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# Game Theory and the Law: Ready for Prime Time?

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GAME THEORY AND THE LAW. By *Douglas G. Baird, Robert H. Gertner, and Randal C. Picker.* Cambridge: Harvard University Press. 1994. Pp. xii, 330. $45.

> With the advent of imperfect competition theory in the 1930s there appeared a profusion of oligopoly theories derived from a host of plausible assumptions, few of them readily testable by empirical evidence. It sometimes seemed as if every theorist aimed to produce a model of his own before breakfast each morning, limbering up with mental calisthenics.
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> No wonder that distinguished reviewers such as Leonid Hurwicz and Richard Stone eagerly welcomed the appearance in 1944 of von Neumann and Morgenstern's great work, *The Theory of Games and Economic Behaviour.* At last economists were properly equipped with powerful and elegant methods of tackling a subject that had become increasingly baroque . . . .
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> Surprisingly and embarrassingly and for reasons hard to fathom, over the next twenty years game theory failed to live up to its promise for economics. . . . [E]ven though as early as 1950 Nash had developed an appealing concept of solution for non-cooperative games, economists still shied away from applying game theory to strategic economic behaviour, its natural home in our discipline. . . .
>
> [T]he analysis of strategic behaviour . . . languished mightily until the mid-1960s, when important papers by Harsanyi and by Selten and others appeared. By the 1970s this trickle of articles had become a swiftly moving stream, and by the 1980s a roaring flood that threatened to engulf the rest of microeconomics . . . .[1]

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1. THE NEW PALGRAVE: GAME THEORY xi-xii (John Eatwell et al. eds., 1989) [hereinafter NEW PALGRAVE: GAME THEORY].

## Introduction

The foundations of noncooperative game theory, the formal study of nonconsensual (or "strategic") interaction among self-interested rational actors, were laid largely during the middle of this century.[2] Since then, game-theoretic work has threatened to engulf not only microeconomics, but virtually every branch of social scientific study. The law rests on slightly higher ground, but certainly is not above the crest. The use of game-theoretic methods to study legal problems dates at least to the early 1970s,[3] and has been growing — albeit at a more measured pace than in economics proper — ever since. Almost surely, the differential rate of diffusion of game theory into law is due partly to its higher entry fee.[4] It has only been with increased numbers of individuals formally trained in both law *and* economics, as well as increased lawyer/economist collaboration, that game-theoretic analysis of legal problems has started to take off.

So it is only possibly surprising that *Game Theory and the Law* (hereinafter *GTL*) marks the first general effort to bring game-theoretic insights to a specifically legal audience. Even so, *GTL* might well encounter differing expectations among different segments of its potential audience. Some aspects of law and economics, in some quarters at least, are viewed as resting on undue simplification, whether in such forms as the core insight of *The Problem of Social Cost*,[5] or simply the relentless application to legal problems of the relentlessly economic *weltanschauung* of such economists as Gary Becker.[6] To be sure, the insights brought to bear on

2. Apart from John von Neumann & Oskar Morgenstern, Theory of Games and Economic Behavior (Science Editions 1964) (1944), pivotal founding contributions also include the mid-century papers by John F. Nash, Jr., including *Non-Cooperative Games*, 54 Annals of Mathematics 286 (1951) [hereinafter Nash, *Games*]; *The Bargaining Problem*, 18 Econometrica 155 (1950) [hereinafter Nash, *The Bargaining Problem*]; and *Equilibrium Points in N-Person Games*, 36 Proc. Natl. Acad. Sci. 48 (1950) [hereinafter Nash, *N-Person Games*]. The slightly later contributions by Reinhart Selten and John Harsanyi include: John C. Harsanyi, *Games with Incomplete Information Played by "Bayesian" Players* (pts. 1-3), 14 Mgmt. Sci. 159, 320, 486 (1967-68); Reinhart Selten, *Spieltheoretische Behandlung eines Oligopolmodells mit Nachfrageträgheit*, 121 Zeitschrift für gesamte Staatsswisenschaft (pts. 1&2), 301, 667 (1965) [hereinafter Selten, *Spieltheoretische*]; R. Selten, *Reexamination of the Perfectness Concept for Equilibrium Points in Extensive Games*, 4 Intl. J. Game Theory 25 (1975) [hereinafter Selten, *Perfectness Concept*].

3. *See, e.g.*, John Prather Brown, *Toward an Economic Theory of Liability*, 2 J. Legal Stud. 323 (1973).

4. See Ian Ayres, *Playing Games with the Law*, 42 Stan. L. Rev. 1291, 1315-18 (1990) (reviewing Eric Rasmusen, Games and Information: An Introduction to Game Theory (1989)), who suggests that a secondary reason for the slow diffusion of game theory into legal analysis may be found in its generally less sanguine account of the economic outcomes of private interaction.

5. *See* R.H. Coase, *The Problem of Social Cost*, 3 J.L. & Econ. 1 (1960).

6. *See* Gary S. Becker, The Economic Approach to Human Behavior 3-14 (1976); Richard A. Posner, Economic Analysis of Law (4th ed. 1992).

legal problems have been distinguished economic insights, and they have richly illuminated our thinking about the law. But it hardly requires citation to say that their application has often been controversial.[7] So, we conjecture at the outset, there are those who will approach both game theory generally and *GTL* particularly in a skeptical frame of mind, vigilant for the possibility that this may constitute an instance of cutting perhaps too wide a swath through the law with perhaps too simple, or too simplified, an economic thought.

We are happy to begin by reporting, then, that such apprehensions are without foundation. *GTL* decidedly does not bring to the law a single bright punch-line, distilled from a more ambiguous economic account. In part that is in the nature of the beast. But it also reflects the authors' aspirations, to which they can speak best themselves:

> First, we wanted to introduce the formal tools of modern game theory to a wide audience using a number of classic legal problems . . . . Second, and as important, we wanted to show how modern game theory allows us to sharpen our intuitions and provides us with new ways of looking at familiar problems. In short, we have tried to write a book that offers those interested in law a new way of thinking about legal rules, and a book that shows those interested in game theory a fertile and largely unexplored domain in which its tools have many applications.
>
> Much of the analysis in this book makes extensive use of concepts that have been developed only within the last decade, and we have not compromised on the rigor that these cutting-edge concepts demand. Nevertheless, we have been able to apply these concepts to the law without requiring the reader to know calculus, probability theory, or any other formal mathematical tools beyond simple algebra . . . . We depend only on the reader's willingness to think through hard problems logically and carefully. [pp. xi-xii].

This suggests that *GTL* will not be found erring on the side of undue or convenient simplification. Indeed that is the case. This is a broad foray, largely unburdened by doctrinaire predispositions, not only into the range of techniques deployed in contemporary game-theoretic work, but across the spectrum of law-related problems to which such techniques, in principle, can be applied.

The authors' prefatory observations nicely frame the issues on which we wish to dwell. Those are, *first,* how well chosen are their

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7. We offer a selection anyhow. On *The Problem of Social Cost,* see William J. Baumol, *On Taxation and the Control of Externalities,* 62 AM. ECON. REV. 307 (1972); Robert Cooter, *The Cost of Coase,* 11 J. LEGAL STUD. 1 (1982); Donald H. Regan, *The Problem of Social Cost Revisited,* 15 J.L. & ECON. 427 (1972); R.H. COASE, *Notes on the Problem of Social Cost, in* THE FIRM, THE MARKET, AND THE LAW 157-85 (1988). On ECONOMIC ANALYSIS OF LAW, see Arthur Allen Leff, *Economic Analysis of Law: Some Realism About Nominalism,* 60 VA. L. REV. 451 (1974).

aspirations, and *second,* how well realized are the chosen aspirations? Given our venue, we take them up with a readership of lawyers curious about game theory — rather than the other way around — in mind. We will, however, say at the beginning that, for the other segment of *GTL's* target audience — game theorists interested in applications of their tools to the law — this will be a very interesting book indeed, one that may well suggest a range of interesting topics on which to work. As for potentially interested lawyers, we imagine that they fall into one of roughly two groups: those already familiar with game theory, including those who do game-theoretic work themselves; and those with just a passing acquaintance, perhaps enough to understand the prisoner's dilemma and its moral, or possibly no more than enough to know that "strategic interaction" is a term that with increasing frequency they have heard. We assume that we can be of service primarily to the latter group, since those already conversant with game theory and the associated legal literature will be familiar with much of what is developed in *GTL.*

For readers interested in learning a little, or a little more, about both game theory and its relevance to the law, what might constitute a reasonable set of preliminary questions? Essential elements would seem clearly to include an introduction to what game theory is, an introduction to its principal analytic methods and illustrations of how they can be deployed to illuminate aspects of the law. *GTL* aspires to all of this and more. It introduces the reader to the more elementary game-theoretic techniques.[8] Most conspicuously, it surveys the ways in which the tools of game theory and information economics can be applied to aspects of the law. The survey takes in a lot of ground. It extends not only to advanced applications of game theory and information economics, but to such related topics as optimal contracting (pp. 109-18), mechanism design (Chapter Six), and bargaining (Chapters Seven and Eight). Unavoidably, then, it must introduce the reader to more-advanced techniques, and that is a third important feature of the book.[9] Finally, reflecting its multiplicity of authors and their current research interests, *GTL* incorporates detailed treatment of problems on which they separately have worked.[10] By any standard the undertaking is ambitious. It is also overdue. Game-theoretic work currently is scat-

8. Pp. 6-78, 159-87; *see infra* section II.A. For purposes of discussion we adopt the following taxonomy: by "game theory" we mean the underlying mathematical results on which the discipline rests; by game-theoretic "techniques" or "methods" we have in mind the collection of means, to which that theory gives rise, of "solving" non-cooperative games; and by game-theoretic "applications" we have in mind the application of those methods to modeling concrete problems.

9. *See, e.g.,* chapter 3; *see infra* section II.B.

10. *See, e.g.,* pp. 147-53 (drawing on Ian Ayres & Robert Gertner, *Strategic Contractual Inefficiency and the Optimal Choice of Legal Rules,* 101 YALE L.J. 729 (1992)); pp. 232-37

tered throughout the literature, at varying levels of accessibility and technical detail. There is a need for a general introduction to these materials.

At the extremes, the organizing thread of *GTL* — its survey of applications — could be spun out in one of two quite different ways. At each stage it could describe for the reader the techniques that were involved, and then proceed to articulate, above the level of gritty technical detail, how those techniques might be applied in particular legal settings, and with what insights and implications — relegating the details to footnotes, appendices, or references to other texts.[11] This facilitates covering a lot of ground. Alternatively, it could take the time genuinely to school the reader in game-theoretic methods, developing the survey as a set of "worked-out" applications.[12] That would require a heavier investment by the reader and almost surely would limit the range of things surveyed. For the additional investment, however, the reader would end up with a better grasp of what actually is going on. With the former, the reader is more likely to end up with a sense of the insights that *others* have obtained by applying the techniques of game theory to the law. Either could produce a very useful book, although they would be very different books.

In important respects, *GTL* pursues the former course. It does not, as the preface immediately makes clear, require the reader to know — or to learn — any calculus (there is very little and, really, very little need) (pp. 112-16 & nn.34-38) or probability (of which there is a lot, none even remotely "theoretical," almost all of it as elementary as can be) (e.g., pp. 244-67 & nn.6-29). It does, by and large, develop its account of both the theory and its applications almost entirely in words. Those constraints effectively foreclose *GTL* from offering a genuinely systematic account of the range of game-theoretic techniques. Nevertheless, *GTL* does repeatedly expose the reader to game-theoretic applications in detail. Explanatory passages are often interspersed with pages of detailed verification of whether some set of actions is or is not a solution to some game. That, to be sure, is an integral feature of what game theory is about, and it is that to which we take the authors to be referring when they ask for the "reader's willingness to think through hard problems logically and carefully" (p. xii). But it is a form of exposition perhaps better suited to a book devoted to

(drawing on Douglas G. Baird & Randall C. Picker, *A Simple Noncooperative Bargaining Model of Corporate Reorganizations,* 20 J. LEGAL STUD. 311 (1991)).

11. One model for this basic approach would be STEVEN SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW (1987).

12. For comparison, see ROBERT GIBBONS, GAME THEORY FOR APPLIED ECONOMISTS (1992); ERIC RASMUSEN, GAMES AND INFORMATION: AN INTRODUCTION TO GAME THEORY (2d ed. 1994), the first edition of which was reviewed in Ayres, *supra* note 4.

teaching lawyers how to do game theory than to a book about game theory and the law. At bottom, however, *GTL* is *about* game theory and the law. As such, one might question its allocation of so much space to the details.

This problem is not, we should immediately add, especially serious in the introductory chapters of the book. There, the reader is more carefully introduced to the techniques, and the techniques themselves are not that difficult to grasp. But *GTL* also devotes considerable space to more esoteric matters — those recently developed "cutting-edge" concepts to which the prefatory remarks refer — developed to deal with problems of "asymmetric" information.[13] Its doing so reflects the authors' considered judgment, with which many would agree, that "[i]ncomplete information is the central problem in game theory and the law" (p. 2). Here, however, *GTL* courts two more serious difficulties, both traceable to its concomitant decision to do it (almost) all in words. First, there inevitably *is* some compromise, not merely on the rigor but more importantly on the kind of systematic development that learning those techniques demands. Modeling uncertainty and informational asymmetry inescapably entails the use of probability, the very thing that *GTL* has chosen to eschew. No wealth of detail is a substitute for the essential analytic foundations of a substantial fraction of what *GTL* sets out to do.

Second, to the extent the theory does emerge, it does so with some important details obscured. Game theory is currently in a state of flux, beset by serious problems that have not been satisfactorily resolved.[14] Chief among them are the extreme sensitivity of its predictions to aspects of formulations that a modeler cannot hope to specify, and a not insignificant body of evidence suggesting that even when these aspects are experimentally controlled for, the theory often fails to predict how people actually do behave. Given *GTL's* preoccupation with illustrating applications of game theory to the law, little space remains for sustained attention to the shortcomings of the theory,[15] or for the more detailed exposition of the theory that would form the essential predicate for that.

A book so intent on taking its readers to the frontiers, so willing to subject them to so *much* detail, ought perhaps be willing to insist on just a little additional effort, and to offer in return a more complete account of, and more importantly a better perspective on, just

13. Problems of "asymmetric" information posit the existence of private information known to some but not to all strategic actors. *See infra* text accompanying notes 84-93.

14. *See infra* text accompanying notes 94-95, section II.C.

15. We do not suggest that *GTL* completely overlooks the issues; only that, by dint of an overwhelming emphasis on applications, these important questions are dealt with in a fragmentary fashion and are too substantially submerged. *See infra* section II.C.

what is being done. For that, we believe, is the important final entry in our list of preliminary questions for the seriously interested reader. One not already acquainted with the theory, its conceptual difficulties, and its mixed success in controlled experiments, is likely to come away inadequately informed about the limits to what game theory may currently and realistically have to offer to the law. Whether game theory really is ready for prime time, and if so just which aspects are ready to be aired, are questions *GTL* does not systematically explore.

The net of it is this. *GTL* does not teach lawyers how to do game theory, but that is something it does not set out to do. *GTL* does succeed in offering interested lawyers a nontechnical introduction to game theory, together with a rich and varied survey of the ways in which game-theoretic insights can be brought to bear on the design of legal rules. That is no small accomplishment in itself. Game-theoretic reasoning focuses on what actors can observe, what they can infer, and what, in light of that, they do. As such it is recursive and complex. In developing an account in words, *GTL* took on an extraordinarily demanding task. In the chapters in which the trickier analyses are performed, however, it is possible that the otherwise uninitiated reader will be able to do little more than watch. Still, it is interesting to watch. *GTL* takes up the most current features of applied game theory and information economics and sets out to explore their relevance to the law.

In the balance of this review, we will say more about what *GTL* actually does. But first we need a methodological preface, since, without that, whatever we might have to say may be unmeaningfully abstract. So, in Part I, we begin with a brief, nontechnical survey of the terminology and methodology of noncooperative game theory. For readers already acquainted with the basics — if specifically you know what a "subgame perfect equilibrium" is — Part I will tell you little new and should be skipped. If, moreover, you are unacquainted but not (or not yet) interested in the details, feel free in any event to proceed directly to Part II.

There we turn to *GTL* itself and survey the range of things the book sets out to do. In lieu of making the catalogue too detailed, we instead focus on one central feature of the exposition. That is the authors' decision to introduce after a mere eighty pages, and thereafter to dwell on in detail, games of "incomplete" information and the solution concept known as the "perfect Bayesian equilibrium."[16] Judging by the language from the Preface, we suspect that this is an aspect of their endeavors of which the authors are most proud. But it puts most severely to the test their prior decision to

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16. If you do not already know, please do not worry for the moment just what any of those terms might mean. We will fill you in.

dispense with mathematical formalities. Together, those decisions induce a self-inflicted inability to lay out for the reader in adequate detail either the operation of, or the central difficulty with, the solution concept that is key to any real grasp of what *GTL* is doing in a substantial fraction of the book.

It is not entirely clear what prompted the first of these decisions. The obvious possibility is that the authors felt it essential to their accessibility to a wider audience. More specifically, they may have been motivated by the thought that lawyers simply cannot be expected to deal with probability, or mathematics at any level of abstraction, or even, really, with what ultimately amounts to no more than simple numerical computations. But it is surely striking that *these* three individuals, inhabitants of the community that is literally the cradle of contemporary law and economics, should have set for themselves the task they did and then elected to do it all in words.

## I. A Game Theory Primer

What *is* "game theory"? At a high level of generality, it studies formally what might be regarded as *the* social scientific question: How do, or should, individuals conduct themselves when each realizes that the consequences of his individual acts will depend in part on what other independent actors do?[17] How, in other words, does he do best at pursuing his own objectives, whatever they might be, in an interdependent milieu? Game theory formalizes that question by positing players and endowing them with moves, specifying what information is available to each player at each point at which he may be called upon to move, assigning payoffs to the ways all players' moves can be combined to play the game, and then investigating the kinds of conduct that might plausibly arise.

More specifically, *noncooperative* game theory — the field of most active interest the past twenty-five years — might be defined as follows.[18] It is the formal study of conduct by two or more "players," each of whom must choose what to do at an explicitly enumerated set of "decision points" or "moves," at each of which it has a specified set of available "actions" from which to choose.[19] The "payoffs" to each player are determined *both* by what that player

17. *See, e.g.,* Robert J. Aumann, *Game Theory, in* New Palgrave: Game Theory, *supra* note 1, at 1; John C. Harsanyi, *Games with Incomplete Information,* 85 Am. Econ. Rev. 291, 292 (1995).

18. In general, noncooperative game theory is concerned with individual conduct, while the object of interest in "cooperative" game theory is with what can be obtained by "groups" or "coalitions." We will use the term "game theory" synonymously with "noncooperative game theory" throughout.

19. Each decision point is called more generally an "information set," which specifies the information available to the player whose move it is to make. *See infra* text accompanying notes 26 and 58-59.

does *and* by what the other players do. Each player is assumed to know the "rules" of the game, including not only *all* the moves available to *each* player and precisely what past choices are observable by each player at each move, but also the payoffs associated with *every possible* way in which the players' choices might be combined to "play" the game. What is more, each player is taken to assume that each other player also knows the rules, usually described by saying the structure of the game is "common knowledge."[20] So it is the formal study of conduct by actors whose payoffs are *jointly* determined by the *interaction* of their individual choices, within the confines of a completely specified, commonly known set of rules.

Once the rules of a game are made concrete — by specifying all the possible moves, who may make them, and what information is available and what actions may be taken at each — there will be different ways in which each player might combine the actions available to it at its different moves, and by so doing to specify completely, for *that player,* one possible way to play the game. Any one such combination is called a "strategy" for that player.[21] The collection of all the strategies open to a given player in a given game — every possible way that player might conceivably play the game — is called the player's "strategy set." Any collection of strategies, formed by choosing one for *each* player in the game, specifies one possible play of the entire game, and is called a "strategy profile" of the game. In a well-defined game, payoffs to *each* player are specified for *every* strategy profile, that is, for *every possible* way the elements of the players' strategy sets can be combined to play the game.

That is all a bit abstract. So, we make the abstractions concrete using two very simple two-person games. But there are two different ways of representing a noncooperative game. To those with just a passing acquaintance with the subject, the most familiar is probably the "normal" or "strategic" form, in which the strategies of the players are arrayed along the margins of a matrix, each cell of which is defined by one strategy for each of the two players, and hence corresponds to one strategy profile of the game. The entries in each cell give the payoffs to each player from the strategy profile that defines that cell. We begin, however, with the "extensive

20. *See infra* text accompanying notes 37-38.

21. *See, e.g.,* Gibbons, *supra* note 12, at 93; R. Duncan Luce & Howard Raiffa, Games and Decisions: Introduction and Critical Survey 51-53 (Dover Publications 1989) (1957); Martin J. Osborne & Ariel Rubinstein, A Course in Game Theory 92-93 (1994); Eric van Damme, *Extensive Form Games, in* New Palgrave: Game Theory, *supra* note 1, at 139, 140-41. We emphasize here that a "strategy" specifies the actions a player will take at *each point* in the game at which she *possibly might* be called upon to move, including points in the game that *never* will be reached. *See infra* text accompanying note 28.

form,"[22] which provides a more detailed description of a game and is often the more convenient form to use. Any game can be represented in extensive form and then reduced to a corresponding and unique normal form.

## A. *The Description of Games in Extensive and Normal Form*

We base our first example ("Game One") on a situation routinely encountered by lawyers and their clients. Imagine, as one possible illustration, the reroofing of a residential building, during which a series of leaks develop, causing substantial damage to a resident of the building's topmost floor. The roofer had exclusive control of the roof, so there is no serious question about liability, nor is there any doubt about the costs to repair the physical damage that was sustained. The resident also claims, however, that she was constructively evicted from her apartment by the repeated water infiltrations, for which she seeks compensation beyond the cost of the repairs. The latter claim is a bit out of the ordinary, and the roofer's Insurer (Player *I*) is reluctant to accede to it. Even so, the belief of both the Insurer and the Resident (Player *R*) is that, on the evidence, it almost surely would be sustained if the dispute were to go to court. Suppose the cost of physical repairs is $7,[23] that the claimed damages for constructive eviction are another $6, and that the resident may choose to litigate in response to the compensation she is offered. The cost of litigation will be $4 to each side.

How will the Insurer and the Resident proceed?[24] If you accept the rules as they are given, you will probably have an intuition. Our objective, however, is to formalize the game, after which we will see if it has a "solution" that corresponds with your intuition. Suppose, to be both simple and specific, we imagine that the Insurer can make one of two offers: "*F*ull" compensation ($13), or "*P*artial" compensation ($10).[25] Confronted by either of these offers, the Resident may choose either to "*s*ettle" or go to "*c*ourt." Formulated as a noncooperative game, Player *I* has a single move, at which it has two "actions" from which to choose. Player *R*, in con-

22. *See generally* LUCE & RAIFFA, *supra* note 21, at 39-55; H.W. Kuhn, *Extensive Games and the Problem of Information, in* 2 CONTRIBUTIONS TO THE THEORY OF GAMES 193 (1953); JEAN TIROLE, THE THEORY OF INDUSTRIAL ORGANIZATION 423-26 (1988); van Damme, *supra* note 21, at 139-44.

23. We have in mind $7000, but for simplicity we suppress the zeroes.

24. We will refer, interchangeably, to "the Resident," "Player *R*," and "*R*"; and likewise for "the Insurer."

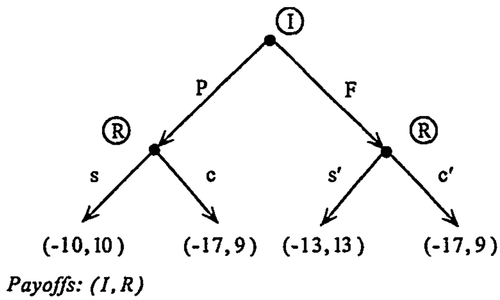
25. We have, in the interests of simplicity, restricted ourselves to offers of compensation that are integers. Our specification of the offer of *P*artial compensation is as the smallest integral offer that, in the solution to the game, does not provoke the Resident to go to court. *See infra* note 52 and accompanying text.

trast, has two possible moves, depending on the Insurer's offer, at either of which she must choose to *s*ettle or go to *c*ourt.

### 1. *The Extensive Form*

The "extensive form" representation of our simple game consists of the "game tree" in Figure I-A, in which a move by either player is denoted by a solid circled "choice node." To indicate whose move it is, we have located a circled *I* or *R* beside each such node. The arrows emanating from each choice node denote the actions open to the player whose move it is to make. Player *I* moves first and may choose *F* or *P*. Either choice leads to a move by Player *R*. The choice by Player *I* of offering *P*artial compensation, for example, leads to a node at which Player *R* chooses whether to *s*ettle or go to *c*ourt. As we have described it, Player *R* might go to *c*ourt even if offered *F*ull compensation, depicted in the tree by the choices *c'* and *s'*. There are four possible sequences of moves by *I* and *R* that can be formed from the choices available to them: *P-s, P-c, F-s', and F-c'*. In Figure I-A, the termination of each resulting "branch" of the tree — denoted by an arrow that does not lead to a move by another player, but to a "terminal node" instead — corresponds to exactly one of those four sequences, and to each sequence associates a set of payoffs, here just two, one for *I* and one for *R*.

FIGURE I-A
EXTENSIVE FORM OF GAME ONE




Thus, if Player *I* offers *F*ull Compensation and Player *R* *s*ettles, the Insurer pays $13 to the Resident, and their respective payoffs are denoted by (-13, 13); if instead *R* chooses to go to *c*ourt, she will recover $13, but each party must pay $4 in legal fees, and the payoffs will be (-17, 9). If, on the other hand, *I* offers *P*artial compensation, the payoffs will be (-10, 10) or (-17, 9), depending on whether the Resident *s*ettles or goes to *c*ourt. (We remind the reader which payoff belongs to which player at the bottom left of the game tree.)

Game One begins with the Insurer's move; the Resident, when called upon to move, can observe what the Insurer has actually done. So, each Player, at each point at which he is called upon to move, knows everything that has thus far happened in the game.[26] As a matter of terminology, a game that has the property that each player at each move has observed the entire history of the play to date is called a game of "perfect" information. Checkers and chess are illustrations.

### 2. *Reduction to Normal (or Strategic) Form*

A strategy for a player, as we have noted, specifies one way in which that player might combine the actions available at its different moves and hence one way for it to play the game.[27] For Player *I* that specification is simple. It has but a single move, at which there are but two actions it might choose. So a complete list of Player *I*'s strategies consists simply of its choices (*F* or *P*). For Player *R*, on the other hand, the matter is a little more complex. Since a strategy is a *complete* specification of one way in which a player might play the entire game, it must prescribe a choice at *every* move that player might be called upon to make.[28] Here, there are two situations in which Player *R* might be called upon to act, and a strategy must specify what she will do at each. In other words, a strategy for the Resident must specify whether she will go to *c*ourt or *s*ettle, and must do so *separately* for the eventuality that the Insurer offers either *P* or *F*. There are thus four possible combinations, and hence four strategies available to Player *R*. For example, the combination (*c, s'*) denotes the strategy in which *R* goes to *c*ourt if *I* offers *P*artial compensation, but *s*ettles if *I* offers *F*.

Note now that Game One has a finite number of players, each of whom has a finite number of strategies from which to choose. Consequently, there exists a finite number of ways in which their strategies may be combined to form a strategy profile for the entire game. Observe also that, even though each of Player *R*'s strategies specifies what she will do for *either* choice by Player *I*, each of Player *I*'s strategies is to do just *one* of those two things. Hence, each strategy profile corresponds uniquely to a path through the game tree leading to just one of its four terminal nodes. For exam-

26. In the extensive form, this property generally obtains whenever each player, at each move, knows exactly where he is in the game tree. As a technical matter it is depicted by the fact that each decision point contains exactly one choice node and is therefore called a "singleton information set." *See, e.g.*, GIBBONS, *supra* note 12, at 115-22; *see supra* note 19; *infra* text accompanying notes 58-59.

27. Strictly speaking, a specification of one way to play the game is a "pure" strategy. A "mixed" strategy, in contrast, involves play that is randomized among more than one pure strategy, according to some probabilistic rule. *See, e.g.*, GIBBONS, *supra* note 12, at 30-31.

28. *See supra* text accompanying note 21. We will say more about just why in a moment.

ple, if *I*'s strategy is *F* and the Resident's strategy is (*c*, *s*') — she takes an offer of *P*artial compensation to *c*ourt but *s*ettles if offered *F* — the play of the game will be *F-s*'. The *strategy profile* [*F*, (*c*, *s*')] leads uniquely down the path along which the Insurer offers *F* and *R* plays *s*' and to payoffs of (-13, 13). More generally, as long as there are no "chance moves" reflecting uncertainty, every strategy profile leads to one, and only one, terminal node of the game tree. So the information captured by the extensive representation of Figure I-A may also be expressed by associating with each strategy profile the payoffs at the terminal node of the extensive form to which it corresponds. That is characteristic of the extensive form, *however* complicated it might become,[29] of *every* finite game (not entailing chance moves) in which the players have discrete and finite strategy sets.[30] When, moreover, as in Game One, there are only two players both of whom have discrete and finite strategy sets, the extensive representation may be reduced to matrix form. That is the "normal form" of the same game.[31]

In our rudimentary example, the transformation from extensive to normal form is also relatively simple. Player *I*'s entire strategy set — offer *P*artial or *F*ull compensation — is listed to the left of the entries in the matrix, each possibility corresponding to one row. Player *R*'s strategy set — all four possible combinations of how she might respond, respectively, to offers of *F* or *P* — is listed above the entries in the matrix, with each strategy corresponding to a single column. So the normal-form representation of a two-player game is

29. It can rapidly become quite complicated. *See, e.g.*, Thomas C. Schelling, *What is Game Theory?*, *in* CONTEMPORARY POLITICAL ANALYSIS 212, 224-32 (James C. Charlesworth ed., 1967), *reprinted in* THOMAS C. SCHELLING, CHOICE AND CONSEQUENCE 213, 226-34 (1984). A dramatic example, described in Harold Kuhn, *Introduction to Montmort, in* PRECURSORS IN MATHEMATICAL ECONOMICS: AN ANTHOLOGY — (W.J. Baumol & S. Goldfield eds., 1968), *reprinted in* SCARCE WORKS IN POLITICAL ECONOMY No. 19, is a 1713 analysis by James Waldegrave of a two-person card game in which each player was dealt a single card, after which each player could exchange it for another card just once. The normal form of the game is a square matrix with $2^{13}$ rows and $2^{13}$ columns, or a total of $2^{26}$ pure strategy profiles. Waldegrave's analysis was the first of a noncooperative game, the first example of a Nash equilibrium, and the first example of a unique Nash equilibrium in "mixed" strategies. *Id.*

30. That characteristic is described formally in LUCE & RAIFFA, *supra* note 21, at 51-53; van Damme, *supra* note 21, at 139. In DAVID M. KREPS, A COURSE IN MICROECONOMIC THEORY 363, 365-66 (1990), it suggestively is called an "arboresence." But it is easier just to think about the nearest tree. Start with any leaf: there is a unique path connecting it to the ground.

31. The normal form, in fact, is more general. When the extensive form involves chance moves reflecting uncertainty, each strategy profile results in the various terminal nodes being reached with known probabilities, and what is reported as the entry in the normal form corresponding to a given strategy profile is the "expected payoff," *see infra* note 101, to each player from the lottery induced by that strategy profile. In addition, the normal form is confined neither to games with two players nor to those with finite strategy sets, *see, e.g.*, GIBBONS, *supra* note 12, at 3-4, although its simple visual representation as a matrix usually is.

a matrix whose dimensions correspond to the dimensions of their respective strategy sets — in this particular instance two by four. The entries in each cell are the payoffs to each player for each strategy profile, as given by the payoffs at the terminal node of the extensive form to which that strategy profile uniquely corresponds.[32] In the extensive representation of Figure I-A, there are, as we already noted, four possible *sequences* of moves by *I* and *R*. In the normal-form matrix representation of Figure I-B, those four possible sequences correspond to eight possible strategy profiles of the game.[33] More generally, to any extensive form of any noncooperative game, there corresponds a unique normal form.[34] A virtue of the matrix representation in games with two players is that it provides a simple means of visual verification, separately for each player, of how each of their pure[35] strategies will fare.

FIGURE I-B
NORMAL FORM OF GAME ONE

| Player I's Strategy | Player R's Strategy: (s, s') | (s, c') | (c, s') | (c, c') |
|---|---|---|---|---|
| *P* | (-10, 10)* | (-10, 10)** | (-17, 9) | (-17, 9) |
| *F* | (-13, 13) | (-17, 9) | (-13, 13)*** | (-17, 9) |

*Payoffs: (I, R)*

In writing Game One, in both extensive and normal form, it is assumed that each player knows the structure of the game, including the payoffs to each player for each strategy profile of the game.[36] It is also assumed that each player knows that the other players know it, that each knows that the others know that they know it, and to which is usually added "and so on *ad infinitum*."[37]

32. As at the terminal nodes of the extensive form depicted in Figure I-A, the entries (*I*, *R*) in the cells of Figure I-B give the payoffs to (respectively) Player I and Player R.

33. Since each of the Resident's four strategies specifies what she will do for each *possible choice* by the Insurer, each can form a constituent part of two different strategy profiles, leading to one of two different terminal nodes, depending on the Insurer's *actual choice*.

34. The normal form may, however, correspond to several different extensive representations. *See, e.g.*, DAVID M. KREPS, GAME THEORY AND ECONOMIC MODELLING 24-25 (1990).

35. *See supra* note 27.

36. *See, e.g.*, LUCE & RAIFFA, *supra* note 21, at 49.

37. *See, e.g.*, Robert J. Aumann, *Agreeing to Disagree*, 4 ANNALS OF STAT. 1236 (1976); John Geanakoplos, *Common Knowledge*, J. ECON. PERSP., Fall 1992, at 53; *see also* DREW FUDENBERG & JEAN TIROLE, GAME THEORY 4 (1991); GIBBONS, *supra* note 12, at 7.

This infinitely recursive awareness — sometimes called "ultrarationality"[38] — is usually denoted by saying that the structure of the game is "common knowledge." When, as in Game One, what is common knowledge is not subject to uncertainty about the nature of the other players or their payoffs, the "information structure" of the game is said to be "complete." As we already have pointed out, a game in which each player at each move also knows everything that has previously *happened* in the game is called a game of perfect information. Game One, then, is a game of complete and perfect information.

### B. *Solution Concepts and Solutions*

What we are most interested in, however, is how we might reasonably expect the Insurer and the Resident to behave, and how the "game" represented by Figure I is likely to be "played." It is to *how we should go about fashioning answers to that question* — to determining *what* we should reasonably regard as a (or the) "solution" to a game — that the most basic research in game theory is devoted. The fundamental postulate that underlies the inquiry is that each player in the game is "rational," in the sense that his objective is to maximize his payoff, and that it is common knowledge that every other player has a corresponding goal.[39] In the context of the normal form, which lists *every possible* strategy profile of the game, the search for a "solution" amounts to winnowing that list by eliminating strategy profiles that rational players are unlikely, or less likely, to play. A "solution concept" is simply a criterion that is more or less useful for that task.

#### 1. *Rational Players and Strictly Dominated Strategies*

Some games have strategies that a player would *never* rationally play. Game One is such a game. Keep in mind that Player *R*'s payoff is the second entry in each cell in Figure I-B, and look at the rightmost column of the matrix, in which *R*'s strategy is to take *either* offer by Player *I* to *c*ourt — i.e., the strategy (*c, c*'). Since, by the rules of the game, she always wins but must always pay legal fees, *R*'s payoff is always 9. Compare that to the leftmost column, in which *R*'s strategy (*s, s*') is to *s*ettle for any offer she observes. Her payoff will be 10 or 13, depending on whether the Insurer offers *P* or *F*. *Irrespective* of what the Insurer might choose to do, then, the Resident can do strictly better by always *s*ettling than by always going to *c*ourt. That property is described by saying that, for

38. *See* Howard Raiffa, *Game Theory at the University of Michigan, 1948-1952, in* Toward a History of Game Theory 165, 175 (E. Roy Weintraub ed., 1992).

39. *See, e.g.*, Luce & Raiffa, *supra* note 21, at 50; Gibbons, *supra* note 12, at 7.

Player *R*, the strategy (*c*, *c*') is "strictly dominated" by the strategy (*s*, *s*'). Player *I* can therefore eliminate the strategy (*c*, *c*') as one that Player *R* might play, and thus immediately rule out two of the eight strategy profiles as possible solutions to the game.

There are games in which *each* player may have strictly dominated strategies. Occasionally the elimination of all the dominated strategies of a player leaves that player with just one remaining strategy — denoted his "strictly dominant" strategy. If *every* player has a dominant strategy, there is a best way for every player to proceed, irrespective of what the other players do. When that does occur, the "elimination of strictly dominated strategies" defines the only strategies rational players would play, and identifies the resulting strategy profile as the solution to the game.[40] But many games of interest cannot be solved that way, and Game One is a case in point. *Only* the strategy (*c*, *c*') is ruled out by elimination of dominated strategies, still leaving us with six strategy profiles as possible solutions to the game. To make further progress other solution concepts are required.

### 2. *Nash Equilibrium*

We proceed then, to the best-known and most fundamental solution concept, the "Nash equilibrium," one of John Nash's several founding contributions to the theory of games.[41] Turn to the northwest cell of Figure I-B, containing the payoff "(-10, 10)" and denoted by "*." That cell corresponds to the strategy profile [*P*, (*s*, *s*')], in which the Insurer offers *P*artial compensation, and the Resident's strategy is to *s*ettle whether the Insurer offers *P* or *F*. Keep in mind that the Insurer's payoff is the *first* of the two numbers in the cell. Fix Player *R*'s strategy at (*s*, *s*') — *that is, restrict your attention to the first column* of the matrix — and ask whether Player *I* can do better than play *P*. It can't. Its only alternative is *F*, in which event, by paying 13 rather than 10 to the Resident, its payoff declines to –13. Now fix *I*'s strategy at *P* — restrict your attention to the first *row* — and observe that the Resident can *also* do no better than play (*s*, *s*'). Given *I*'s having offered *P*, *her* payoff changes only if she chooses a strategy — (*c*, *c*') or (*c*, *s*') — in which she takes a *P*artial offer to *c*ourt. If she does, however, her recovery of 13 will be reduced by litigation costs of 4, and she will end up with 9, less than if she had settled for the *P*artial offer. Given that *I* chooses *P*, *R* can do no better than by playing (*s*, *s*'); given that *R*

40. The "Prisoner's Dilemma" is one such game. *See infra* note 65 and accompanying text. Sometimes a strategy that is not strictly dominated will *become* dominated *after* the elimination of a dominated strategy of some other player. That is called the "*iterated* elimination of strictly dominated strategies." *See, e.g.*, GIBBONS, *supra* note 12, at 6-7.

41. Nash, *Games, supra* note 2, at 289-95; Nash, *N-Person Games, supra* note 2, at 48-49.

plays (*s, s'*), *I* does best by choosing *P*. That, by definition, is a Nash equilibrium. It is the tie that binds contemporary noncooperative game theory.

More generally, a (pure strategy) Nash equilibrium is a strategy profile with the property that, *given* the strategies of all the other players, no player can do strictly better by unilaterally choosing a different strategy than he has.[42] In the shorthand commonly employed, if the strategy choice of *each* player in the game is a "best response" to the strategies of *all* the others, that strategy profile is a Nash equilibrium of the game. It is often regarded as a minimal requirement of equilibrium in a noncooperative game, since, if a strategy profile were *not* a Nash equilibrium, at least one player could *unilaterally* do better by altering his move. There is at least one Nash equilibrium of *every* finite noncooperative game.[43]

Many games have more. That property is exhibited by Game One. The other cells denoted by asterisks are *also* Nash equilibria of the game. One — the profile [*P*, (*s, c'*)] (denoted by "**"), in which *R*'s strategy is to take an offer of *F*ull compensation to *c*ourt — differs from that already identified only in terms of the payoff to Player *I* if it should deviate and offer *F* instead; but *I*'s best response is still to offer *P*.[44] The third — [*F*, (*c, s'*)] (denoted by "***"), in which the Resident *s*ettles for *F* but takes *P* to *c*ourt, while Player *I* offers *F* — is a more problematic equilibrium, to which we shall return.[45] For the moment, however, note three things. First, use of the Nash equilibrium has ruled out *five* of eight possible strategy profiles as solutions to Game One, as contrasted with the dominance argument, which, of those five profiles, eliminated only two.[46] In that sense, the Nash equilibrium is a more powerful solution concept. What follows from the fact that the Nash equilibrium has ruled out only five of eight strategy profiles,

42. *See, e.g.*, GIBBONS, *supra* note 12, at 8-9; KREPS, *supra* note 34, at 28.

43. *See* Nash, *N-Person Games*, *supra* note 2, at 48. What Nash actually proved was that every finite has at least one Nash equilibrium, although it may involve mixed strategies. *See supra* note 27. By "finite" we mean that the game has a finite number of players, each with a finite strategy set. *See, e.g.*, GIBBONS, *supra* note 12, at 45-47.

44. Each Nash equilibrium identified in the normal form can also be found in the extensive form, as can be seen from Figure I-A. To take as an example the Nash equilibrium denoted by "*," given the Resident's strategy of settling for either *F* or *P*, a comparison of the payoffs to the Insurer at the first and third terminal nodes shows that the Insurer does best to offer *P*. Given that choice, the Resident can do no better by any strategy combination other than *(s, s')* — though she can do as well by playing *(s, c')*. In general, we will, except where otherwise necessary, identify Nash equilibria in the normal form of the games we use as illustrations.

45. *See infra* text accompanying notes 48-50.

46. If each player has a strictly dominant strategy for any noncooperative game, that strategy profile must obviously form a Nash equilibrium of the game. More generally, every Nash equilibrium strategy profile will survive the iterated elimination of strictly dominated strategies. *See supra* note 40; GIBBONS, *supra* note 12, at 12.

however, is that it may not be powerful *enough.* That unfortunately pervasive fact undermines the predictive power of Nash equilibrium solution(s) to a game. The set of Nash equilibria in our example implies that the dispute will always be settled, but offers no prediction about whether *F*ull or *P*artial compensation will be paid. More generally, multiple equilibria can blunt, often seriously, the extent to which theory offers testable restrictions on how people actually do behave.

3. *Incredible Threats and Subgame Perfection (Reinhart Selten)*

The problem of multiple equilibria is among the most serious afflictions of game theory. It has touched off intensive efforts to "refine" the notion of a Nash equilibrium into more powerful solution concepts, capable of eliminating "less plausible" elements from a set of equilibria. The most widely accepted of these refinements is the subgame perfect Nash equilibrium. Subgame perfection has the happy property of eliminating all but a single strategy profile as a solution to our illustrative game. It yields a *unique* solution to Game One.

For reasons that eventually will become apparent, it is with the strategic representation of Figure I-B to which we first turn. In two of its three Nash equilibria (those denoted "*" and "**"), *R*'s strategy is to *s*ettle whenever *I* offers *P,* and *I*'s strategy is to offer *P.* The intuition for these equilibria is straightforward. Given *R*'s strategy of settling for *P, I* does best to offer *P.* Given *I*'s strategy of offering *P, R* does best to *s*ettle, since by going to *c*ourt, any additional compensation is more than eaten up by legal fees. It is the third Nash equilibrium (denoted "***") on which we wish to dwell. There *R* threatens to go to *c*ourt if *I* offers *P,* and *I* responds by offering *F.* Given *R*'s threat of going to *c*ourt for less, offering *F* is the only route by which *I* can avoid the legal fees; given that strategy choice by *I, R* does as well to threaten litigation as anything else. A key difficulty with the *[F, (c, s')]* equilibrium cannot be detected in the normal form (Figure I-B).[47]

47. As we explain immediately below, the *[F, (c, s')]* strategy profile is not "subgame perfect," a defect that can be identified only in the extensive form but which renders it unlikely that the strategy profile actually will be played. There is a distinct reason why that profile might not be played. It requires *R*'s playing the strategy *(c, s')* when she has an alternative *(s, s')* that provides her at least as high a payoff no matter what Player *I* does and a strictly higher payoff if Player *I* chooses *P.* For that reason the strategy *(c, s')* is said to be "weakly dominated," and the Nash equilibrium profile *[F, (c, s')]* to be "supported by a weakly dominated strategy." The latter is a defect that can be detected in either the normal or the extensive form. For an example of an equilibrium profile that is supported by a weakly dominated strategy but is nevertheless "subgame perfect," see the equilibrium profile denoted (***) of Game Two below. *See infra* notes 62-69 and accompanying text. For a useful discussion of what "defects" can be identified in both the normal and the extensive form and which only in the more detailed extensive form, see van Damme, *supra* note 21, at 143.

The problem is that *R*'s "threat" is not "credible," as can readily be seen in the extensive representation of Figure I-A.[48] Note, first, that *R*'s threat is "off the equilibrium path" of play: she threatens to litigate a *P*artial offer, while *I* offers *F*ull compensation, so in the [*F*, (*c*, *s*')] equilibrium *R* is *never called upon* to carry out the threat. But if Player *I were* to offer only *P*artial compensation, *R* in fact would *not* do best by acting on the threat: because of legal fees, the payoff from taking a *P*artial offer to *c*ourt would be less than the payoff from settling instead. Assuming (as we do) that *R* is rational, she would not, if actually presented with the opportunity, carry out the threat, something that, by the assumption of common knowledge,[49] Player *I* can see as plainly as can we.

But what, more generally, defines an incredible threat? It begins with the notion of a (proper) subgame, defined loosely as a subset of the game tree, beginning at a choice node (*other than* the initial node), that forms a self-contained game from that point forward in the tree.[50] In isolation, a subgame has the same strategic properties as any other game. So it seems natural to insist that conduct in every subgame comport with the postulate of rationality to the same extent as in any other game. That, in turn, implies that, given the strategies of the other players in every subgame, each player should play his best response. A strategy entails an incredible threat when it calls for conduct that does not induce a Nash equilibrium *in some subgame.* Such conduct is not rational in the subgame, since by definition the threat (if carried out) would not be the player's best response.

The refinement, due to Reinhart Selten,[51] that each player's conduct form a Nash equilibrium, not only for the game in its entirety, *but also* in every proper subgame — that it be "subgame perfect" — effectively rules out equilibria of games of perfect information that rest on incredible threats. In Game One, the sequence of moves following *I*'s choice of *P* forms a proper subgame. Subgame perfection then requires that, in *both* that subgame *and* the game as a whole, *R* choose her "best response," and that response is to *s*ettle. Consequently the Nash equilibrium of the *original* game in which *R*'s strategy is (*c*, *s*') — she *s*ettles if offered *F*ull

48. On threats generally, the best introduction is perhaps still to be found in THOMAS C. SCHELLING, THE STRATEGY OF CONFLICT 35-52 (1980).

49. *See supra* text accompanying notes 37-38.

50. A "subgame" is a subset of the game tree that begins at a "singleton" information set — that is, an information set that contains a single choice node. *See supra* note 26. The subset, to be a subgame, must (1) include the entire balance of the game from that information set to all terminal nodes that follow it and (2) contain all information sets that follow it in their entirety. *See, e.g.*, GIBBONS, *supra* note 12, at 122-24. The adjective "proper" simply means a "subgame" *other than* the entire game itself.

51. *See* Selten, *Spieltheoretische, supra* note 2.

compensation but threatens to go to court if she is not — is *not* a Nash equilibrium in the subgame and is not a subgame perfect equilibrium. The same is true of the [*P*, (*s*, *c*')] Nash equilibrium (denoted "**") of the original game, in which *R* threatens to litigate an offer of *F*ull (but not *P*artial) compensation; going to *c*ourt when offered *F*ull compensation self-evidently is not her best response.

In contrast, the equilibrium ("*") in which *R*'s strategy is to settle if offered either *F* or *P and I*'s strategy is to offer *P is* a Nash equilibrium in the game and in every proper subgame. It is the *only* Nash equilibrium of Game One that is. Now, finally, we have arrived at a solution — a unique subgame perfect Nash equilibrium — to Game One. We suspect, moreover, that the implied prediction comports with your intuition: The Insurer's equilibrium offer is just enough to deter the resident from going to *c*ourt, and the Resident's (possibly reluctant) equilibrium strategy is to *s*ettle.[52]

Is this happy outcome — Game One has a subgame perfect equilibrium (in pure strategies) *and* the equilibrium is unique — more than just a fluke? Just how powerful *is* the refinement of subgame perfection? In the class of games — extensive games of perfect information — to which our game belongs, it works quite wonderful results. At minimum, *every* game of perfect information having different payoffs at each terminal node has a unique, pure strategy subgame perfect equilibrium.[53]

### C. *Games of Imperfect Information and the Limits of Subgame Perfection*

Subgame perfection is, however, not the Holy Grail. While especially effective at solving games of complete and perfect information, it does nothing to rule out multiple equilibria — including implausible equilibria — in many other games. That has been a major source of difficulty for noncooperative game theory, a difficulty reflected in what ultimately strikes us as most problematic about *GTL*. So we close by turning to games of "imperfect information," and to a simple illustration of the difficulties such games can entail.

52. It also would correspond with intuition that, if the litigation cost was only 2, the unique subgame perfect equilibrium strategy profile would be for the Resident to settle for a *F*ull offer but take a *P*artial offer to court, and for the Insurer to offer *F*.

53. *See, e.g.*, van Damme, *supra* note 21, at 139, 141. The result is perhaps too wonderful, in the sense that some games of perfect information, including several well-known examples involving repeated but finite interactions, have unique subgame perfect equilibria that do not seem to be the evident way to play the game. *See, e.g.*, pp. 163-65; KREPS, *supra* note 34, at 77-82; Richard D. McKelvey & Thomas R. Palfrey, *An Experimental Study of the Centipede Game*, 60 ECONOMETRICA 803 (1992); Robert W. Rosenthal, *Games of Perfect Information, Predatory Pricing and the Chain-Store Paradox*, 25 J. ECON. THEORY 92 (1981).

In a game of imperfect information, at least one player must make at least one move *without* having observed what some other player has done.[54] We can illustrate how that feature of a game is formalized using a second game ("Game Two"), obtained by a simple modification to Game One. Suppose that, in lieu of cash as Partial compensation, the Insurer offers to repair the physical damage using a contractor of its choosing and to pay the Resident $4 in cash as well. That offer is worth $11 to the Resident, *if* the Insurer selects the same sort of "High quality" contractor to carry out the repairs (at a cost of $7) that the Resident would have hired herself. It introduces, however, the possibility that the Insurer might try to save money by using a "*L*ower" quality contractor, in which event the offer will be worth less.

Our objectives here are illustrative and limited, so we single out a rather trivial alternative to the *H*igh quality choice.[55] Suppose that the selection of a modestly *L*ower quality contractor will cost the Insurer only $6, that the Resident cannot distinguish between *H*igh and *L*ow quality contractors ex ante, and cannot cheaply verify the quality of the work ex post.[56] Then, when the Insurer offers *P*artial compensation, consisting of $4 cash and the repairs, it may *either* be using a *H*igh-quality contractor (*P-H*), at a total cost of $11 to the Insurer and worth that to the Resident if the Resident accepts; or using a *L*ow quality contractor (*P-L*), worth at most $10 to the Resident if she accepts. In Game Two Player *I* has three moves, *P-L, P-H* and *F* — not just two as in Game One — each of which we depict in extensive form in Figure II-A below. For each possible choice by the Insurer, the Resident again must choose either to *s*ettle or go to *c*ourt. The payoffs are (-10, 10) if the Resident *s*ettles for the *P-L* offer; (-11, 11) if she settles for the *P-H* offer; and (as before) (-17, 9) if in either event she goes to *c*ourt.[57]

In Game Two, however, the Resident cannot distinguish among *all three* of the Insurer's moves. She *can* observe whether the Insurer offers *F*ull or *P*artial compensation. But when she is confronted by a *P*artial offer, she *cannot* observe whether it involves *H*igh or *L*ow quality work. That "imperfection" in Player *R*'s information is captured by combining her choice nodes following the *P-L* and *P-H* moves into one "information set," defined by the property that the Resident does not know *which* of the two choice nodes

54. *See, e.g.*, Gibbons, *supra* note 12, at 118-22.

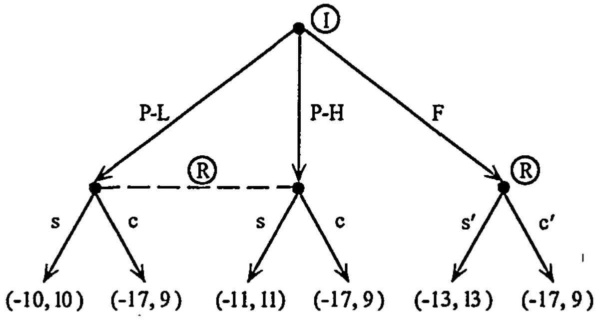
55. Our reasons for this choice will become apparent. *See infra* text accompanying notes 67-69 and 104-05.

56. The lower quality work might, for example, affect longevity, and might be more costly to the Resident than the $1 difference to verify on completion of the work.

57. The payoffs when the Insurer offers *F*ull compensation are identical to the corresponding payoffs in Game One. *See supra* Figure I-B.

she is actually at,[58] and depicted by connecting those nodes (as in Figure II-A) by a dotted line.

FIGURE II-A
EXTENSIVE FORM OF GAME TWO




*Payoffs: (I, R)*

More generally, an information set is used formally to specify what each player can observe when it is that player's turn to move. When all preceding actions are observable — as when Player *I* offers *F*ull compensation in Game Two — the Resident's information set reduces to the *single* choice node (called a "singleton" information set) to which the immediately preceding action leads. The inclusion, in contrast, of both the *P-L* and *P-H* offers in a second information set specifies both that the Insurer can make different Partial offers *and* that the Resident cannot distinguish between the two. That is how a game of imperfect information is described in extensive form.

The net effect is that although Player *I* has three possible moves, there are still only two possibilities for which each of Player *R*'s strategies must specify what she will do. In Game Two, she has, accordingly, the same four possible strategies as in Game One. The normal form of Game Two is thus a three-by-four matrix.

58. To satisfy this requirement, all choice nodes in any information set must be assigned to the same player and must offer that player the same possible actions at each choice node that it contains. *See, e.g.*, GIBBONS, *supra* note 12, at 119-20; KREPS, *supra* note 30, at 367-69.

FIGURE II-B
NORMAL FORM OF GAME TWO

Player R's Strategy

| Player I's Strategy | (s, s') | (s, c') | (c, s') | (c, c') |
|---|---|---|---|---|
| *P-L* | (-10, 10)* | (-10, 10)** | (-17, 9) | (-17, 9) |
| *P-H* | (-11, 11) | (-11, 11) | (-17, 9) | (-17, 9) |
| *F* | (-13, 13) | (-17, 9) | (-13, 13)*** | (-17, 9) |

*Payoffs: (I, R)*

Given the payoffs to the *P-H* and *P-L* offers in Game Two, no new Nash equilibrium strategy profiles have been introduced.[59] As indicated by the asterisks in Figure II-B, the same three strategy profiles remain Nash equilibria of the game.[60] As in Game One, moreover, the strategy profile [*P-L*, (*s*, *s*')] is a subgame perfect equilibrium; conversely, also as in Game One, the strategy profile [*P-L*, (*s*, *c*')] — in which the Resident (implausibly) threatens to litigate an offer of *F*ull compensation — is a Nash but not a subgame perfect equilibrium.[61]

Game Two, however, in contrast with Game One, does *not* have a unique subgame perfect equilibrium. The problem, again, is with the [*F*, (*c*, *s*')] equilibrium, in which the Resident threatens to litigate either *P*artial offer and the Insurer offers *F*. That corresponds to the suspect equilibrium that did not satisfy the requirement of subgame perfection and was eliminated as a solution to Game One.[62] In Game Two the Resident's threat to litigate either *P*artial offer *remains* implausible. But, in contrast with Game One, subgame perfection cannot be used to eliminate the Nash equilibrium supported by that threat. As a practical matter, a "game" that began with the *P*artial offers in Game Two would not have a unique starting move. By the same token, the portion of the game tree in Figure II-A beginning with those moves is not, as a technical mat-

59. At an intuitive level, the reason should be clear. In the face of *either* *P*artial offer, the Resident does best to settle; so the Insurer *always* does better by offering *P-L* than *P-H*. Hence, *P-H* — the newly introduced middle row to the normal form matrix of Figure II-A — can *never* be part of a Nash equilibrium strategy profile of Game Two.

60. *Compare supra* Figure I-B. The payoffs to the strategy profiles in Figure II-B in which the Insurer makes the *P-L* offer correspond to those in Figure I-B in which the Insurer simply offers *P*.

61. *See supra* text accompanying notes 51-52; Figure I-B.

62. *See supra* text accompanying note 52.

ter, a (proper) subgame of Game Two.[63] In all events, however implausible her threat to litigate either *P*artial offer, the [*F*, (*c*, *s*')] profile remains a "subgame perfect" equilibrium of Game Two.[64] So we are left with multiple equilibria in this simple imperfect information game and with no equilibrium prediction about whether *F*ull or *P*artial compensation will be paid.

Multiple equilibria are not inevitable in games of imperfect information. For example, simultaneous-move games are games of imperfect information, and the best-known of them, the "Prisoner's Dilemma," has a unique solution.[65] At the same time, many such games do have multiple equilibria, none of them inherently implausible or, indeed, superior to any of the others.[66]

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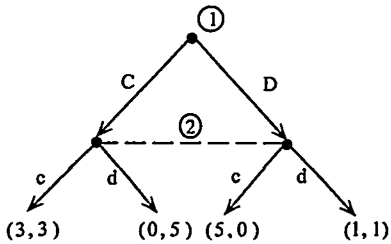
63. It does not, in particular, satisfy the requirement that a subgame begin at a "singleton" information set. *See supra* note 50.

64. *But see infra* notes 68–69, 104 and accompanying text.

65. A sequential, two-person game in which the second player cannot observe the action of the first is conceptually equivalent to a game in which the two move simultaneously. *See, e.g.*, Kreps, *supra* note 34, at 16-18; Kreps, *supra* note 30, at 371-72. In the Prisoner's Dilemma, each player has two choices, "cooperate" or "defect." The extensive form is given in Figure III-A.

Figure III-A




*Payoffs: (1,2)*

Since each player has but a single move with just two choices, the normal form is a two-by-two matrix.

Figure III-B
The Prisoner's Dilemma

| | | Player 2: *c* | Player 2: *d* |
|---|---|---|---|
| Player 1 | *C* | (3, 3) | (0, 5) |
| Player 1 | *D* | (5, 0) | (1, 1) |

*Payoffs: (1, 2)*

The reader easily can verify that, although the jointly optimal strategy is to cooperate (*C*, *c*), defecting is a strictly dominant strategy for each player individually, and (*D*, *d*) is the unique Nash equilibrium of the game.

66. This is true, for example, of "coordination games," the usual example of which is the problem of where each of two friends, having agreed to meet in New York City but both

The problem of multiple equilibria is generally quite serious, and the trivial introduction of imperfect information into Game Two has brought us to the edge of a morass.[67] In Game Two, however, there is a way out that is not especially difficult to grasp. Note that, regardless of *which* *P*artial offer the Resident thinks the Insurer has actually made, she *always* does better to *s*ettle. If, then, she acts rationally when she observes a partial offer,[68] it seems plausible that she *will* *s*ettle. Hence, while technically subgame perfect, it is implausible that the [*F*, (*c*, *s*')] strategy profile is an equilibrium solution to Game Two. One refinement that formalizes this more stringent notion of plausibility is the "perfect Bayesian equilibrium."[69] In the present context it rules out solutions involving irrational conduct by the Resident at the *P*artial offer information set, and produces a unique solution to Game Two. But the present context was constructed so that the perfect Bayesian equilibrium not only eliminated an implausible equilibrium but also could be transparently applied. Matters are not always that simple, a point to which we will return.[70]

First, however, it is time to turn to *GTL*.

## II. Game Theory and the Law

*Game Theory and the Law* is in some respects structured along the lines of a conventional game theory text. We would group its eight substantive chapters as follows. Chapters One, Two, and Five deal with elementary topics, including games in normal and extensive form, Nash and subgame perfect equilibria (pp. 6-78), and the additional insights obtained from modeling the repeated play of simple games (pp. 159-87). Chapters Three and Four deal with more advanced matters, species of games of imperfect information that can exhibit a multiplicity of subgame perfect equilibria, for which more elaborate solution concepts are required. Chapter Six is organized thematically around the subject of "collective action" problems, while Chapters Seven to Eight turn to bargaining, under both perfect and imperfect information.

having forgotten exactly where, ought to go. Each going to *any* same location in New York City is a Nash equilibrium. *See* pp. 38-40; Schelling, *supra* note 48, at 54-58.

67. *See infra* text accompanying notes 94-95.

68. This requirement is usually called "sequential rationality." *See, e.g.*, Kreps, *supra* note 30, at 427-29. In effect, it generalizes to every information set — whether or not the beginning of a subgame — the same kind of rationality requirement that subgame perfection imposes on every proper subgame of a game.

69. *See, e.g.*, Fudenberg & Tirole, *supra* note 37, at 321-26; Kreps, *supra* note 30, at 429-31. A closely related equilibrium refinement is the "sequential equilibrium." *See* David M. Kreps & Robert Wilson, *Sequential Equilibria*, 50 Econometrica 863 (1982).

70. *See infra* note 104 and accompanying text.

That would be an agenda of more than ordinary scope for any introduction to game theory, but this is an atypical introductory account. *GTL*'s principal objective is to survey the ways that game-theoretic models can shed light on legal rules. Its ambitions extend beyond examining strategic interaction in the shadow of the law, to studying the implications for the structure of the law of strategic interaction, especially in the presence of asymmetric information. So the game-theoretic models function logically as a backdrop against which to explore how strategic behavior might influence the choice of legal rules. *GTL* does, of course, instruct the reader along the way. But the instruction, while essential, is in important respects subordinate to the larger agenda, which dictates the range of topics *GTL* takes on, and influences not only the way those topics are assembled into chapters but the order in which the chapters are arranged.

*GTL* thus differs from conventional texts in ways that shape its account of game theory itself. Many chapters are organized around legal themes rather than by game-theoretic topic, often juxtaposing problems that require quite different analytic methods.[71] Perhaps most importantly, *GTL* departs from most game theory texts in the order in which topics are introduced. Texts devoted *to* game theory are about how to *do* game theory, and generally adopt a line of exposition that takes the student progressively from elementary to more difficult matters, adding at each stage to the foundation for what is yet to come. Driven by its organization around legal themes, *GTL* departs from that kind of progressive development, beginning very early in the book. In Chapters Three and Four, in particular, it embarks on what proves to be an extensive exploration of matters that are both intricate and problematic, consideration of which most game theory books more judiciously postpone.

The net effect is that part of *GTL* — Chapters One, Two, Five, and Seven — is essentially an introduction to the basics of game theory, more or less along conventional lines, fashioned expressly for lawyers. The balance — Chapters Three, Four, Six, and Eight — is a selection of more advanced applications of game theory and information economics to the law; and, at least as far as the game-theoretic materials are concerned, proceeds in an atypical and far less systematic way. We take up these two very different aspects of *GTL* in turn.

### A. *The Rudiments*

Chapters One ("Simultaneous Decisionmaking and the Normal Form Game") and Two ("Dynamic Interaction and the Extensive

71. We have in mind, particularly, chapters 3 and 6.

Form Game") of *GTL* cover in substantially more detail the basic aspects of game theory that we outlined in Part I. Chapter One deals with games in normal form, and solutions based on dominance arguments as well as Nash equilibria, while Chapter Two takes up subgame perfect equilibria. In these chapters as well as Chapter Five, *GTL* parallels closely conventional game theory texts.

The differences between *GTL* and game theory texts are evident, to be sure, from the very outset of Chapter One. It does not start by developing solution concepts using standard game theory paradigms. It begins, instead, with one of the first explicit, and by now classic, contributions of game theory to the law, the analysis of civil liability rules. That analysis, which originated with John Prather Brown,[72] establishes that a broad class of damage rules for tort liability can create incentives for both an injurer and a victim to exercise "appropriate" or "due" care.[73] *GTL* uses that framework to introduce the normal form game and solutions based on dominance, culminating with the Nash equilibrium and the insight that, under a quite general class of compensatory damage rules, it is a Nash equilibrium (even if not strictly dominant) for both parties to exercise cost-minimizing care.[74]

In its introductory development, *GTL* dwells on the way in which legal rules can influence the conduct of strategic actors. In the abstract, they can do so in one or more of at least three basic ways: (1) by altering the set of available strategies; (2) by altering the payoffs; or (3) by altering the information structure of the game. In its treatment of liability rules, for example, it emphasizes that the choice of legal rule operates by reallocating the payoffs to strategic interaction. *GTL* is also careful to emphasize that players can be expected to adopt equilibrium strategies only if each can rely on the rationality of the other. Recognizing that this may not always be a plausible assumption, *GTL* concludes by exploring other liability rules, including comparative negligence and rules in which a player who exercises due care is reimbursed for the costs of precaution by

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72. Brown, *supra* note 3; *see also* Peter A. Diamond, *Single Activity Accidents*, 3 J. LEGAL STUD. 107 (1974); Steven Shavell, *Strict Liability Versus Negligence*, 9 J. LEGAL STUD. 1 (1980). These explicit formulations built on foundations laid by Guido Calebresi and Richard Posner; *see, e.g.*, GUIDO CALEBRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS (1970); Guido Calebresi and Jon T. Hirschoff, *Toward a Test for Strict Liability in Torts*, 81 YALE L.J. 1055 (1972); Richard A. Posner, *A Theory of Negligence*, 1 J. LEGAL STUD. 29 (1972); Richard A. Posner, *Strict Liability: A Comment*, 2 J. LEGAL STUD. 205 (1973). A very accessible account, using the game-theoretic framework implicitly, can be found in SHAVELL, *supra* note 12.

73. "Due" care is defined as care that minimizes the sum of expected accident and accident prevention costs. *See* p. 13.

74. The class of damage rules that have this property includes strict liability with a defense of contributory negligence, negligence (with or without a defense of contributory negligence), and comparative negligence. *See, e.g.*, p. 24.

a player who does not, which make it strictly dominant for both injurer and victim to exercise due care.[75] That is, under the final class of liability rules that *GTL* surveys, it is optimal for both injurer and victim to take cost-minimizing care *irrespective* of what they expect the other players will do. Thus, informed by the different demands of different game-theoretic solution concepts, the introductory exposition concludes on a skeptical note regarding the degree of reliance on the rationality of one's adversaries so typically assumed in game-theoretic models (pp. 28-31).

Only then does *GTL* revert to a more conventional introduction, surveying the standard introductory game theory paradigms, including the Prisoner's Dilemma, "coordination games" with multiple Nash equilibria, and games with no "pure strategy" equilibria (pp. 37-43). In this, and the other, introductory chapters, *GTL* is careful in qualifying the results that it describes. It is generally sensitive to the problem of multiple equilibria (pp. 38-41). It is good also at modifying the standard stories whenever possible to frame its illustrations in legal settings. As with other chapters, Chapter One concludes with a set of bibliographic notes (pp. 46-49) for the reader interested in pursuing some topic in more detail.

There are, to be sure, questions that might reasonably be raised with respect to Chapter One. Of these, what strikes us as most problematic is *GTL*'s choice of what to emphasize in text. A bit more than half way through its introductory treatment of civil damage rules, *GTL* undertakes to prove — but only after assuring the reader that "we can set [the proof] out quickly" (p. 25) — that when injurer and victim strategically interact in the shadow of a compensatory damage rule, both exercising due care is a Nash equilibrium of the game. The ensuing proof, however, is rendered entirely in words, consumes several pages of text, and might well bring the average reader to a more-than-momentary halt. For one thing, the requisite assumptions are not explicitly collected; nor is it obvious on first reading that what is being proved is that "(Due care, Due care)" is *a* Nash equilibrium, or *the unique* Nash equilibrium, of the game. Wading through a lengthy verbal proof is work enough; the absence of a clear description of just *what* is being assumed, and what is being proved, makes matters genuinely tough.

Overall, however, Chapter One provides a fine introduction, clearly done, and well motivated by legal examples. A careful reader would, we think, come away with approximately the same basic grasp of the normal form, the standard game theory paradigms, and solutions to static games of complete information using

75. *See, e.g.*, Samuel A. Rea, Jr., *The Economics of Comparative Negligence*, 7 INTL. REV. LAW & ECON. 149 (1987); Daniel Orr, *The Superiority of Comparative Negligence: Another Vote*, 20 J. LEGAL STUD. 119 (1991).

dominance arguments and Nash equilibria, as he might obtain from a standard game theory text, together with an appreciation for both the usefulness and the limits of game-theoretic methods in illuminating the effects of legal rules.

Very much the same may be said of Chapters Two and Five which also hew relatively closely to the structure of a conventional game theory text. Incredible threats, subgame perfection, and the role in making threats credible of prior conduct that is both observable and costly to reverse (covered in Chapter Two) were originally developed partly in the context of entry deterrence and are of as much natural relevance to the structure of the antitrust laws as to industrial organization itself. The same can be said of tacit collusion over time, which can be modeled as the indefinitely repeated play of the prisoner's dilemma (as it is in Chapter Five).[76] So models of entry deterrence and tacit collusion, as well as of reputation and predation, are all part of the standard game theory exposition, and they are developed in *GTL*. As in Chapter One, *GTL* goes beyond the standard exposition and fashions examples of particular interest to lawyers. As with Chapter One, the careful reader will come away with an exposure very much like that obtained from an elementary text, together with an enriched diet of applications of relevance to the law. Here, too, the authors preserve a cautionary stance, pausing often to put the implications of the models in perspective.

Special mention should be made of Chapter Seven, where *GTL* takes up bargaining, a matter of particular importance both to economic theory and to law and economics. Its importance lies partly in the fact that, despite the central role of bargains and exchange in economic conduct and economic analysis, modeling the process of bilateral bargaining has proved to be extraordinarily elusive.[77] One of the more remarkable recent advances in game theory is due to Ariel Rubinstein, who showed that a two-person model of the bargaining process as a noncooperative game of perfect information, involving an indefinitely repeated set of alternating offers, has a

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76. When the prisoner's dilemma is played repeatedly, equilibrium solutions involving cooperation arise if players are sufficiently concerned about future payoffs. Although "defection" still generates an immediate gain against a cooperating opponent, that gain is outweighed by the anticipated loss in the benefits of future cooperation which that defection would induce. *See, e.g.*, pp. 167-72; Gibbons, *supra* note 12, at 88-97. This, we also note, is an area in which the problem of multiple equilibria is especially acute. *Id.*

77. *See, e.g.*, Kreps, *supra* note 34, at 91-97; Kreps, *supra* note 30, at 551-56. Another of John Nash's signal contributions was a model of bargaining. In lieu of specifying a particular bargaining process in extensive form, Nash formulated a set of axioms that any "reasonable" solution to the bargaining problem should satisfy. He then established that these axioms imply a unique solution. *See* Nash, *The Bargaining Problem*, *supra* note 2. For discussions of the relevance of attitudes towards bargaining to law and economics generally, see Avery Katz, *The Strategic Structure of Offer and Acceptance: Game Theory and the Law of Contract Formation*, 89 Mich. L. Rev. 215, 217-19 (1990); Ian Ayres, *supra* note 4, at 1315-17.

unique subgame perfect equilibrium.[78] Chapter Seven develops for the reader the Rubinstein bargaining model together with a series of interesting illustrations.[79] It is one of the nicer chapters in *GTL*. It also is, we might add, the locus of one of the more striking omissions from the book. One of the few unambiguous claims in *The Problem of Social Cost* is that, when unimpeded by transactions costs, economic actors will arrive at mutually advantageous bargains.[80] The matter is debated to this day.[81] *GTL* devotes two full chapters to bargaining without so much as mentioning its relevance to the work of Ronald Coase.

In sum, however, these chapters give an accessible elementary account, expressly tailored to an audience of lawyers, of game-theoretic work. If what one is looking for is a nontechnical introduction to basics of game theory and its use in legal settings, Chapters One, Two, Five, and Seven of *GTL* — in that order, we suggest — would be a useful place to start.

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78. *See* Ariel Rubinstein, *Perfect Equilibrium in a Bargaining Model,* 50 ECONOMETRICA 97 (1982). The alternating offer model of bargaining is originally due to INGOLF STÅHL, BARGAINING THEORY (1972). Rubinstein's pivotal contribution was to establish that a version of the model had a unique subgame perfect equilibrium. For a less technical introduction to the subject see, for example, KREPS, *supra* note 30, at 556-65. *See also* Ken Binmore et al., *The Nash Bargaining Solution in Economic Modelling,* 17 RAND J. ECON. 176 (1986); John Sutton, *Non-Cooperative Bargaining Theory: An Introduction,* 53 REV. ECON. STUD. 709 (1986). A more complete treatment of bargaining can be found in MARTIN J. OSBORNE & ARIEL RUBINSTEIN, BARGAINING AND MARKETS (1990).

79. In the simplest version of Rubinstein's model, in which the payoff to both players is zero in the absence of agreement, they (approximately) divide the surplus from cooperation. If, however, one of them has an outside option worth more than he would obtain from the equilibrium solution in the absence of the option, his equilibrium share is the value of his outside option. *GTL* focuses on this feature of the Rubinstein model in several of the examples it develops in chapter 7.

80. *See* Coase, *supra* note 5, at 3, 15.

81. The important early contributions include Robert Cooter, *The Cost of Coase,* 11 J. LEGAL STUD. 1 (1982); Donald H. Regan, *The Problem of Social Cost Revisited,* 15 J.L. & ECON. 427 (1972); *see also* Robert Cooter, Stephen Marks, & Robert Mnookin, *Bargaining in the Shadow of the Law: A Testable Model of Strategic Behavior,* 11 J. LEGAL STUD. 225 (1982); Joseph Farrell, *Information and the Coase Theorem,* J. ECON. PERSP., Fall 1987, at 113. Recent manifestations include Ian Ayres & Eric Talley, *Distinguishing Between Consensual and Nonconsensual Advantages of Liability Rules,* 105 YALE L.J. 235 (1995); Ian Ayres & Eric Talley, *Solomonic Bargaining: Dividing a Legal Entitlement To Facilitate Coasean Trade,* 104 YALE L.J. 1027 (1995); Louis Kaplow & Steven Shavell, *Do Liability Rules Facilitate Bargaining? A Reply to Ayres and Talley,* 105 YALE L.J. 221 (1995). From the experimental literature on bargaining, compare Glenn W. Harrison & Michael McKee, *Experimental Evaluation of the Coase Theorem,* 28 J.L. & ECON. 653 (1985) and Elizabeth Hoffman & Matthew L. Spitzer, *The Coase Theorem: Some Experimental Tests,* 25 J.L. & ECON. 73 (1982) with Ken Binmore et al., *Hard Bargains and Lost Opportunities,* (unpublished manuscript on file with authors). For a recent review of that literature see RICHARD H. THALER, THE WINNER'S CURSE: PARADOXES AND ANOMALIES OF ECONOMIC LIFE 21-36 (1992).

### B. *The Central Problem in Game Theory and the Law and the Demands of Complex Models*

We have more serious reservations, however, beginning with Chapters Three and Four, in which *GTL* introduces a set of related topics that make use of more intricate games of imperfect information (including games of "incomplete" information) and more advanced solution concepts that refine the notion of a subgame perfect equilibrium.[82] The decision to introduce this material at an early point reflects *GTL's* animating belief that asymmetric information is the central problem in game theory and the law. That belief is widely shared. In principle, the introduction of asymmetric information brings economic analysis an important step closer to the kinds of problems with which the law must actually deal. In practice, much current work in game theory and the law involves asymmetric information games. What at this point is rather less clear is that game theory has evolved to a point at which it can furnish reliable solutions. As illustrated at the end of Part I, the very simplest games of imperfect information can have multiple subgame perfect equilibria.[83] That multiplicity is, unfortunately, pervasive. What is more, the various equilibrium refinements that have been proposed to eliminate implausible equilibria are both controversial and intricate with which to work. So *GTL's* decision to devote extended consideration to games of incomplete information leads to significant problems of exposition and elevates materially the difficulty of the book. After describing the sort of games that *GTL* takes up, we turn to its introductory account.

#### 1. *Games of Incomplete Information (John Harsanyi)*

The imperfect information in Game Two, analyzed at the conclusion to Part I, arose from a prior action by a *human* player that another player could not observe. There is, however, an important class of games of imperfect information that is derived from games of "incomplete" information, in which some *characteristic* of a player is what some other player cannot observe. The unobserved characteristic is usually called the player's "type";[84] different types of players have different motivations; and those different motivations can always be represented by ascribing distinct *payoffs* to

82. Subgame perfect equilibria form a subset of the set of Nash equilibria. By "refinements" of subgame perfection we mean a *further* narrowing of that subset of all Nash equilibria that *survive* the requirement that they be subgame perfect, i.e., a subset of subgame perfect equilibria.

83. *See supra* text accompanying notes 59-64.

84. *See* FUDENBERG & TIROLE, *supra* note 37, at 209-11; GIBBONS, *supra* note 12, at 146-47, 174; OSBORNE & RUBINSTEIN, *supra* note 21, at 231-32; Harsanyi, *supra* note 2; *see also,* Harsanyi, *supra* note 17, at 294-95.

players of the different types.[85] Among John Harsanyi's pivotal contributions was in showing that, by positing a fictitious player — usually called "nature" — any game of incomplete information could be reformulated as a game that opens with a "chance move" at which, in accordance with a posited probability distribution — assumed to be common knowledge[86] — nature randomly "chooses" the player's type.[87] Since what is unobserved by the "uninformed" player in the reformulated game is nature's opening *move,* the Harsanyi transformation converts a game of incomplete information into a game of *imperfect* information, which may then be studied along the lines outlined in Part I.[88] It is that class of games on which Chapters Three and Four extensively dwell.

An illustration may serve to make this point concrete. For simplicity, regard us as of a single mind in all material respects, and consider the game that you, the Reader, and we, the Reviewers, might easily be viewed as playing. Our move is our assessment of *GTL,* and *it* is something you *can* observe: we praise the book or we do not. You *cannot,* however, observe our motivation, which (you may assume) affects our payoff from the way in which we fashion this review. Are we disinterested, guided only by the objective of providing an honest evaluation, content with the satisfaction of a job well done; or do we have a hidden agenda that we wish discreetly to pursue? Perhaps the book is wonderful, but we have our own book on game theory and the law that happens to be just coming off the press;[89] or, possibly, the book itself is really very bad, but we wish to curry favor in Chicago. How you interpret what we *say* in deciding whether to invest in reading *GTL* — your payoff, after all, is what you might derive from reading it, net of time and cost, or from the ways you might otherwise deploy your money and your time — should take account of your assessment of which we are.

It is likely, of course, that you in general have some prior belief about the fraction of honest reviewers in the general population. Suppose, possibly naively, you put that fraction at as high as thirty-five percent, the balance in your view being opportunists with their own books in the works. Using the Harsanyi transformation, a game theorist would regard us, Reader and Reviewer, as playing a

85. *See* Harsanyi, *supra* note 17, at 293.

86. *See supra* text accompanying note 37.

87. *See* Harsanyi, *supra* note 17.

88. It is sometimes stressed that a game of "incomplete" information is not sufficiently well structured to be a game at all; and that, once the structure has been completed using the Harsanyi transformation, it is simply a game of imperfect information. *See, e.g.,* K.G. BINMORE, FUN AND GAMES: A TEXT ON GAME THEORY 502 (1992); RASMUSEN, *supra* note 12, at 55. While this point is well taken, we adhere to the conventional if abused terminology of referring to such games as "games" of incomplete information.

89. For the record, we don't. If we did, admittedly we might strategically deny it.

game of imperfect information, in which "nature" opens the game by randomly drawing an opportunistic or disinterested reviewer — choosing the reviewer's type — with the probability of the latter being thirty-five percent.[90] We then make our move by writing the review, and, after observing *our* move but *not* nature's, you — the "uninformed" player — move by deciding whether to invest in reading *GTL* or to wait, perhaps for some some future book.

As you might imagine, strategic actors are frequently uncertain about the nature of the other players. A buyer may be uninformed about the quality of goods offered by sellers of different types;[91] an employer may be uncertain about the "quality" of prospective workers;[92] a defendant may be uncertain about the true nature of the injury to a plaintiff from whom it has received a settlement demand.[93] With the Harsanyi transformation, each of these, and the myriad of analogous possibilities, can be modeled as a game of imperfect information.

The structure of such models, while formally like that of other imperfect information games, is often more complex. They always involve chance moves and require the use of probability, features that lend intricacy to the analysis. As with our Game Two, more elaborate solution concepts must typically be invoked to eliminate implausible equilibria of the kind exhibited by that game. Those refined solution concepts, although extensively invoked by *GTL*, are more open to debate than one might ever gather from *GTL* itself. For all these reasons, most accounts of game theory of which we are aware treat games of incomplete information as a more advanced topic, to be taken up only after a careful grounding in the rudiments,[94] and treat equilibrium refinements as a subject for

90. We offer this example for its accessibility. As the reader may have noticed, it is actually more complicated than we have suggested in the text. At the beginning of the game, nature chooses *both* the reviewer's type (disinterested or opportunistic) *and* the quality (high or low) of the book. Hence, there are four possible states of the world amongst which nature must choose. In the simpler case more typically studied, nature chooses between just two states.

91. *See, e.g.*, George A. Akerlof, *The Market for "Lemons": Quality Uncertainty and the Market Mechanism*, 84 Q.J. ECON. 488 (1970); *see also* pp. 79-121; *infra* text accompanying notes 96-97.

92. *See, e.g.*, pp. 122-58; A. MICHAEL SPENCE, MARKET SIGNALING: INFORMATIONAL TRANSFER IN HIRING AND RELATED SCREENING PROCESSES (1974).

93. *See, e.g.*, pp. 244-67; Barry Nalebuff, *Credible Pretrial Negotiation*, 18 RAND. J. ECON. 198 (1987); I.P.L. P'ng, *Strategic Behavior in Suit, Settlement, and Trial*, 14 BELL J. ECON. 539 (1983); Jennifer F. Reinganum & Louis L. Wilde, *Settlement, Litigation, and the Allocation of Litigation Costs*, 17 RAND J. ECON. 557 (1986); Stephen W. Salant, *Litigation of Settlement Demands Questioned by Bayesian Defendants*, 516 CAL. INST. TECH. SOC. SCI. WORKING PAPER 1 (1984).

94. For comparison, a newly published micro-economic theory text, with extensive treatment of game theory, broaches these topics in the most preliminary way only after an eighty page introduction devoted *entirely* to game theory. ANDREU MAS-COLELL ET AL., MICROECONOMIC THEORY 217-301, 282-96 (1995). *See also* FUDENBERG & TIROLE, *supra*

which a healthy dose of skepticism is required. As one eminent game theorist put it, at the outset of a graduate textbook discussion of the subject, "there is no settled conventional wisdom about refinements of Nash equilibrium. Indeed, there is much controversy about which refinements are reasonable and which not."[95]

### 2. *Solutions to Games of Incomplete Information and Chapter Three of GTL*

From that perspective, *GTL's* early introduction of, and sustained subsequent preoccupation with, games of incomplete information and equilibrium refinements is a problematic expositional decision. That is especially so in a book that has devoted more of its first eighty pages to illustrating applications of game theory *to* the law than to schooling readers in the *solution of* noncooperative games. Nevertheless, *GTL* delves deeply into these topics in Chapters Three and Four, and returns to them again in Chapters Six and Eight. That is something it did not have to do. But *given* its point of view, and given also the delicate handling that Nash equilibrium refinements require, one would naturally expect *GTL* to be especially meticulous in introducing an audience of uninitiated readers to the solutions of such games, and to the elements of probability

note 37, at 319-434; GIBBONS, *supra* note 12, at 173-255; KREPS, *supra* note 30, at 417-450; OSBORNE & RUBINSTEIN, *supra* note 21, at 197-254.

95. KREPS, *supra* note 30, at 418. In the more outspoken words of another game theorist in an undergraduate text, "the subject of refinements of Nash equilibrium . . . is the most controversial . . . within game theory . . . . [T]his is an area in which I recommend not believing *anyone* until the experts achieve some sort of consensus." BINMORE, *supra* note 88, at 544-45. Kreps' remarks are especially germane, since he is responsible for two of the more prominent equilibrium refinements, the "sequential equilibrium," formalized in Kreps & Wilson, *supra* note 69, at 863, and the "intuitive criterion" of In-Koo Cho & David M. Kreps, *Signaling Games and Stable Equilibria,* 102 Q.J. ECON. 179 (1987). Other prominent equilibrium refinements include "trembling-hand perfection," *see* Selten, *Perfectness Concept, supra* note 2; "proper" equilibria, Roger B. Myerson, *Incentive Compatibility and the Bargaining Problem,* 47 ECONOMETRICA 61 (1979); the set of "stable" equilibria," Elon Kohlberg & Jean-Francois Mertens, *On the Strategic Stability of Equilibria,* 54 ECONOMETRICA 1003 (1986); the set of "perfect sequential equilibria," Sanford J. Grossman & Motty Perry, *Perfect Sequential Equilibrium,* 39 J. ECON. THEORY 97 (1986); and the set of "universally divine" equilibria, Jeffrey S. Banks & Joel Sobel, *Equilibrium Selection in Signaling Games,* 55 ECONOMETRICA 647 (1987). Many are deployed at one point or another by *GTL. See, e.g.,* pp. 86-90 (perfect Bayesian equilibrium), 132-33 (the intuitive criterion); 252-59 (perfect sequential equilibrium).

Many of these refinements narrow the set of equilibria by restricting the "beliefs" that players may hold when they encounter eventualities that are off the equilibrium path. *See, e.g.,* JEFFREY S. BANKS, SIGNALING GAMES IN POLITICAL SCIENCE 14-15 (1991); *see also infra* note 104. In other words, they attempt to impose restrictions on what players should be permitted or taken to believe when they observe events that, in equilibrium, they expect *never* to observe *at all.* An excellent non-technical account of the problems generally can be found in KREPS, *supra* note 34, at 108-22. For more technical surveys, see, for example, MAS-COLELL ET AL., *supra* note 94, at 282-96; KREPS, *supra* note 30, at 417-43. A thoughtful discussion of the relevance of the issues to game theory and the law can be found in Ayres, *supra* note 4, at 1291, 1311-13; *see also* Ian Ayres, *Three Approaches to Modeling Corporate Games: Some Observations,* 60 CIN. L. REV. 419, 421-22 (1991).

that such solutions routinely require. Those, however, are things that *GTL* simply does not do.

From a substantive perspective, Chapter Three focuses on information disclosure and disclosure laws. *GTL* chooses for its organizing thread what has been called the "unraveling result," due to Sanford Grossman and Paul Milgrom.[96] The central insight of that work is that if private information, held for example by a seller of goods, can be verified and misrepresentation remedied costlessly ex post, accurate disclosure of favorable information is optimal for every type of seller, and silence effectively discloses "bad news." Although its assumption of costless verifiability is relatively strong, in principle it has intriguing implications for the desirability of disclosure laws. In its substantive dimension, Chapter Three begins by describing that result, and exploring its implications in a variety of settings. Ultimately, it settles into extended consideration of a model, due to Steven Shavell,[97] that goes beyond the unraveling result to explore the impact of disclosure laws on incentives to engage in costly acquisition of information. Shavell's work suggests that, even when voluntary disclosure may privately be optimal, mandatory disclosure may be useful in deterring socially excessive investments in acquiring information.[98]

*GTL* weaves into this story its introduction to games with informational asymmetries. Our concerns begin with its exposition of the refinements of subgame perfection that forms the analytic centerpiece of Chapter Three. The Chapter does begin on a note of intuition. But it proceeds immediately to "formalize" the intuition by introducing that refinement of subgame perfection called the perfect Bayesian equilibrium.[99] That move will confront any untutored reader with something for which she will not be adequately prepared. Any real grasp of that solution concept, and others like it, requires a facility with simple expected values and an acquain-

96. Sanford J. Grossman, *The Informational Role of Warranties and Private Disclosure About Product Quality,* 24 J.L. & ECON. 461 (1981); Paul R. Milgrom, *Good News and Bad News: Representation Theorems and Applications,* 12 BELL J. ECON. 380 (1981).

97. *See* Steven Shavell, *Acquisition and Disclosure of Information Prior to Sale,* 25 RAND J. ECON. 20 (1994); *see also* Anthony T. Kronman, *Mistake, Disclosure, Information, and the Law of Contracts,* 7 J. LEGAL STUD. 1 (1978).

98. Shavell's work draws on a distinction between information of social and that of purely private value, first apparently articulated in Jack Hirshleifer, *The Private and Social Value of Information and the Reward to Inventive Activity,* 61 AM. ECON. REV. 561 (1971).

99. *See supra* text accompanying notes 68-70; *infra* note 104. The implication in the text that the set of "perfect Bayesian equilibria" is a subset of the set of subgame perfect equilibria is, strictly speaking, correct for games with no proper subgames. Games with proper subgames can, however, have perfect Bayesian equilibria that are not subgame perfect. *See, e.g.,* MAS-COLELL ET AL., *supra* note 94, at 290, Figure 9.C.5. In such cases an accurate characterization is that solutions that are perfect Bayesian equilibria *in every subgame* are always subgame perfect.

tance with both "conditional probabilities" and Bayes' Law.[100] If, like *GTL*, your operating premise is that asymmetric information is what counts, those are matters you simply cannot avoid. The economics of asymmetric information cannot be *done* without expected values. Except in the very simplest of settings, you cannot *think about* a perfect Bayesian equilibrium without knowing how to work with probabilities, and how to use Bayes' Law to update probabilities in response to things that are observed. Those, however, are matters that *GTL* never develops for its readers.[101] Instead, it launches headlong into games of asymmetric information with none of those prerequisites in hand.

Having done so, moreover, *GTL* proceeds to a formal introduction using a game of imperfect information that is neither especially well chosen nor instructive. *GTL* begins by asserting that its illustrative game has multiple equilibria and no proper subgames, so that subgame perfection is no help. It goes on to claim that, using the perfect Bayesian equilibrium to "incorporate beliefs into the solution concept, we can eliminate some Nash equilibria as solutions to the game" (p. 86). *GTL* then consumes several difficult pages establishing that the game has two perfect Bayesian equilibria, but it never identifies just *which* Nash equilibria the exercise managed to rule out. The answer, it happens, is "none." A feature of the illustration — which *GTL* never mentions — is that the two strategy profiles that survive the application of the perfect Bayesian equilibrium are the *only* two pure-strategy Nash equilibria of the game. *GTL* thus devotes ten pages to introducing an intricate new solution concept, the purpose of which is to eliminate implausible equilibria, using an example in which it has no effect at all! It is insufficient to suggest that *GTL* manages to obscure the point. We

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100. Bayes' Law is an elementary but important proposition about conditional probabilities that offers a natural method by which to update beliefs, in the sense that it offers a way of evaluating the probability of an unobserved event in light of some observed "signal" that has a bearing on its probability. *See, e.g.*, PAUL L. MEYER, INTRODUCTORY PROBABILITY AND STATISTICAL APPLICATIONS 39-41 (2d ed. 1970). Its principal (and controversial) appearances in legal literature have been in connection with evidence. *See, e.g.*, Lawrence H. Tribe, *Trial by Mathematics: Precision and Ritual in the Legal Process*, 84 HARV. L. REV. 1329 (1971); Richard D. Friedman, *A Close Look at Probative Value*, 66 B.U. L. REV. 733 (1986); *see also* Steven C. Salop, *Evaluating Uncertain Evidence with Sir Thomas Bayes: A Note for Teachers*, J. ECON. PERSP., Summer 1987, at 155.

101. In the interests of completeness, we note that a "probability distribution" over two discrete events is just a pair of non-negative numbers that sum to one; and, that the "expected value" of a random experiment whose outcomes are numbers associated with the two events is the average of those numbers, weighted by the associated probabilities. Although *GTL* routinely computes expected values throughout the book — nearly every footnote to chapter 8, for example, contains an expected value calculation (pp. 285-87) — it never takes the time to explain to the reader what they are, and the index does not even contain an entry for the topic. There appear to be no references to "conditional probability" anywhere in the book. Of Bayes' Law *GTL* says that it "provides a means to capture formally the way rational people should update their beliefs in the wake of new information" and little else. P. 83.

know of no other introduction to this material that is quite so thoroughly opaque.[102] At its end, the reader is *still* left to discern for herself what useful purpose, if any, this innovation is really supposed to serve.

Finally, *GTL* casually invokes yet *another* equilibrium refinement to rule out one of the two equilibria, thereby producing a "solution" to the game. It does so, moreover, without extended description or discussion, leaving the reader not a clue to just what it is invoking, whether it is original with *GTL* or not, and whether it is technically a controversial or commonplace thing to do.[103] It never does tell the reader just what, if anything, Bayes' Law has to do with any of this.

With that as its prologue, *GTL* proceeds immediately to the unraveling result and into the heart of Chapter Three, as though its ideal reader, having stopped to think about the matter "logically and carefully," would thereafter be equipped to follow what was going on. When, another ten pages later, *GTL* takes up Shavell's model of the consequences of disclosure, we suspect it will rapidly become quite difficult for any reader not already well versed in game theory to keep up. For, despite the mystifying introduction, *GTL* plunges into the solution of a series of games using equilibrium refinements in excruciating detail. It does so, moreover, without ever formally specifying a single game in either extensive or normal form. It is, to be sure, possible to follow the details, and perhaps to discern the moral of the stories being told. But, given *GTL's* self-imposed commitment to do it almost all in words, there is little possibility that an otherwise unschooled reader of Chapters Three and Four will end up with a real grasp of what is going on.

We do not mean to suggest that games with asymmetric information require formal training to understand. To the contrary, our view is that they do not. In fact, the solution that we sketched to Game Two at the conclusion of Part I was itself a perfect Bayesian equilibrium, used in a setting in which that solution concept actually

102. Games typically used to introduce a rarefied refinement of subgame perfection like this are those in which (a) the refinement operates to eliminate some equilibria and (b) the eliminated equilibria are arguably implausible. *See, e.g.*, Gibbons, *supra* note 12, at 175-80; Kreps, *supra* note 30, at 425-28; Mas-Colell et al., *supra* note 94; *see also supra* text accompanying notes 67-69; *infra* note 104 and accompanying text.

103. *See* pp. 88-89. The added refinement does not appear in the bibliographic notes, which tell the reader only that "perfect Bayesian equilibrium" is related to "sequential equilibrium." P. 119. A trip to the index entry for "sequential equilibrium" refers the reader to "equilibrium," whereupon he encounters a dead end. The invoked refinement is sometimes referred to as "forward induction," or "iterated elimination of weakly dominated strategies," and its merits are open to dispute. See, for example, Mas-Colell et al., *supra* note 94, at 292-95, where, after canvassing arguments both for and against the refinement's plausibility, the authors conclude: "Clearly, the issues here, although interesting and important, are also tricky." *See also* Osborne & Rubinstein, *supra* note 21, at 110-14, 244.

ruled an implausible equilibrium out.[104] It was structured, however, to be transparently simple. It requires, in particular, no obvious Bayesian updating or expected value calculations, things that will not be true in general.[105] But, when they *are* needed, the expected value calculations that *GTL* never systematically explains are often little more demanding than adding two and two; and the uses to which Bayes' Law is actually put, while requiring more careful groundwork, are only modestly more difficult and no stranger to

104. *See supra* text accompanying notes 67-69. Speaking loosely, equilibrium refinements like the perfect Bayesian equilibrium restrict the set of subgame perfect equilibria in a game of imperfect information by requiring that the play of the game be "sequentially rational" at every information set, including information sets that are off the equilibrium path of play. That condition extends in a natural way to every *non-singleton* information set a requirement of out-of-equilibrium rationality comparable to what subgame perfection requires in proper subgames (which, by definition, begin at *singleton* information sets). *See supra* notes 50-51, 62-64 and accompanying text. At a nonsingleton information set, however, a prerequisite to assessing sequential rationality is a system of "beliefs," in the form of a set of probabilities, conditional on being in *that information set,* of being at the different *choice nodes* that it contains. The beliefs are used to compute the expected values of the actions available to the player whose move it is to make.

More formally, a perfect Bayesian equilibrium consists of both a strategy profile *and* a system of beliefs, requiring (wherever possible) the beliefs to be consistent with the strategy profile (which is where Bayes' Law comes into play) and the strategy profile to be sequentially rational. The strategy profile is sequentially rational if each player chooses the action at each of his information sets that maximizes his expected payoff, computed using the beliefs. The various refinements differ in the restrictions they impose on beliefs at information sets that are off the equilibrium path. *See, e.g.*, BANKS, *supra* note 95, at 14-15. The weakest form of perfect Bayesian equilibrium, in particular, imposes no restriction on beliefs at any information set that would never be encountered if the equilibrium strategy profile were played. *See, e.g.*, KREPS, *supra* note 30, at 427-31; BINMORE, *supra* note 88, at 536-38 & n.40; MAS-COLELL ET AL., *supra* note 94, at 285-95.

In Game Two, however, irrespective of whether the Insurer makes the *H*igh or *L*ow quality *P*artial offer, the Resident's payoff from settling exceeds her payoff from going to court. *See supra* text accompanying notes 56-57 and 67-69. So for *any* system of beliefs — any set of probabilities that she is faced with the *P-H* or *P-L* offer — the expected value of settling *always* exceeds the expected value of going to court, and it is always sequentially rational for the Resident to settle. Given that, the Insurer always should make a *P-L* offer; the Resident should always observe a *P*artial offer which, while of *unobserved* quality, the Resident should always *believe* to be of *L*ow quality; and the Resident's sequentially rational action should be to settle. Given the equilibrium strategy profile, the equilibrium beliefs are unique.

What makes our example seem easy is the absence of any dependence of the sequential rationality of the equilibrium strategy profile on the beliefs, which permits us to determine the beliefs implied by the strategy profile almost as an afterthought. More typically, the sequential rationality of a strategy profile *depends* on the beliefs, but the beliefs depend in turn on the strategy profile: it is the joint determination of the two that can make matters so complex.

Nevertheless, while Game Two illustrates the use of the perfect Bayesian equilibrium in a deceptively simple setting, it is a setting in which the concept has some bite. It eliminates as a solution the implausible equilibrium in which the Resident's strategy involves a threat to go to *c*ourt, despite the fact that it is always best for her to *s*ettle.

105. That is why we originally stipulated that the payoff to the Resident from *s*ettling, even for the *P-L* offer, exceeded the $9 payoff from taking it to court. *See supra* text accompanying note 55. If, in contrast, the payoff from *s*ettling for *P-L* had been *less than* $9 while the payoff from *s*ettling for the *P-H* offer remained $11, it would then be sequentially rational for the Resident to *s*ettle only if, given a set of probabilities that the Insurer had made the *P-H* or *P-L* offers, respectively, the *expected* (*i.e.*, probability-weighted) payoff from *s*ettling exceeded the $9 payoff from going to *c*ourt. *See supra* note 104.

legal discourse in any event.[106] If the reader were adequately prepared and the materials more judiciously positioned and methodically presented, there is no reason why interested lawyers could not master them. The economics of disclosure, with which Chapter Three is substantively concerned, makes for a fascinating story in and of itself. A case for including a discussion of the topic somewhere in *GTL* is compelling, after the requisite groundwork has been laid.

The matter of positioning aside, at least two distinct courses were open to *GTL* as ways of presenting these materials. One would have been to provide a more soundly conceived introductory account of equilibrium refinements — *including* the prerequisites — treating disclosure regimes (on perhaps a less ambitious scale) as an illustrative application. It might alternatively have structured the chapter as an essay on the economics of disclosure, describing the technical results to the extent necessary to lend real content to the story. At different points Chapter Three reads as though it had both of these in mind. What it failed to do was *choose.* Chapter Three oscillates between introducing and then using advanced solution concepts *and* exploring the economics of disclosure, leaving the reader no single thread with which to negotiate the maze. The study of disclosure leads to a fragmentary account of the theory but then itself disappears in a sea of details, as *GTL* investigates more than a dozen possible equilibria of nearly a half-dozen different games. The novice reader — *however* attentive he might be — could easily emerge confused about the exact message for the structure of disclosure laws, and a sense of the game theory that is surely incomplete, could easily be incorrect, and might be lacking altogether in coherence.

### C. *Plausibility, Game Theory, and the Law*

As far as asymmetric information is concerned, the consequences linger for the balance of the book. The headlong exposition more generally persists. One further consequence of that form of exposition is that it leaves little space in which to reflect on the operational plausibility of the theory *GTL* so extensively surveys. While relatively scrupulous about such matters at the outset,[107] *GTL's* concerns become attenuated as the book proceeds. Modeling problems of asymmetric information has become a large-scale industry, as *GTL's* existence itself reflects. But more sophisticated models are increasingly sensitive not merely to details of the ways that they are specified, but also to what they assume of human ra-

106. *See supra* note 100.

107. *See supra* text accompanying notes 74-75.

tionality, as reflected in the solution concepts they employ.[108] At the same time, in part because their predictions are so frequently imprecise, game theoretic models are notoriously hard to falsify. As it ventured into the realm of more demanding models, one might reasonably have wished for *GTL* to become more attentive to questions of verisimilitude, not less.

We offer two examples, the first of which underlies Chapter Three itself. Both the basic unraveling result and Shavell's model of acquisition and disclosure assume that affirmative representations must be truthful and, therefore, will be believed.[109] In an entire chapter spun together with the unraveling result, the authors devote no space to what might happen were that important assumption to be relaxed; indeed, they do not even mention that the assumption is crucial to the chapter's core result.

We draw our second from among our favorite chapters in the book. It does not even involve asymmetric information. Rubinstein's model[110] opened a new vista on bargaining, eliciting a wave of new theoretical work. An entire chapter of *GTL* is fashioned around the basic prediction of that model. But the prediction is wildly sensitive to assumptions, a well-known fact to which *GTL* only indirectly alludes.[111] At the same time, bargaining is more than ordinarily amenable to controlled experiment and has elicited a body of empirical evidence against which the theory may be gauged. Even where the extensive form is entirely straightforward — two-person, two-move games of perfect information — the results persistently conflict with what the theory would predict.[112] It is possible that such findings are the product of defects in experimental design, so it remains open whether it is the design or the theory that is flawed.[113] Even so, such persistent, disquieting find-

108. This point is addressed in Ayres, *supra* note 4, at 1311-15.

109. *See, e.g.*, Grossman, *supra* note 96, at 464-65; Shavell, *supra* note 97, at 22. *GTL* recasts this as an assumption that misrepresentation — as contrasted with simple silence — can be costlessly remedied ex post (p. 90).

110. *See supra* text accompanying notes 97-100.

111. *See* pp. 224, 239-41. *Compare, e.g.*, KREPS, *supra* note 30, at 561-65. When incomplete information is introduced, to which *GTL* turns in chapter 8, the problem of multiple equilibria intrudes in a serious way. *See, e.g.*, Sutton, *supra* note 78, at 717-21.

112. One such game, the "ultimatum game," involves the simple division of a monetary stake, in which the first player makes an offer that the second observes and may accept or reject. If the offer is rejected, each player gets nothing. Theory predicts that the first player should make the smallest possible positive offer, which the second player should accept. But first players typically make substantial offers, and small offers are frequently rejected. *See, e.g.*, Colin Camerer & Richard H. Thaler, *Ultimatums, Dictators and Manners*, J. ECON. PERSP., Spring 1995, at 209; RICHARD H. THALER, THE WINNER'S CURSE 21-31 (1992); K. Binmore et al., *Testing Noncooperative Bargaining Theory: A Preliminary Study*, 75 AM. ECON. REV. 1178 (1985).

113. *See, e.g.*, Elizabeth Hoffman et al., *Preferences, Property Rights and Anonymity in Bargaining Games*, 7 GAMES & ECON. BEHAVIOR 346 (1994).

ings, in the very simplest of settings, counsel caution in bringing the insights of game theory to bear on the design of legal rules. They strike us as meriting more space and emphasis than the two bibliographic sentences (p. 242) *GTL* devotes to them.

In this respect, to be fair about it, *GTL* is surely not alone. More energy is currently devoted to doing game theory in legal settings than to musing about its shortcomings, and their implications for the real usefulness of game theory to the law. Still, this is a full-length book devoted entirely to game theory and the law. Just how useful game theory truly is, or ultimately may become, is something *GTL* might have taken more time to explore.

## Conclusion

*GTL,* in sum, is really two quite different books. The more elementary chapters provide an accessible, nontechnical introduction to the basics of game theory, well illustrated in the context of the law. For beginners, however, those that dwell on informational asymmetries will require more than just care and logic to get through. In all, *GTL* has performed an unquestionable service, in rendering the basic insights of game theory in terms that will be both companionable and accessible to nonspecialists whose primary training is in law. Judiciously approached, it will provide rewarding insights to those prepared to do some work.

The real questions, we suppose, are whether you are interested in learning more game theory; if so, how much; and where would you be well-advised to start. If your answer to the first is "yes," *GTL* is one obvious answer to the last. If that is what you choose, we do encourage you to bypass Chapters Three, Four, and Six on your first pass through the book.[114] There are, however, three other possibilities — complements, really, not substitutes for *GTL* — that we might suggest. One, of course, is Thomas Schelling's classic, *The Strategy of Conflict.* If you are interested in strategic thinking generally, even if not formally in game theory, it should not in any event be missed.[115] An updated account along similar lines is Avinash Dixit and Barry Nalebuff's *Thinking Strategically,*[116] which provides a chatty, nontechnical introduction to the subject and its underlying intuition.

But for a current, nontechnical introduction to noncooperative game theory, there is a third possibility that genuinely stands out.

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114. Chapter 6 is a somewhat free-standing essay on collective action problems, but it draws on some of the solution concepts developed in chapter 3.

115. Schelling, *supra* note 48. See also the essays collected in Choice and Consequence, *supra* note 29, especially *What is Game Theory,* at 213.

116. Avinash K. Dixit & Barry J. Nalebuff, Thinking Strategically: The Competitive Edge in Business, Politics, and Everyday Life (1991).

David M. Kreps's *Game Theory and Economic Modelling*[117] offers an honest, critical account of the field, with both fond praise for its accomplishments and unflinching attention to its shortcomings. Although written more than seven years ago, everything Kreps said then continues to ring true. It is not intended for an audience of lawyers, but it will be at least as accessible to them as *GTL*. It reflects at length on the plausibility of Nash equilibrium analysis, and the extent to which game-theoretic models can reasonably be expected to provide insight into how real people actually do behave. That, as we have said, is a dimension of the subject on which *GTL* does not dwell. For a serious, critical account of game theory for the novice, Kreps's book is the place that *we* would start. Then we would turn to *GTL*, primarily for its more introductory chapters, and their insights into the relevance of the more basic aspects of game theory to the law.

If, however, you are interested in the kinds of asymmetric information problems that *GTL* takes up in Chapters Three and Four, additional investment will be required. A short introduction to expected values, conditional probability, and Bayes' Law is essential; there are many places one can go for that.[118] After that there is a growing list of possibilities, all of which assume at least an acquaintance with mathematical notation.[119] To understand equilibrium refinements and solutions to games of imperfect information, you will in all events have to read beyond *GTL*.

An important prior question, however, is whether you should *want* to extend your horizons quite that far. One indisputable contribution of game theory, as *GTL* frequently points out, is that, even at what Martin Shubik has called its "conversational" level,[120] it helps us hone our instincts about how the possibility of strategic interaction might influence our thinking about legal rules. Or as Thomas Schelling put it:

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117. Kreps, *supra* note 34.

118. One good choice for the nonspecialist is Edith Stokey & Richard Zeckhauser, A Primer for Policy Analysis 209-11, 221-29 (1978). Those extracts are included in an introductory chapter on statistical decision theory which, for anyone interested in noncooperative game theory, is more generally worthwhile. Conditional probabilities and Bayes' Law are also covered early in any introductory probability text.

119. Two of the most popular introductory accounts are Gibbons, *supra* note 12, which contains a wealth of worked-out applications; and Rasmusen, *supra* note 12, which devotes considerable space to intuition. The review of the first edition of Games and Information by Ian Ayres remains worth reading for its own interest. Ayres, *supra* note 4. Graduate-level introductory microeconomic theory texts increasingly contain extended treatments of game theory. One of the best introductory accounts will be found in Mas-Colell et al., *supra* note 94, at chapters 7-8; another excellent choice is Kreps, *supra* note 30, at 355-719. Yet another recent possibility is James D. Morrow, Game Theory for Political Scientists (1994).

120. Martin Shubik, *Game Theory, Law, and the Concept of Competition*, 60 U. Cin. L. Rev. 285, 289-300 (1991).

> For the social scientist, what is rudimentary and conceptual about game theory will be, for a long time, the most valuable. And it will be valuable not as "instant theory" just waiting to be applied but as a framework — one with a great deal of thought now behind it — on which to build his own theory in his own field.[121]

But, for applications to the law, more is required than merely that. If game-theoretic insights are properly to influence our choice of legal rules it must also be because formal game-theoretic models provide us with credible insights into how human actors really do behave. Doubts remain about the extent to which even simple models of strategic interaction offer reliable predictions. Those doubts become more acute when the interactions involve asymmetric information or are otherwise complex. They have provoked skepticism, even among those who do game theory for a living, sometimes more pessimistic than the measured self-assessment that will be found in Kreps. One of them, Kenneth Binmore, recently put the matter this way:

> It was not until the early 1970s that it was fully realized what a powerful tool Nash had provided in formulating the equilibrium concept that bears his name. Game theory then enjoyed a renaissance as economists applied the idea to a wide range of problems. However, a fly in the ointment was awaiting discovery. Games typically have many Nash equilibria .... At first it was thought that the problem could be tackled by refining the Nash equilibrium concept. Despite Nash's remarks in his thesis about a possible evolutionary interpretation of the idea of a Nash equilibrium, attention at that time was focused almost entirely on its interpretation as the only viable outcome of careful reasoning by ideally rational players. Various bells and whistles were therefore appended to the definition of rationality. These allowed some Nash equilibria to be discarded as inadequately rational according to whatever new definition of rationality was being proposed. However, different game theorists proposed so many different rationality definitions that the available set of refinements of Nash equilibrium became embarrassingly large. Eventually, almost any Nash equilibrium could be justified in terms of someone or other's refinement. As a consequence a new period of disillusionment with game theory seemed inevitable by the late 1980s.[122]

Or, as the editors of the New Palgrave continued, in the quotation with which we began, "[s]ometimes, it seems that we are back again at our early morning calisthenics, only this time using high-tech equipment."[123]

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121. SCHELLING, *supra* note 29, at 241.

122. Ken Binmore, *Foreword* to JÖRGEN W. WEIBULL, EVOLUTIONARY GAME THEORY vi (1995); Binmore's criticism of the "refinements literature" should not be offered without context. It is from the forward to a book devoted to *another* of game theory's research frontiers, so-called "evolutionary" game theory. *See, e.g.*, Eric Van Damme, 38 EUR. ECON. REV. 847, 856 (1994).

123. NEW PALGRAVE: GAME THEORY, *supra* note 1, at xii.

*GTL* does well at introducing its readers to game theory. Its agenda is dominated by a fascination with precisely those aspects of the field that, while unquestionably of greatest current interest to law and economics scholars, have simultaneously elicited skepticism among such talented and thoughtful game theorists as Ken Binmore and David Kreps. Even so, *GTL* is a very good book. It could, we think, have been a better book had it been slightly less preoccupied with the current frontiers of game theory and more systematically attentive to the possible limits of what, at this stage of its development, game theory realistically might have to offer to the law.