Law and economics models have often been criticized for assuming full information on the part of all participants.[83] At a general level, the new game theory responds to this criticism by rigorously exploring how imperfect information among players can affect the resulting equilibria.

### III. CRITICALLY ASSESSING THE STATE OF THE ART

The dominance of the new informational game theory will almost inevitably affect law and economics scholarship. Those seeking to capitalize on a form of academic arbitrage—selling the new contributions of one discipline to another academic market—will speed the diffusion rate. This section pauses momentarily to consider whether game theory is appropriate for legal analysis. I analyze three criticisms of the game-theoretic approach. The first two are more technically substantive and reveal certain failures of game theory to construct well specified and robust models. The last relates more broadly to a researcher's methodological "tastes."

#### A. *The Scylla and Charybdis of Nonexistent and Multiple Equilibria*

A continuing problem of the game-theoretic approach concerns the failure of many models to produce a unique equilibrium. Many dynamic game theory models have either no equilibrium or literally an infinity of possible equilibria. Rasmusen properly warns us that "[a] model with no equilibrium or multiple equilibria is underspecified."[84]

The problem of multiple equilibria inheres particularly in infinitely repeated games and is enshrined in what game theorists call the "Folk Theorem, so called because no one remembers who should get credit for it."[85] The Folk Theorem guarantees that there will be an infinity of equilibria in many games if they are repeated infinitely. Thus, if the Entry Deterrence Game were repeated not twenty times but infinitely, one could prove that a wide variety of strategies—such as always fight or fight half the time—could be part of perfect Nash equilibria.

The problem of nonexistence of a unique equilibrium dissipates, however, if we merely reduce the number of repetitions from infinity to a finite but arbitrarily large number. As discussed above, the Chain-store paradox insures that, for any finitely repeated version of entry deterrence, the unique perfect Nash equilibrium will be new entry with incumbent accomodation in each round. Finitely repeated games often

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82. *See* Robert Gertner, Inefficiency in Three-Person Bargaining (Sept. 1989) (unpublished manuscript) (on file with the *Stanford Law Review*).

83. *See, e.g.*, W.L.F. Felstiner & Peter Siegelman, *Neoclassical Difficulties: Tort Deterrence for Latent Injuries*, 11 LAW & POL'Y 309 (1989).

84. P. 27.

85. P. 92.

produce unique equilibria—but these equilibria often are inconsistent with our expectation: In a repeated game, incumbents should benefit from establishing a tough reputation to deter entry.

The introduction of imperfect information games has mitigated this problem. For example, David Kreps and Robert Wilson have shown that the unraveling of the Chainstore paradox is not inevitable if the entrants face incomplete information.[86] If there are a small number of incumbents who are irrationally tough and if potential entrants cannot initially tell which type of incumbent they are playing against, then even soft (rational) incumbents may have incentives to fight entry in the early rounds of a finitely repeated entry game. The beauty of this type of model is that it stops the perversity of complete unraveling merely by interjecting a little incomplete information; there need only be a small · percentage of "tough" incumbents.[87]

The incomplete information "solution" to the unraveling of finitely repeated games unfortunately falls prey to the multiple equilibria "problem." Indeed, Jean Tirole and Drew Fudenberg have extended the results of the Folk Theorem to finite games of incomplete information.[88] The failure of game theory to reduce the multiple equilibria of repeated games without creating the conditions of Chainstore paradox unraveling significantly reduces its predictive power. The multiplicity of equilibria described in the Folk Theorem might be the by-product of unpredictability in the world, or it may be that one needs noneconomic theories to predict which equilibrium will emerge. Further research will attempt to refine the solution concept or to change the game's description to reduce these multiple equilibria. But even the leading theorists "suspect that we are running into diminishing returns in the use of game theory."[89]

## B.  *The Arbitrary Importance of Out-of-Equilibrium Beliefs*

A second technical weakness afflicting dynamic games of incomplete information concerns the arbitrariness with which modellers can impose out-of-equilibrium assessments. The problem is especially important in analyzing pooling equilibria in incomplete games. Consider, for example, a different version of the Entry Deterrence Game in which

86. David M. Kreps & Robert Wilson, *Reputation and Imperfect Information*, 27 J. ECON. THEORY 253 (1982).

87. The use of incomplete information to impede unraveling in finitely repeated games is also found in the classic article that Rasmusen labels "The Gang of Four," *see* p. 118, after its four authors. *See* Kreps, Milgrom, Roberts & Wilson, *supra* note 4. This model similarly shows how a small amount of incomplete information, here in the form of a few "irrational" tit-for-tat players, can avoid the repeated one-shot "finking" equilibrium caused by unraveling. Rasmusen summarizes: "The irrational players have a small direct influence, but they matter because other players imitate them. . . . Not only is hypocrisy the tribute vice pays to virtue; it's just as good for maintaining social order." P. 118.

88. Drew Fudenberg & Jean Tirole, *The Folk Theorem in Repeated Games with Discounting or with Incomplete Information*, 56 ECONOMETRICA 533, 547 (1986); *see also* p. 119.

89. Shapiro, *supra* note 1, at 134.

there are two types of potential entrants, "strong" and "weak." It is more costly for incumbents to fight "strong" entrants, and the payoffs for fighting strong entrants are accordingly lower than the payoffs for fighting weak entrants. The game has asymmetric information, because the incumbent only knows the proportions of strong and weak in the general population, not the particular type of potential entrant in this game.

Under these assumptions, there are two possible pooling strategies for the two types of potential entrants: Both could choose to enter or both could choose not to enter. If we wanted to check to see whether a pooling equilibrium existed, we would, for example, examine whether strategies

Potential entrant plays:
[Don't Enter, if "strong"; Don't Enter, if "weak"]; and
Incumbent plays: [Fight]

constitute a perfect Bayesian equilibrium. In this pooling equilibrium, the incumbent does not learn anything from the entrant's decision not to enter because all entrants—both weak and strong—behave the same. Accordingly, if 90 percent of the potential entrants are "weak," then an incumbent would deduce that in equilibrium the proportion of "weak" entrants would continue to be 90 percent.[90]

The problem in evaluating pooling equilibria is to determine how uninformed players should make out-of-equilibrium assessments of the other player's type. In the previous example, what is an incumbent's assessment of the entrant's type if for some reason entry occurs? Because this is a pooling equilibrium, neither weak nor strong entrants are supposed to enter. How are we to determine which type is more likely to make a mistake?[91]

Game theory does not provide definite answers to this question. Indeed, any assessment can be consistent with a perfect Bayesian equilibrium. Without more, a modeller might arbitrarily posit that, if entry occurs, incumbents will assume there is only a 20 percent chance that the entrant is "weak." More importantly, the specification of these out-of-equilibrium assessments will often determine whether a given pooling equilibrium is perfect.

There is a sense in the literature that the discretion to choose these assessments arbitrarily gives modellers too many degrees of freedom to skew the results of a model. Game theorists have responded by developing a number of what Rasmusen calls "exotic refinements"[92] which restrict in one way or another the out-of-equilibrium assessments that

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90. In probabilistic terms, the probability that a potential entrant is "weak" conditioned on its entry remains 90%: Prob("weak"/entry) = 90.

91. Bayes's Rule is of no assistance in updating conditional beliefs after out-of-equilibrium behavior, because using it in such instances would impermissibly require division by zero.

92. P. 114.

can be used to support a pooling equilibrium. For example, using *passive conjectures* means that prior beliefs would be unchanged by out-of-equilibrium behavior. Passive conjectures in the foregoing version of the Entry Deterrence Game would mean that the incumbent would continue to believe that there is a 90 percent chance that an entrant is weak.

These exotic refinements lack general applicability, but it is not clear whether the game theorists should be embarrassed by this "problem." The difficulty of drawing inferences from events that in equilibrium are supposed take place with zero probability inheres in the real world. Indeed, it may be that other social sciences can be used to guide the choice of these assessments. There is, for instance, a large literature in sociology on deviance and the inferences that are drawn from deviant behavior.[93] Our assessments of deviance or out-of-equilibrium behavior can intuitively affect the stability of an equilibrium. In the Entry Deterrence Game, if an incumbent infers that entry means there is a high probability that an entrant is weak, the pooling equilibrium will cease to be perfect. The "weakness" of game theory in specifying particular assessments is to my mind a species of strength because game-theoretic research has forced us to probe this conundrum in a more rigorous and clearly specified manner.

## C. *Nature Does Not Jump*[94]

The time-honored trilogy of the microeconomic method has been to model economic phenomena by making reductionist assumptions about reality,[95] to solve the model to determine what equilibrium will result given these assumptions, and to examine how the equilibrium is affected by small perturbations in the underlying assumptions. At this metamethodological level, the game-theoretic approach is no different. This review has shown that game theorists model and solve their models in distinctive ways. It is in the third enterprise, however, that the game-theoretic approach most distinguishes itself.

The third goal might be labelled "kicking around the model"—one kicks (or perturbs) an underlying assumption to see if and how this perturbation affects the equilibrium. Resolving the model reveals whether the results are "robust" to alternative assumptions. For neoclassical economists, this enterprise has often focused on how the equilibrium values respond to small perturbations in the underlying parameters of the model. Since Paul Samuelson created the field of "comparative statics,"[96] economists have concerned themselves with policy questions

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93. *See, e.g.,* DEVIANCE: THE INTERACTIONIST PERSPECTIVE (E. Rubington & M. Weinberg 5th ed. 1987); SOCIAL DEVIANCE (R. Farrell & V. Swigert 2d ed. 1978).

94. *See* CAROLUS LINNAEUS, PHILOSOPHIA BOTANICA § 77 (1751) ("Natura non facit saltus" or, in English, "Nature does not proceed by leaps").

95. *See* MILTON FRIEDMAN, ESSAYS IN POSITIVE ECONOMICS (1953).

96. *See* P. SAMUELSON, *supra* note 3, at 7-8.

of the type: What would happen to United States unemployment if we slightly raised a given tariff or tax? Traditional neoclassical economists answer these questions by taking a derivative.[97] The traditional model would state equilibrium values for such variables as unemployment in terms of underlying assumptions such as the tariff or tax rate and then analyze the comparative statics of the model by taking the derivative of the equilibrium variable with respect to the underlying parameters.[98]

The core result of the comparative statics method is that infinitesimal changes in a parameter of a model will only bring about infinitesimal changes in the equilibrium variables. Changing the underlying values will move the equilibrium, but the equilibrium values will not move discontinuously—that is, they will not jump.

Calculating the comparative statics in game theory models, however, is often much more difficult than simply taking derivatives. Moreover, many games exhibit discontinuous changes when the underlying structure is changed slightly. Rasmusen warns the reader that comparative statics

> can be especially tricky in game theory. If a parameter is changed, and one player changes his strategy in response, that change in turn induces a change in the strategies of the other players, so when the game settles down to its new equilibrium, the strategies might be quite different.[99]

The discontinuous nature of many game-theoretic models should caution legal policymakers. To the extent that such models are appropriate, equilibrium outcomes may not be robust to even slight changes in legal standards: A slight change in a due care standard, for example, might generate significant changes in the players' underlying behavior. More fundamentally, the discontinuous nature of game theory models might signal that the models offer weak predictions of human behavior. If one's underlying view of reality is like Einstein's—that "nature does not jump"—then one cannot find solace in many of the results of game theory.

Game-theoretic nature does jump, at times, in ways that put electron clouds to shame.[100] A similar tension over whether nature jumps is being played out now among evolutionary biologists, as Stephen Jay

97. Consistent with this traditional approach, many economic dissertations consist of solving simple models and then taking derivatives of the equilibrium variables with respect to every conceivable underlying parameter. *See, e.g.,* Ian Ayres, Essays on Vertical Foreclosure, Cartel Stability and the Structural Determinants of Oligopolistic Behavior (Dec. 1987) (Ph.D dissertation) (on file with the *Stanford Law Review*).

98. For example, if in solving a model one could calculate a value for unemployment as a function of tariff, $U(t)$, then one could calculate the effect of increasing the tax rate slightly by taking the derivative $dU(t)/dt$.

99. P. 124; *see* Steven Lippman, John Mamer & Kevin McCardle, *Comparative Statics in Non-Cooperative Games via Transfinitely Iterated Play*, 41 J. ECON. THEORY 288 (1987).

100. The argument that game theory models are "wrong" because nature does not jump is analogous to the argument that complicated models must somehow be flawed because underlying reality must be comprehensible.

Gould has attempted to refine Darwinian notions of gradual change with his own notion of "punctuated equilibria."[101] While such deep structural aspects of reality cannot be tested in statistically meaningful ways, I submit that one's intuitive sense about their truth influences whether particular readers will have a taste for game-theoretic models.

## IV.  CONCLUSION: THE POLITICS OF GAMES

The current failure of game theory to penetrate legal analysis may be due to these weaknesses or to the novel and technical aspects of modelling and solving games. This review has argued that *Games and Information* reduces the costs of acquiring the new tools and that investing time and effort in mastering the new techniques for modelling games of asymmetric and incomplete information is cost-justified, especially now. Whether readers should make this investment, however, turns in part on whether one believes the new game theory will catch on in the legal community in the coming years. I have argued that these new techniques will command a wider audience.[102] But in the interest of full disclosure, I sense that the rate of diffusion will have a political determinant as well.

The thrust of many game theory articles is to demonstrate how strategic interactions can lead to inefficient results.[103] The "new" game theory thus runs against the laissez-faire policy prescriptions of the Chicago school of law and economics. Game theory applications are susceptible to George Stigler's criticism of traditional (non-Chicago) oligopoly theory by "making departures from competition the central problem of industrial organization."[104] Indeed, the new game theory is the core methodology of the new "new learning" in industrial organization[105]—which, for example, has attempted to resuscitate discarded notions that predation and leveraging might be rational profit-maximizing strategies.[106] The Chicago school had proposed *a priori* theories suggesting why market competition should generate efficiency. Game-theoretic analysis demonstrates rigorously that under at least certain

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101. *See* STEPHEN JAY GOULD, WONDERFUL LIFE (1989).

102. Indeed, there are already signs of seepage. The Law and Economics Section of the Association of American Law Schools on January 6, 1990, sponsored a panel coincidentally entitled "Games and Information." The panelists—Carl Shapiro, Louis Kaplow, and Alan Schwartz—demonstrated a number of legal applications of the new informational tools.

103. *See, e.g.,* pp. 205 ("the outcome [of signalling models] is often inefficient"), 231 (noncooperative bargaining models generate equilibria that are neither "neat, fair, beautiful, [nor] efficient"), 273 (in determining the location of stores "the competitive market does not achieve efficiency").

104. George J. Stigler, *Palgrave's Dictionary of Economics,* 26 J. ECON. LITERATURE 1729, 1734 (1988).

105. *See* Janusz A. Ordover & Daniel M. Wall, *Proving Predation After* Monfort *and* Matsushita: *What the "New Learning" Has to Offer,* ANTITRUST, Summer 1987, at 5, 6.

106. *See* Janusz A. Ordover & Garth Saloner, *Predation, Monopolization, and Antitrust,* in 1 HANDBOOK OF INDUSTRIAL ORGANIZATION 537 (R. Schmalensee & R. Willig eds. 1989); David Scharfstein, *A Policy to Prevent Rational Test-Market Predation,* 15 RAND J. ECON. 229 (1984); Janusz A. Ordover, Vertical Integration and Overbuying (ABF Working Paper) (1989).

assumptions markets can fail to promote social welfare.[107] The results of these models force laissez-faire advocates to change the nature of their arguments.

Rasmusen's own analysis of health insurance illustrates this point. Because of adverse selection, "[W]hen the price of insurance is appropriate for the average old person, healthier ones stop buying."[108] After these people drop out of the insurance pool, "[t]he price must rise to keep profits nonnegative."[109] If adverse selection is severe, the market for old age health insurance will unravel to the point where only the sickest people will be sold insurance at much higher prices. This simple story provides what might seem a powerful rationale for government intervention: "[A]dverse selection is an argument for government-enforced pooling. If all old people are required to purchase government insurance (Medicare in the United States), then while the healthier of them may be worse off, the vast majority could be helped."[110] But Rasmusen goes on to warn readers not to be beguiled by such "dangerous" arguments:

> Using adverse selection to justify medicare, however, points out how dangerous many of the models in this book can be. For policy questions, the best default opinion is that markets are efficient. On closer examination, we have found that many markets are inefficient because of strategic behavior or information asymmetry. It is dangerous, however, to immediately conclude that the government should intervene, because the same arguments applied to government show that the cure might be worse than the disease.[111]

Once game-theoretic models demonstrate the potential for market failure, supporters of nonintervention by government can no longer rely solely on *a priori* arguments that the market is a first best solution. In-

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107. Avery Katz has similarly argued that

for scholars who work within the framework of law and economics, whatever account of strategic behavior costs that one is led to by one's theory of bargaining will determine one's basic normative stance toward legal rules. . . . [T]his is the primary difference separating the so-called "conservative" and "liberal" wings of law and economics scholarship.

Katz, *supra* note 26, at 14.

108. P. 196.

109. *Id.*

110. *Id.*

111. *Id.* I would note that Rasmusen's presumption or "best default opinion" that markets are efficient is not a prerequisite of economic or game-theoretic analysis. In a different context, Richard Posner has debated with John Donohue whether Title VII drives out discrimination in employment at the efficient rate. *Compare* John J. Donohue III, *Is Title VII Efficient?*, 134 U. PA. L. REV. 1411 (1986), *with* Richard A. Posner, *The Efficiency and the Efficacy of Title VII*, 136 U. PA. L. REV. 513 (1987). In an oral debate at Northwestern, Posner argued that as a historical matter he did not believe that in 1964 the market was driving out discrimination at an efficient rate, but as an economist one must presume efficiency.

Unlike Rasmusen and Posner, I do not believe that an economist has to presume efficiency and am leery of public policy decisions that turn on that initial presumption. Even if one presumes efficiency, much will turn on what are the necessary and sufficient conditions for rebutting this presumption.

stead, advocates of nonintervention must argue either that the assumptions of the game theory model are empirically invalid or that laissez-faire policies are a second best because the costs of any government intervention outweigh its benefits.

In the 1950s and 1960s, the "Harvard" school of industrial organization focused the attention of economists on detailed case studies of individual industries.[112] In the 1970s and 1980s, however, the "Chicago" school replaced this fact-intensive industry analysis with price theory. Its explicit claim was that powerful and simple tools of price theory could be applied to diverse markets better than the industry case studies which, while factually detailed, were often poorly grounded in economic theory.[113] The new game theory harks back, in a sense, to the earlier case study approach in that game theorists have developed a number of models to examine individual aspects of industrial behavior.[114] The game-theoretic analysis then is similarly susceptible to the Chicago critique that the particularized games are not neatly applicable to a broad spectrum of markets. Game theorists respond that the broad generalization of price theory is inappropriate when small numbers of players act strategically—that is, when the assumptions of price theory are violated. At a minimum, the stylized games rigorously demonstrate a number of "possibility" theorems which force both sides toward empirical analysis.

I predict that in the next decade there will be a small skirmish over the propriety of using game-theoretic analysis to answer legal questions. The dispute will not merely be an academic quarrel about the correct way to express the same reality: Decisions about legal policy will hang in the balance. Game theory models can generate substantively different policies than other modes of law and economic analysis. Laissez-faire advocates have often been able to claim the "scientific" mantle of law and economics, but game theory may allow proponents of government intervention to seize the scientific high ground.

Game theorists will be attacked by those who have grown leery of the reductivist methods of economic reasoning, but possibly stronger attacks will come from laissez-faire advocates within the law and economics community itself. Politics will undoubtedly influence the debate, but Rasmusen's book offers insights for both friend and foe. By making the fundamental concepts accessible, *Games and Information* paves the way for a more reasoned analysis of whether and when it is appropriate to play games with the law.

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112. *See, e.g.,* JOE S. BAIN, INDUSTRIAL ORGANIZATION (1959); JAMES W. McKIE, TIN CANS AND TIN PLATE: A STUDY OF COMPETITION IN TWO RELATED METHODS (1959).

113. *See, e.g.,* RICHARD A. POSNER, ANTITRUST LAW: AN ECONOMIC PERSPECTIVE 8 (1976).

114. Carl Shapiro also made this analogy at his recent address to the Association of American Law Schools convention. *See* note 102 *supra.*