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GAME THEORETIC ANALYSIS OF LEGAL RULES AND INSTITUTIONS

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ABSTRACT

We offer a selected survey of the uses of game theory in the analysis of law.

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Game Theoretic Analysis of Legal Rules and Institutions[1]

by

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1. Introduction

Game theoretic ideas and analyses have appeared explicitly in legal commentaries and judicial opinions for over thirty years. They first emerged in the immediate aftermath of early reapportionment cases. As the United States courts struggled to articulate the meaning of equal representation and to give content to the slogan "one person, one vote", they considered, and for a time endorsed, a concept of voting power that has game theoretic roots. At approximately the same time, the publication of Calabresi [1961] and Coase [1960] provoked an outpouring of economic analyses of legal rules and institutions that continues to grow. In the late 1960s, the first game theoretic models of contract doctrine (Birmingham [1969a, 1969b]) appeared. Models of accident law in Brown [1973] and Diamond [1974a, 1974b] followed a few years later. In the mid-1980s, the explicit use of game theory in the economic analysis of law burgeoned.

The early uses of game theory encompass the two different ways in which game theory has been applied to legal problems. On the one hand, as in the reapportionment cases, courts and

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analysts have adopted game theoretic tools to further the goals of traditional Anglo-American legal scholarship. In this tradition, both judge and commentator seek to rationalize a set of related judicial decisions by articulating the underlying normative framework that unifies and justifies the judicial doctrine. In this use, which we shall call *doctrinal analysis*, game theoretic concepts elaborate the meaning of key, doctrinal ideas that define what the law seeks to achieve.

On the other hand, as in the analyses of contract and tort, game theory has provided a theory of how individuals respond to legal rules. The analyst considers the games defined by a class of legal rules and studies how the equilibrium behavior of individuals varies with the choice of legal rule. In legal cultures that, as in the United States, regard law as an instrument for the guidance and regulation of social behavior, this analysis is a necessary step in the task facing the legal policymaker. It is worth emphasizing that nothing in this analytic structure ties the analyst, or the policymaker, to an "economic" objective such as efficiency or maximization of social welfare.

In this essay, we offer a selective survey of the uses of game theory in the analysis of law. The use of game theory as an adjunct of doctrinal analysis has been relatively limited, and our survey of this area is correspondingly reasonably exhaustive. In contrast, the use of game theory in understanding how legal rules affect individual behavior has been pervasive.[4] Game theory has been explicitly applied to analyses of contract,[5] torts between strangers,[6] bankruptcy and

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[4]Kornhauser [1989], argues that virtually all of the economic analysis of law can be understood as an exercise in mechanism design in which a policymaker chooses among legal rules that define games played by citizens.

[5] E.g., Birmingham [1969a, 1969b], Shavell [1980], Kornhauser [1983], Rogerson [1984], and Hermalin and Katz [1993].

corporate reorganization,[7] corporate takeovers and other corporate problems,[8] product liability[9], and the decision to settle rather than litigate[10] and the consequent effects on the likelihood that plaintiff will prevail at trial.[11]

Kornhauser [1989], argues that virtually all of the economic analysis of law can be understood as an exercise in mechanism design. Moreover, certain traditional subdisciplines of economics and finance, such as industrial organization, public finance, and environmental economics, are inextricably tied to legal rules. Game theoretic models in those fields invariably shed light on legal rules and institutions.

Given the size and diversity of this latter literature, we cannot provide a comprehensive survey of game-theoretic models of legal rules and hence make no attempt to do so. Furthermore, in some areas at least, such literature surveys already exist: see, for example, Shavell [1987] on torts, Cooter and Rubinfeld [1989] on dispute resolution, Kornhauser [1986] on contract remedies, Pyle [1991] on criminal law and Hart and Holmstrom [1987] and Holmstrom and Tirole [1989] on the incomplete contracting literature. In addition, Baird, Gertner

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[6] E.g., Brown [1973], Diamond [1974a, 1974b], Diamond and Mirrlees [1975], and Shavell [1987].

[7] E.g., Baird and Picker [1991], Bebchuck and Chang [1992], Gertner and Scharfstein [1991], Schwartz [1988, 1993], and White [1980, 1994].

[8] E.g., Cramton and Schwartz [1991], Grossman and Hart [1982],and Kahan and Tuckman [1993].

[9] E.g., Oi [1973], Kambhu [1982], Polinsky and Rogerson [1983], and Geistfeld [1995]..

[10] E.g., Bebchuck [1984], Daughety and Reinganum [1993], Hay [1995], Png [1982], Reinganum [1988], Reinganum and Wilde [1986], Shavell [1982], Spier [1992, 1994]

[11] E.g. Priest and Klein [1984], Eisenberg [1990], Wittman [1988]

and Picker [1994] is an introduction to game theory that presents the concepts through a wide variety of legal applications.

Having forsworn comprehensive coverage, we have four aims in this survey. First, we illustrate the ways in which legal rules influence behavior. Second, we emphasize the aspect of mechanism design that underlies game-theoretic analyses of legal rules and institutions. Third, we suggest the wide variety of legal rules and institutions on which game theory as a behavioral theory sheds light. Fourth, we examine some of the difficulties in the use of game theoretic concepts to clarify legal doctrine.

In section 2, we examine the simple two-person game that underlies much of the economic analysis of accidents as well as the analysis of contract remedies and tort. In this model, the legal rule serves as a direct incentive mechanism.

In section 3, we examine the insights that game theoretic models have provided into the "Coase Theorem" which often serves as an analytic starting point for economic analyses of law. In section 4 we introduce a literature that extends the use of game theory as a behavioral predictor from private law to public law and the analysis of constitutions. Section 5 discusses the small literature that has used game theory in doctrinal analysis. Section 6 offers some concluding remarks.

2. Economic Analysis of the Common Law when Contracting Costs are Infinite.

2.1 The Basic Model.

Brown [1973] offers a simple model of accident law. We discuss it extensively here for two reasons. First, it underlies many, if not most, economic analyses of law that examine how legal rules can solve externality problems. Second, and more importantly, this simple model of torts illustrates clearly the use of game theory as a theory of the behavior of agents in response to legal rules.

There are three decisionmakers: the legal policymaker, generally thought of as the Court, and two agents, called the (potential) injurer I and the (potential) victim V. I and V are each independently engaged in an activity, which may result in harm to V. They simultaneously choose an amount x and y, respectively, to expend on care. These amounts determine the probability p(x,y) with which V may experience a loss and the value L(x,y) of such a loss. The functions p(x,y) and L(x,y) are common knowledge. The policymaker seeks to regulate the (risk-neutral) agents' choices of care levels.

The policymaker selects a legal rule from a family of permissible rules R(x,y;X,Y) which divide any incurred loss between the two parties according to a particular pattern of liability. The parameters $X \geq 0$ and $Y \geq 0$ are interpreted as I's and V's standard of care, respectively, and R(x,y;X,Y) is the proportion of the loss L(x,y) legally imposed on I.

Any given rule R(x,y;X,Y) defines a two-person non-zero sum game between I and V. Each agent seeks a level of care that minimizes her expected personal costs. Thus, I chooses x to minimize:

1) $x + p(x,y)L(x,y)R(x,y;X,Y)$

while V chooses y in order to minimize:

2) $y + p(x,y)L(x,y)[1-R(x,y;X,Y)]$

Although this framework is simple, it enables a comparison of many legal rules. Thus, a general regime of *negligence with contributory negligence* is characterized by a loss assignment function of the form:

$$3)\quad R(x,y;X,Y) = \begin{cases} 1 & \text{if } x < X \text{ and } y \geq Y \\ 0 & \text{otherwise} \end{cases}$$

Under a *pure negligence* rule the injurer is responsible whenever she fails to take an "adequate" level of care; this corresponds to $0 < X < \infty$, $Y = 0$. With *strict liability* the injurer is responsible for damage regardless of the level of care she takes; thus, $X = \infty$, and $Y = 0$.[12] Under strict liability with contributory negligence the injurer is responsible whenever the victim takes an adequate level of care; thus, $X = \infty$, $0 < Y < \infty$.

Strict liability with dual contributory negligence has a different pattern of liability defined by:

$$4)\quad R(x,y;X,Y) = \begin{cases} 1 & \text{if } x < X \ \underline{\text{or}}\ y \geq Y \\ 0 & \text{otherwise.} \end{cases}$$ [13]

Under a rule of *comparative negligence*, R may assume values strictly between 0 and 1 when each party fails to meet its standard of care.

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[12]The legal literature generally distinguishes between "strict liability rules" and "negligence rules". As the text indicates, a strict liability rule (without contributory negligence) can be understood as a member of the general class of negligence with contributory negligence rules. A different distinction between strict liability and negligence rules is suggested by equation (4) below; namely, that under strict liability the default bearer of liability, i.e., the party who bears the loss when each party meets her standard of care, is the injurer rather than the victim.

[13]In fact, if we rename the parties, the pattern of liability under this rule is identical to the pattern under negligence with contributory negligence. Put differently, in Brown's model, the loss is perfectly transferable between parties and the legal rule simply assigns the loss to one party or another. This is not an adequate model of *personal injury,* since a personal injury may alter V's utility *function,* and some injuries may not be compensable. See, for example, Arlen [1992] for a modification that addresses the problem of personal injury.

In principle, the economic analysis of law would study the equilibria of these various games. Once these equilibria have been identified, the policymaker can choose the rule that induces the best equilibrium, given the social objective function. The analysis is thus not inextricably linked to a search for an efficient or welfare maximizing rule. One could as easily search for the rule that minimizes the accident rate or equalizes care expenditures or for any other social objective that the policymaker seeks to implement. Ideally, then, one would analyze the case law to identify the Court's objective function and choose the legal rule that induces the equilibrium that is best in these terms.

In practice, however, and perhaps unfortunately, the literature has to a large extent chosen as objective function the minimization of the expected social costs of accidents.[14] That is, the minimization of:

$$x + y + p(x,y)L(x,y).$$

Let (x^*,y^*) be the (assumed) unique minimizing care levels. Consider the common law regime of negligence with contributory negligence as characterized by 3). Clearly choosing standards $X = x^*$ and $Y = y^*$ induces the agents to take the optimal levels of care. However, these are not the only such standards. In fact, an infinite number of rules of the form $(X = x^*, Y \varepsilon [0,y^*])$ and of the form $(X \varepsilon [M,\infty]$ (for sufficiently large M), $Y = y^*)$ induce an equilibrium in which the agents adopt care levels that are socially optimal.

Consider first a rule with $X = x^*$ and $Y \leq y^*$. When I chooses x^*, V is responsible for the total loss, i.e. $R = 0$. From 2) V chooses y to minimize:

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[14]Diamond [1974b], Kornhauser and Schotter [1992], and Endres and Querner [1995] are examples of exceptions to this practice.

$$y + p(x^*,y)L(x^*,y)$$

But this is just 5) shifted down by x* so that 2) is also minimized at y*. Likewise, given V's choice of y*, I minimizes 1) by choosing x*.[15] A similar argument shows that (x*,y*) is the equilibrium for those games in which Y=y* and X is sufficiently large.

Thus, efficiency can be obtained even if the court can only observe the level of care being taken by one of the parties. In particular, if the court can only observe x, then an appropriate pure negligence rule is efficient -- the court sets X = x*, Y=0 and lets V, whose action it cannot observe, optimize against I's choice. Similarly, when the court only observes y, the strict liability with contributory negligence rule ($X=\infty$, Y=y*) is efficient.

Notice that these payoff functions, which accurately capture the structure of the negligence rule, are discontinous at the standard of care.[16] This discontinuity plays an important role in generating the efficient outcome, because it allows both agents to "see" the full cost of her decision simultaneously. For example with the rule X = x* and Y = 0, I bears the full cost of the accident in the event he chooses x < x*, and none of the cost at x = x*. Therefore, at a choice of x = x*, I's marginal cost of lowering x is the entire accident cost. At the same time, when I chooses x = x*, V bears the entire loss and sees the full cost of her actions.

2.2 Extensions within Accident Law.

Several modifications of this basic framework have been studied. Shavell [1987] analyzes

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[15](x*,y*) is the only pure strategy equilibrium for games with the standards of care as indicated. If I chooses x < x*, then V chooses y = Y and the injurer's payoff falls; I would be better off choosing x*. If I chooses x > x*, it makes unnecessary expenditures on care.

[16]Kahan [1989], however, argues that these payoff functions do not correctly model the measure of damages. He contends that in an appropriate model, the payoffs are continuous functions.

a model in which each party chooses both a level of care and a level of activity, but the allocation of the loss still depends only on the parties' choice of care levels. Unsurprisingly, no legal rule can induce both parties to choose efficient activity levels and efficient care levels; after all, the court has only one instrument (for each party) to control the two decisions that each party makes. One can still identify the rule that is best given the social objective function. Shavell [1987] also investigates the impact of an insurance market on care decisions. (See also Winter [1991] for a discussion of the dynamics of the market for liability insurance.)

A number of other variants of this model have also been analysed. Green [1976] and Emons and Sobel [1991] for example study the equilibria of the basic model of negligence with contributory negligence when injurers differ in the cost of care. Beard [1990] and Kornhauser and Revesz [1990] consider the effects of the potential insolvency of the parties on care choice. Shavell (1983) and Wittman (1981) analyze games with a sequential structure. Leong [1989] and Arlen [1990] study negligence with contributory negligence rules when both the victim and the injurer suffer damage. Arlen [1992] studies these same rules when the agents suffer personal (or non-pecuniary) injury.

Several authors have integrated the analysis of the incentives to take care into a fuller description of the litigation process that enforces liability rules. Ordover [1978] showed that when litigation costs are positive some injurers will be negligent in equilibrium. Craswell and Calfee [1986] study how uncertainty concerning legal standards affects the equilibria. Polinsky and Shavell [1989] studies the effects of errors in fact finding on the probability that a victim will bring suit and hence on the incentives to comply with the law. Hylton [1990, 1995] introduces costly litigation and legal error. Png [1987] and Polinsky and Rubinfeld [1988] study the effect of the rate of settlement on compliance. Png [1987] and Hylton [1993] consider how the rule allocating the costs of litigation between the parties affects the incentives to take care. Cooter, Kornhauser, and Lane [1979] assume that the court only observes "local" information about the private costs of care and the costs of accidents. In their model the courts adjust the standards of care over time and converge to the optimum. Polinsky [1987b] compares strict liability to negligence when the injurer is uncertain about the size of the loss the victim will suffer.

Many authors have compared the efficiency of negligence with contributory negligence rules to comparative negligence rules. Under a rule of comparative negligence injurer and victim share the loss when both fail to meet the standard of care. That is, the injurer pays the share

$$R(x,y;X,Y) = \begin{cases} 1 & \text{for } x < X \text{ and } y \geq Y \\ f(x,y;X,Y) & \text{for } x < X \text{ and } y < Y \\ 0 & \text{otherwise } (x \geq 0) \end{cases}$$

where $0 < f(x,y;X,Y) < 1$. Landes and Posner [1980] argues that both rules can induce efficient care taking; Haddock and Curran [1985] and Cooter and Ulen [1986] argue for the superiority of comparative negligence when actual care levels are observed with error; Edlin [1994] argues that with the appropriate choice of standards of care the two rules perform equally well even when such error is present. Rubinfeld [1987] considers the performance of comparative negligence when the court cannot observe the private costs of care.

2.3 Other interpretations of the model.

This model can be recast to yield insights into other areas of law. Indeed, some (Cooter [1985]) have suggested that the pervasinesess of this model shows the inherent unity of the common law. While this claim seems too strong-- common law rules govern a wider set of interactions than those described here--the model does illuminate a wide variety of legal institutions.

To begin, we reinterpret the problem in terms of remedies for breach of contract. Consider, for example, two parties, a buyer B and a seller S contemplating an exchange.[17] B requires a part produced by S. The value to B of the part depends upon the level of investment y that B makes in advance of delivery. Denote this value by v(y). y is known as the "reliance" level, as it indicates the extent to which B is relying upon receiving the part. S agrees to deliver the part and chooses an investment level x. This results in a probability [1-p(x)] that S will successfully deliver the part and a probability p(x) that he will not perform the contract. B pays S an amount k up front for the part. A legal rule R(x,y) determines the amount R(x,y)v(y) that S must pay B if S fails to deliver the part.[18] S then chooses x to maximize:

5) $k - x - p(x)v(y)R(x,y)$.

while B (simultaneously) chooses y to maximize:

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[17]The model in the text is similar to ones presented in Shavell [1980], Kornhauser [1983] and Rogerson [1984].

[18]A number of other aspects of contract law have been modelled. Hadfield [1994] considers complications created by the inability of courts to observe actions. Hermalin and Katz [1993] examines why contracts do not cover all contingencies. Katz [1990a,1990b, 1993] has studied doctrines surrounding offer and acceptance, which determine when a contract has been formed. Various authors--e.g., Posner and Rosenfield [1977], White [1988], and Sykes [1992]--have considered the related doctrines of impossibility and impracticability which are, in a sense, the converse of breach as they state conditions under which contractual obligation is discharged. Rasmussen and Ayres [1993] examine the doctrines governing unilateral and bilateral mistake. Polinsky [1983, 1987a] addresses some more general questions of the risk-bearing features of contract that are raised by the mistake and impossibility doctrines.

The rule of Hadley v. Baxendale has also received much attention as in Perloff [1981], Ayres and Gertner [1989, 1992], Bebchuck and Shavell [1991], and Johnston [1990]. The latter four articles are particularly concerned with the role of the legal rule in inducing parties to reveal information.

6) $- k - y + [1-p(x)]v(y) + p(x)R(x,y)v(y)$

Notice the congruence of this model to Brown's basic model of section 2.1. Indeed, subtract a term g(y) from the victim's objective function 2). We interpret g(y) as V's (added) payoff from her investment of y, should no accident occur. In Brown's basic model this is zero. This corresponds to a potential victim who, by taking care, can reduce the value of her assets that are at risk, say by putting some of them in a fireproof safe, but whose actions have no effect on the overall value of the assets.

On the other hand, consider a potential victim whose investment determines the value of some assets should no accident occur, but which assets will be completely lost in the event of an accident. Then $g(y) = L(y)$ $(=L(x,y))$ in 2). If this investment affects only the value of the assets, and not the probability that they are lost, then $p(x,y) = p(x)$. Now the accident model of equations 1) and 2) is identical to the breach of contract model 5) and 6) (with $v(y) \equiv L(y)$ and $k=0$).

Thus, the accident interpretation and the contract interpretation differ largely in the characterization of the net benefits of the victim's action. Despite this congruence courts, and analysts, have treated these situations differently. Rather than rules setting standards of care X and Y to determine liability, courts have commonly used a "reliance measure", $R(x,y) = R(y) = y/v(y)$ (so that $R(y)v(y) = y$),[19] and an expectation measure, $R(x,y) = 1$. These measures of contract damages are rules of "strict liability" as the amount of the seller's liability is not

[19]At least, these models interpret the reliance measure as $R(y)v(y) = y$. Some legal commentators understand reliance as a measure that places the promisee in the same position he would have been in had the contract not been made. Reliance then includes the opportunity cost of entering the contract. On this interpretation, reliance damages would equal expectation damages in a competitive market.

contingent on its own decisions; they are also "actual damage" measures as they depend on the actual, as opposed to any hypothetical, choice of the Buyer.

It is easy to see that neither of these two damage measures will generally induce an efficient level of care and reliance. The total expected social welfare of the contract is,

$$[1-p(x)]v(y) - x - y .$$

Let (x^*,y^*) maximize this social welfare function.[20] Thus,

$$p'(x^*) = -1/v(y^*), \text{ or } p(x^*) = 0 \text{ and } p'(x^*) < 1/v(y^*)$$

$$v'(y^*) = 1/(1-p(x^*))$$

When $R(y) = 1$, B's maximizing choice, y_e, is independent of S's action and is implicitly defined by

$$v'(y_e) = 1.$$

Given this, S's equiibrium action is defined by:

$$p'(x_e) = -1/v(y_e)$$

$(x_e, y_e) = (x^*, y^*)$ only when $p(x^*) = 0$. When $p(x^*) \neq 0$, this expectation measure leads to too much reliance on the part of B; S, however, adopts the optimal amount of care given B's reliance.

Under the reliance measure $R(y)=y/v(y)$, B again maximizes independently of S by setting:

$$v'(y_r) = 1$$

S's equilibrium action is now defined by:

$$p'(x_r) = -1/ y_r$$

[20]We assume sufficient conditions for a unique nonzero solution, and that all our functions are differentiable.

Again y_r is efficient only if $p(x_r) = 0$. In this case, S also adopts the efficient level of care. Otherwise, B underrelies and S breaches too frequently given B's reliance.

We may also use this example to suggest how non-efficiency concerns might enter into the legal analysis. Consider a technology in which, by taking a reasonable amount of care, S can get p close to 0; further reductions in p are very costly without much gain. Indeed, there may be a residual uncertainty which S can not avoid. Then the solutions to the three programs above may well all result in a very small probability of nonperformance. The solutions will all be close to each other, so that fairness considerations may clearly outweigh efficiency considerations. Under the reliance measure, for instance, when S fails to deliver despite his "best efforts" he must only repay B for B's out-of-pocket (or reliance) losses, rather than the loss of B's potential gain, which may be quite high.[21]

Brown's model of accident law is easily converted to a model of the taking of property. The Fifth Amendment to the Constitution of the United States requires that "property not be taken for a public use without compensation." How does the level of required compensation affect the extent to which the landowner develops her land and the nature of the public takings?

We model this as follows. Let the landowner choose an amount y to expend on land development, resulting in a property value v(y). v(y) is an increasing function of her investment. The value of the land to the government is a random value whose realization is unknown at the time the landowner chooses his investment level. Let q(a) denote the probability that the value of the land in public hands will be greater than a, and let p(y) = q(v(y)). Assume that the state

[21]One might convert this fairness argument into an efficiency argument by extending the analysis to consider why B does not choose to integrate vertically with S.

appropriates the land if only if it is worth more in public hands than in private hands. As before, we consider compensation rules of the form R(y)v(y). Then the landowner chooses y to maximize:

$$(7)\quad -y + (1 - p(y))v(y) + p(y)R(y)v(y)$$

Note that (7) is identical to (6),when k=0 and p is written more generally as p(x,y). Suppose that the state is benevolent so that its objective function is net social value:

$$(8)\quad -y + [1-p(y)]v(y) + E[a \mid a > v(y)]$$

The government chooses R(y) to maximize (8), given the landowner's program (7).[22] As a simple example, consider a rule $R(y) = \alpha$ and suppose that the land is either worth more to the state than max v(y) or worth less than v(0) (perhaps a new rail line must be situated). Thus $p'(y) \equiv 0$, $E'(v(y)) = 0$ and efficiency demands that:

$$v'(y) = 1/[1 - p(y)].$$

The landowner maximizes by setting:

$$v'(y) = 1/[1 - p(y)(1 - \alpha)].$$

Efficiency calls for no compensation, i.e. $\alpha = 0$. However, if p(y) is small, then setting $\alpha = 1$ may be fairer while causing only a small loss in total welfare.

It is striking that radically different legal institutions are captured by models that are structurally so similar. Why do legal institutions vary so much across what seem to be

[22]Analyses of takings as in Blume et al. [1984] and Fischel and Perry [1989] are more complex because they are set in a broader framework in which the government must also set taxes in order to finance the takings. In this context one is able to consider a non-benevolent government as well. This government acts in the interest of the majority; see Fischel and Perry [1989] and Hermalin [1985]. Hermalin, whose analysis is explicitly normative, examines a set of non-standard compensation rules as well. We have ignored these complexities because we are interested in showing the doctrinal reach of the simple model.

structurally similar strategic situations? The literature does not offer a clear answer; indeed it has not explicitly addressed the issue. Two suggestions follow.

First, the nature of the externality differs slightly across legal institutions. In the accident case, the likelihood of an adverse outcome depends on the care choices of each party. In the contract case, the seller determines the likelihood of breach while the buyer determines the size of the loss. In the takings context, the land owner determines the market value of the value of the land. Perhaps the shifting judicial approaches reflect important differences in the court's ability to monitor the differing transactions. Second, the differences in institutions may reflect different values that the courts seek to further in the differing contexts.

3. Is Law Important? Understanding the Coase Theorem.

The analysis of accident law in the prior section assumed that the parties could not negotiate or enforce agreements concerning the level of care that each should adopt. The interpretation of the model as one of accidents between strangers presents a situation in which such a bar to negotiation is plausible; the pedestrian contemplating a stroll rarely has the opportunity to negotiate with all drivers who might strike her during her ramble. Under other interpretations, however, the barriers to negotiation are less. In these contexts, one must confront a seductive, though ill-specified, argument for the irrelevance of certain legal rules.

This irrelevance argument is generally attributed to Ronald Coase [1960] who argued through two examples that the assignment of liability would not, in the absence of *transaction costs*, affect the economic behavior of agents because an "incorrect" assignment of liability could always be corrected through private, enforceable agreements. In the context of contract remedies, for example, the parties could negotiate a contingent claims contract specifing the level of reliance that the buyer should undertake. Coase also emphasized that the assignment of liability might indeed matter when transaction costs were present.

Coase never stated the "theorem" that goes by his name and subsequent scholars have had difficulty formulating a precise statement. Precision is difficult because Coase argued from example and did not clearly define several key concepts in the argument. In particular "transaction costs" are never defined and the legal background in which the parties act is underspecified.

Game theorists have generally treated the theorem as a claim about bargaining and, as we shall see, have used both the tools of cooperative and non-cooperative game theory to illuminate our understanding of Coase's examples. The Coase Theorem, however, is also a claim about the importance of legal rules to bargaining outcomes. At the outset, we must thus understand precisely which legal rules are in question so that they may be modelled appropriately.

The Coase theorem implicates two sets of legal rules: the rules of contract and the assignment of entitlements. The rules of contract determine which agreements are legally enforceable and what the consequences of non-performance of a contract are. For the Coase theorem to hold, it is clear that the law must be willing to enforce virtually every contract and that the consequences of non-performance must be sufficiently grave that non-performance does not occur.[23]

The entitlement defines the initial package of legal relations over which the parties

[23]Absent this possibility, repetition and reputation effects might ensure compliance with contracts in certain situations.

negotiate.y[24] This package has several elements: it identifies the set of actions which the entitlement holder is free to undertake and it identifies the consequences to others for interfering with the entitlement holder's enjoyment of her entitlement. The law and economics literature, drawing on Calabresi and Melamed [1972], has generally focussed on the two forms of entitlement protection called property rules and liability rules. Under a property rule, all transfers must be consensual; consequently the transfer price is set by the entitlement holder herself. Under a liability rule, an agent may force the transfer of the entitlement; if the parties fail to agree on a price, a court sets the price at which the entitlement transfers.

Consider, for example, two adjoining landowners A and B. B wishes to erect a building which will interrupt A's coastal view. Suppose A has an entitlement to her view. Property rule protection of A's entitlement means that A may enjoin B's interfering use of his land and thus subject B to severe fines or imprisonment for contempt should B erect the building. Put differently, A may set any price, including infinity, for the sale of his view, without regard to the "reasonableness" of this price. Under a liability rule, A's recourse against B is limited to an

[24]An entitlement is actually a complex bundle of various types of legal relations. A classification of legal relations offered by Hohfeld (1913) is useful. He identified eight fundamental legal relations which can be presented as four pairs of jural opposites:

right	privilege	power	immunity
duty	no-right	disability	liability

When an individual has a right to do X, she may invoke state power to prevent interference with her doing X. By contrast, if she has the privilege to do X, no one else may invoke the state to interfere (though they may be able to "interfere" in other ways). An individual may hold a privilege without holding a right and conversely. When an individual has a power, she has the authority to alter the rights or privileges of another; if the individual holds an immunity (with respect to a particular right or privilege), no one has a power to alter it. Kennedy and Michelman [1980] apply this classification to illuminate different regimes of property and contract.

action for damages. Put differently, should B erect a building against A's wishes, the courts will determine a reasonable "sale" price for the loss of A's view.

The Coase Theorem is commonly understood as a claim that, in a world of "zero transaction costs", the nature and assignment of the entitlement does not affect the final allocation of real resources; legal rules are (economically) irrelevant. One might ask two very different questions about the asserted irrelevance of legal rules. First, one might assume a perfect law of contract and specify more precisely what "zero transaction costs" means in order to assure the irrelevance of the assignment of entitlements. Alternatively, one might ask how "imperfect" contract law could be without disturbing the irrelevance of the assignment of the entitlements. Following most of the literature, we investigate the first question.

Much controversy revolves around the concept of transaction costs. At the most basic level, transaction costs involve such things as the time and money needed to bring the various parties together and the legal fees incurred in signing a contract. One may go further, however, and consider a transaction cost to constitute anything which prevents the consummation of efficient trades. Game theory has clarified the different impediments to trade by focussing on two types of barriers: those that arise from strategic interaction per se and those that arise from incomplete information.

We might then understand the Coase theorem as one of two claims about bargaining.[25] First, we might understand the Coase theorem as a claim that bargains are efficient regardless of the assignment and nature of the entitlement. Call this the Coase Strong Efficient Bargaining

[25]The literature on the Coase Theorem is vast and offers a variety of characterizations of the claim. For overviews of the literature that offer accounts consistent with that in the text see Cooter [1987] and Veljanovski [1982].

Claim. Second, we might understand the Coase theorem as a claim that, although bargaining is not always efficient, the degree of efficiency is unaffected by the nature and assignment of the entitlement. Call this the Coase Weak Efficient Bargaining Claim.

The game theoretic investigations of the Coase Claims, while providing some support, suggest that both are, in general, false.[26] One set of arguments focusses on the strategic structure of games of complete information. A second set considers the problems created by bargaining under incomplete information. A third set circumvents the bargaining problem using cooperative game theory. We consider each set of arguments in turn.

3.2 The Coase Theorem and Complete Information.

Reconsider the injurer/victim model of section 2.1. Suppose that I engages in an activity that can cause a fixed amount of damage, $L(x,y) = d$, to V. I can avoid causing this damage at a cost of c. That is, $p(x,y) = 0$ if $x \geq c$, $p(x,y) = 1$ if $x < c$. Both c and d lie in the interval (0,1). We assume that the benefit to I of the activity is greater than 1, so that it is always socially desirable for I to undertake the potentially harmful activity.

We can view V as being entitled to be free from damage. As previously noted, an entitlement can be protected with a property rule or a liability rule. Consider a compensation rule which specifies a lump sum R that I must pay V for damage. We interpret $R \geq 1$ as a property rule, since I will only fail to take care if V consents.[27] V's entitlement is protected by

[26]Hoffman and Spitzer [1982, 1985, 1986] and Harrison and McAfee [1986] provide experimental evidence in support of the Coase claims.

[27]This characterization of a property rule is not wholly satisfactory because the court might enforce a property rule by injunction (and by contempt proceedings should the injunction be violated). Thus this characterization might differ from the operation of such a legal rule should I act irrationally.

a liability rule when $0 < R < 1$. Clearly, the larger R the greater the protection afforded V. When $R = 0$, V has no protection; this can be interpreted as giving I an entitlement to cause damage that is protected by a property rule.

A surface analysis suggests that if $R = 0$, I does not take care since the damage I causes is external to I, whereas with $R = 1$, I takes care since $c < 1$. In particular, when $R = 0$ and $c < d$, I causes harm to V, and when $R = 1$ and $c > d$ I takes care, even though both these outcomes are inefficient.

The Coase theorem holds that this conclusion is unduly negative. For instance, when $R= 0$ and $c < d$, V could induce I to take care by offering I a side payment of, say, $c + (d-c)/2$. This is possible provided that "transaction costs" are not too high. If making the side payment involved a separate cost greater than (d-x), no mutually beneficial payment could be made.

When transaction costs are negligible then, for any values of c and d, and for any value of R, we might expect the firms to negotiate a mutually beneficial transfer which yields the efficient level of care. Note that even if this expectation is correct, it does not imply that the legal regime R is irrelevant, as R affects the direction and level of the transfer.

While the insight that firms will have an incentive to "bargain around" any legal rule is important, the blunt assertion that they will successfully do so seems hasty. Exactly how are the firms to settle on an appropriate transfer? What if, with $c < d$, V offers to pay c to I, while I insists upon receiving d? Negotiations could break down, resulting in the inefficient outcome of no care being taken. In any case, Coase did not specify the bargaining game which would permit us to rule out this possibility.

Suppose that firms always seek to reach mutually beneficial arrangements and that they can costlessly implement any contract upon which they agree. Consider the polar cases of R = 0, and R = 1. A simple dominance argument shows that in the former case I will never take care when c > d, since it is dominated for V to offer I more than d to take care. Thus, there will never be more than an efficient level of care taken . Similarly, when R(x,d) = 1 there will never be less than an efficient level of care. Without making more assumptions no more than this can be said; the legal regime affects the level of care taken and the Coase theorem fails in both its forms. To establish a Coase Theorem one requires additional structure. Notice that the material facts do not in themselves determine this additional structure. To evaluate the Coase theorem we must posit a bargaining game and examine how its solution changes with legal regimes.

Consider any legal rule R and a simple game in which V makes a take it or leave it offer to I. Then, in the unique subgame perfect equilibrium, when c < d V offers I a side-payment of max [c - R, 0] to take care and I accepts. Hence I takes care regardless of the legal rule. When c > d, V offers to accept a side-payment of max[R - c, 0] from I if I does not take care, and under every legal rule I does not take care. In both cases, the efficient outcome is reached regardless of the legal rule R(c,d).

This is a particularly simple model of bargaining. Rubinstein [1982] offers a more sophisticated model in which two parties alternatingly propose divisions of a surplus until one of the parties accepts the other's offer. In our present situation, if c < d there is a surplus when care is taken and if c > d there is a surplus when care is not taken, regardless of the rule R(c,d). Thus, suppose that when c < d, in period 1 V offers I a payment to take care. If I rejects the payment, in period 2 I makes a counter demand of a payment. If V rejects I's proposal he makes a counteroffer in period 3 and so forth. When c > d the game is the same except that the payments are for not taking care. Each party attaches a subjective time cost to delay and the game ends when an offer is accepted or when I decides to act unilaterally. Rubinstein's results imply that for all R(c,d) the parties instantly agree upon an efficient transfer.

Thus, we have some support for the Coase Strong Efficient Bargaining Claim. However, the result that bargaining will be efficient is delicate. Shaked has shown that with three or more agents bargaining in Rubinstein's model may be inefficient.[28] Avery and Zemsky (1994) present a unifying discussion of a variety of bargaining models that result in inefficient bargaining.[29] Perhaps most importantly, we have been assuming complete information. We consider incomplete information in the next section.

3.3 The Coase Theorem and Incomplete Information.

Generally, we might expect a firm to possess more information about its costs than outside agents possess. We now modify the model of the previous section in this direction. Specifically, following Kaplow and Shavell [1995], suppose that while I knows the cost c of taking care, V knows only that c is distributed with density f(c) on the unit interval. Similarly, while V knows the level of damage d which I would cause, I knows only that d is distributed with density g(d) on the unit interval. We focus on the two rules R = 0 and R=1. Call these rules R_0 and R_1, respectively. Notice that to implement R_0 and R_1 the court only needs to know whether or not damage has occured.

Efficiency requires that I take care whenever $c < d$. Let $S_i = \{(c,d) \mid \text{I takes care under}$

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[28]Shaked's model is discussed in Osborne and Rubinstein [1990].

[29]These models, which include Fernandes and Glazer (1991) and Haller and Holden (1990) all have complete information.

rule R_i}. The strong efficient bargaining claim asserts that $S_0 = S_1 = \{(c,d) \mid c \leq d\}$. Call this set E. The weak efficient bargaining claim could be taken to mean one of two things; that $S_0 = S_1 \neq E$ or that, although $S_0 \neq S_1$, R_0 and R_1 are equally inefficient.

Again consider the simple bargaining procedure in which V makes a take-it-or-leave-it offer to I. Consider first the stituation when R_0 prevails. Then V may seek to bribe I to take care. We calculate how V's offer to buy I's right to cause harm varies with V's damage cost d. Suppose V of type d makes an offer of o(d) to I. I accepts if $c \leq o(d)$. Thus, when V makes an offer of o(d), he incurs expected costs of $F(o(d))o(d) + (1\text{-}F(o(d))d$. These costs are minimized by that o(d) which satisfies

$$o(d) = d - F(o(d))/f(o(d)).$$

Call this value $o_0(d)$. Thus:

$$S_0 = \{(c,d) \mid c \leq o_0(d)\}.$$

Since $o_0(d) < d$ efficiency fails in the presence of incomplete information; the strong efficiency claim is false.[30] To check the weak efficiency claim we examine the effect of a change in the legal regime. Consider the situation when R_1 prevails. V may now offer to sell I the right to cause the harm. Suppose that V offers to forego his damage payment of 1 at a price o(d). I accepts if $c > o(d)$ as it would be cheaper for I to buy the right than to avoid the harm. Thus, when V makes an offer of o(d), he expects profits of $(1\text{-}F(o(d))(o(d)\text{-}d)$. These profits are maximized by that o(d) which satisfies

$$o(d) = d + [1-F(o(d))]/f(o(d)).$$

[30]Indeed, Myerson and Satterthwaite (1983) show that, quite generally, bargaining under incomplete imformation will be inefficient.

Call this value $o_1(d)$. Thus:

$$S_1 = \{(c,d) \mid c \leq o_1(d)\}.$$

Since $o_1(d) > d$, again efficiency fails. There is an important difference in regimes R_0 and R_1, however. Under R_0, there are instances when efficiency demands that I take care but he does not. In no case does I take care when he should not. In contrast, under R_1, there may be too much care taken, but never too little.[31]

From this comparison, we may conclude that the Weak Efficiency Claim is false in both its forms. For instance, if F places more weight in the interval $[o_0(d),d]$ than in the interval $[d,o_1(d)]$ then R_0 results in an inefficient level of care more often than R_1 does.[32]

3.4 A Cooperative Game Theoretic Approach to the Coase Theorem.

In the example of the previous section the firms were in a situation of asymmetric information. One might interpret the difficulties imposed by this asymmetric information as an *informational* transaction cost, thereby rescuing the Coase Theorem. Similarly, one might interpret the inefficiencies that arise with three or more agents in a Rubinstein-type bargaining model as resulting from *strategic* transaction costs. On this view, cooperative game theory would seem to provide the best hope for the Coase Strong Efficiency Claim. After all, the characteristic function form of a game simply posits that firms can reach any agreement they

[31]This is in keeping with a claim from the previous section.

[32]Several authors have considered the differential effects of legal rules on the revelation of private information. Ayres and Gertner [1989] argues that this consideration should inform judicial choice of contract default rules. The response to their claim (Johnston [1990]), their reply (Ayres and Gertner [1992]), and a related analysis (Bebchuck and Shavell [1991]) provide insight into the force of Coase Theorem arguments in contract law. See also Ayres and Talley [1995] and Kaplow and Shavell [1995]. Johnston's [1995] study of the effects of blurriness in the entitlement in situations of incomplete information provides related insights.

choose, effectively assuming away any "bargaining costs".

Consider the classic externality problem in which air pollution generated by two factories interferes with the operation of a nearby laundry. There are two possible assignments of the entitlement: (1) the factories pay for "damage" caused to the laundry and (2) the factories do not pay for such damage. Each of these assignments yields a game in characteristic function form that derives from the underlying technological interaction between factories and laundry. In this context, one might formulate the Coase Theorem as a claim either that the (relevant) solution to each of the games is the same or that each solution contains only (equally) efficient allocations. Although there is no general theory that studies (or even formulates) this problem, it is easy to provide examples that contradict each claim. We present here a modification of the examples underlying Aivazian and Callen [1981] and Aivasian, Callen, & Lipnowski [1987].

There are three firms. Firms 1 and 2 are industrial factories, and firm 3 is a laundry. Each firm can operate at one level or shut down. Firm 3 operating on its own earns a profit of 9. If either firm 1 or 2 operates, however, a pollution cost of 2 is imposed on firm 3. If both firms 1 and 2 operate a cost of 8 is imposed on firm 3. Firms 1 and 2 operating independently each earn a profit of 1, regardless of the actions of other firms. Firm 1 and 2 operating together earn joint profits of 7.

We must define two characteristic function form games: one in which the laundry legally bears the pollution cost; and one in which the factories legally bear the cost. In general, defining a characteristic function game from underlying data is not altogether obvious. For instance, in defining the value of a firm operating on its own, should it be assumed that the other firms operate independently or jointly? Should it be assumed that the other firms maximize their profits or that they minimize the profits of the firm under consideration? Our example has been chosen to circumvent these difficulties. Here, the same game is defined regardless of how these questions are answered.

We first derive the characteristic function of the game in which the laundry bears the pollution costs. We have v(3) = 1; this value of 1 is obtained by taking the 9 that firm 1 earns by operating and subtracting the cost of 8 which is imposed upon it by firms 1 and 2 operating separately or jointly. v(23) = 7 since the best that these firms can do jointly is have firm 2 shut down and firm 3 operate. Their profits are then 9 minus the cost of 2 imposed by firm 1. v(123) = 9; firm 3 alone operates, since having one of the other firms also operate would yield the grand coalition a total of 8 and having all three firms operate would yield it 3. Similar reasoning yields the following characteristic function:

v(1) = v(2) = v(3) = 1; v(12) = v(13) = v(23) = 7; v(123) = 9.

Consider now a liability regime in which the court awards damages to the laundry based upon the maximal possible return to any coalition containing the laundry. Under such a regime we have:

w(1) = w(2) = w(12) = 0; w(3) = w(13) = w(23) = w(123) = 9.

The Coase theorem relates the solutions of the two games v and w. Probably the most salient solution concept for cooperative games is the core. The core of the liability game w consists of the unique point (0,0,9). On the other hand, the no-liability game v has an empty core.

Informal Coase-type reasoning would hold that in the absence of a liability rule, firm 3 will simply bribe firms 1 and 2 not to produce, say by offering each of them 3.5. However, such an arrangement is unstable. Firm 1, for instance, would suggest a separate agreement just between itself and firm 3. Since the core is empty, there is in fact no arrangement among the three firms which cannot be blocked by a subset of them. Although there are no (obvious) transaction costs, it is quite possible that the firms will fail to settle on an efficient outcome. On the other hand, in the liability regime of game w, the efficient outcome in which only firm 3 produces is the obvious stable outcome.

Given that the core of v is empty we might want to consider other solution concepts. The Shapley value and nucleolus are both the point (0,0,9) for w and the point (3,3,3) for v. These solution concepts always exist and are always efficient for superadditive games so that this Coasian result is not terribly revealing about the validity of the Strong Efficiency Claim.[33]

Now consider the bargaining set[34]. For the game w the bargaining set still consists of the unique point (0,0,9). For v, however, while the efficient outcome (3,3,3) with coalitional structure {(123)} is an element of the bargaining set, the inefficient point (1, 3.5, 3.5) with coalitional structure {1,(23)} is also an element of the bargaining set[35]. Note that this inefficient outcome in which firms 2 and 3 form a coalition is better for firms 2 and 3 than the efficient element of the bargaining set (and better than the Shapley value and nucleolus).

[33]The difference in the solutions for the two games, however, may be of great significance to a legal policymaker whose social objective extends beyond efficiency to fairness or other concerns.

[34]See Aumann and Maschler [1964] for a definition of the bargaining set. We are using the definition of M**.

[35]Other elements of the bargaining set are (1,1,1) for coalitional structure {(1),(2),(3)}, (3.5,3.5,1) for coalitional structure {(1,2),(3)}, and (3.5,1,3.5) for coalitional structure {(1,3). See Aivasian, Callen, & Lipnowski [1987] for a derivation (in an equivalent game).

The complete information, no transaction cost world of cooperative game theory might seem to be the perfect setting for the Coase theorem. However, even here the theorem is problematic; the choice of entitlement might very well matter to a legal policymaker concerned solely with efficiency. Clearly, a policymaker with other concerns or faced with a more recalcitrant environment or designing the contract regime rather than assigning the entitlement will also need to evaluate the solutions of games defined by different legal rules.

4. Game Theoretic Analyses of Legal Rulemaking.

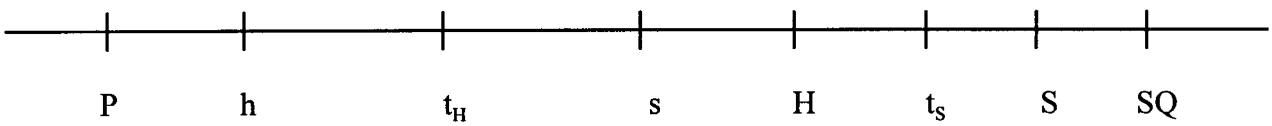
Legal controversies arise over broad questions concerning the structure of adjudication and the consequences of specific legal doctrines. Game theory has played an increasingly important role in illuminating these structural questions. Schwartz [1992], Cameron [1993], and Rasmussen [1994], for instance, have analyzed the practice of precedent both within a court and with respect to lower court obedience to higher court decisions. Others have addressed the claim that judicial review of of legislative action is countermajoritarian (see e.g. Ferejohn and Shipan [1990]) and the effects of specific decisions of the United States Supreme Court (e.g. Cohen and Spitzer [1995]).

Eskridge and Ferejohn [1992] employs a now standard model to illuminate difficult questions of the interrelation of Congress, administrative agencies and the courts. In principle, under the U.S. Constitution policy is promulgated through Congress, with the policy views of the President accommodated to some extent because of the existence of the presidential veto power. The recent rise of lawmaking promulgated by administrative agencies under the control of the President has shifted additional power to the President. In response, Congress has attempted to redress the balance by assuming the power to veto administrative action. In Immigration and

Nationalization Service v. Chadha, the Supreme Court ruled such legislative vetoes unconstitutional. Eskridge and Ferejohn analyze the consequences of these decisions in the following simple model.

There are four actors: The House of Representatives, the Senate, the President, and an executive Agency. They play a sequential game which results in some policy which can be represented as a point along a one-dimensional continuum. Diagram 1 presents a possible distribution of preferences. P is the ideal point of the President; H is the ideal point of the median voter in the House; h is the ideal point of the "2/3rds" house voter;[36] S is the ideal point of the median voter in the Senate; s is the ideal point of the 2/3rds Senate voter; SQ is the status quo. Preferences are linear so that a person with ideal policy X_i prefers x to y if $|x - X_i| < |y - X_i|$.

Diagram 1



Consider the Legislation Game which involves the House, the Senate, and the President. This game determines whether the United States will shift away from the prevailing status quo policy, SQ. In stage 1 of the Legislation Game, the House chooses some point x in the policy space. If x = SQ the game ends and the policy SQ is maintained. If x ≠ SQ the game continues. In stage

[36]The 2/3rds voter is the voter such that she and all voters to her right just constitute a 2/3 majority.

2, the Senate approves or rejects the proposed point x. If the senate rejects x, the game ends with SQ. If the Senate approves x, the game proceeds to stage 3. In stage 3, the President either signs the bill x or vetoes it. If the President signs the bill the game ends and the bill x becomes law. If the President vetoes the bill, the game proceeds to stage 4, in which the Senate and the House move simultaneously. If two thirds of each house approves x, the bill is passed and becomes law. If x lacks a two-thirds majority in either house, then SQ prevails.

For any specified distribution of ideal points, this game is easily solved. Consider the pattern displayed in diagram 1. Since the status quo is to the right of all ideal policies, clearly some new policy will be enacted. t_S in diagram 1 is a point such that $|t_S - S| = |S - SQ|$. The new policy will be no further to the left of S than t_S, since the Senate would reject any such proposal in favor of SQ. In fact, in the unique subgame perfect equilibrium for the configuration of Diagram 1, the House proposes t_S and this is approved by both the Senate and the President.

Next consider the Delegation Game in which Congress does not formulate policy, but instead delegates this task to an executive agency (such as the Environmental Protection Agency). In the Delegation Game, the Agency chooses a policy y in stage 0 and then the above Legislation Game is played with y serving as the new status quo. Since the executive agency is staffed by the President we will assume that its ideal point is that of the President (i.e. P). With the configuration of diagram 1, the unique subgame perfect equilibrium policy outcome is now h.

The delegation of power to the Agency dramatically shifts the equilibrium policy from t_S to h. How might Congress moderate Agency's exercise of its discretion? In the Two-House Veto Game and the One-House Veto Game, Congress intervenes directly. These two games model the effects of Chadha, where the Supreme Court ruled such supervision unconstitutional.

In the Two-House Veto Game, Congress delegates decision making authority to an executive agency but reserves the right to overturn any policy proposal by a majority vote of each house. Specifically, in stage 1 of the Two-House Veto Game, the Agency chooses a policy y. In stage 2, the House votes on the policy. If a majority approves the policy it is adopted. Otherwise, the game proceeds to stage 3. If a majority of the Senate also approves y, it is adopted. Otherwise, the game ends with the original status quo SQ remaining in place.

Reconsider the ideal point configuration Diagram 1. t_H is such that $|t_H - H| = |H - SQ|$ Clearly, t_H is the equilibrium of the Two-House Veto Game as any point to the left of t_H will be vetoed by both Houses. The Two-House Veto Game thus moderates the action of the Agency by bringing the equilibrium from h to t_H, which is closer to the policy t_S that would be enacted directly by Congress (with consent of the President).

In the One-House Veto Game a specific house of Congress has the power to approve or disapprove of the Agency's policy choice . Clearly the outcome will be t_H if the House has the veto power and the policy t_S if the Senate has the veto power.

Thus, Chadha's announcement of a constitutional prohibition on the power of Congress to veto agency decisions dramatically restricts Congress' ability to control power that it statutorily delegates to a Presidential agency. The previous analysis of the Legislation, Delegation and Veto games suggests how one might analyze the way that different institutional structures determine which legal policies prevail. Of course, a complete analysis would compare equilibria across all possible distributions of preferences of the relevant institutional actors.

5. Cooperative Game Theory as a Tool for Analysis of Legal Concepts.

The prior discussion has examined the use of game theory to understand the behavioral consequences of legal rules. As we have seen, the structure of much legal doctrine can be illuminated by models of simple games. These models have had an important impact on the legal commentary of cases and legislation. Moreover, courts have occasionally cited such game theoretic analyses in support of particular decisions.[37]

Game-theoretic tools have also played another role in legal analysis, a role that may have had a more direct impact on legal development. Game theory, particularly cooperative game theory, permits a conceptual analysis of ideas central to some areas of legal doctrine. This doctrinal approach may explicate the social objective underlying legal rules.[38]

In this section, we discuss two doctrinal analyses. We first examine the treatment of an index of voting power by the United States' judicial system. We then consider a case law problem of fair division.

5.1 Measures of Voting Power.

In 1962, the Supreme Court of the United States began a voting rights revolution when it held in Baker v. Carr [1962] that the apportionment of state legislatures is subject to judicial review under the 14th amendment of the U.S. Constitution. In the cases that immediately

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[37]See, e.g., McDermott Inc. v. Amclyde et al, at notes 14, 20, and 24 (1994) citing Kornhauser and Revesz [1993] in support of its analysis of the effects of joint and several liability on settlements and the role of the set-off rule in these settlements and In re BMW Group I Ltd (1992) citing Baird and Picker [1991].

[38]The distinction between the use of game theory to predict behavior and game theory to explicate doctrine is sometimes fuzzy. For example, one might rationalize the structure of product liability doctrine as a set of legal rules that induce efficient behavior on the part of manufacturers and consumers. This rationalization might use game theory both as a predictive tool (to show that some particular rule in fact induces efficient conduct) and as a conceptual tool (to illuminate the meaning of efficiency (e.g., to distinguish between ex ante, interim, and ex post efficiency).

followed, the Court announced that the U.S. Constitution guarantees each citizen "fair and effective representation" (Reynolds v. Sims (1964)). It enunciated a maxim of "one person, one vote" to guide states in legislative reapportionment. In the context of legislative elections from single-member districts, this slogan had a clear meaning and an immediate impact: it required redistricting when the population discrepancy between the largest and smallest districts was too great.[39] As the court widened the reach of jurisdictions and governmental bodies subject to judicial oversight it gradually confronted a wider and wider range of election practices which required it to elaborate a more complete theory of fair representation. In particular, the Court encountered systems that weight the votes of legislators to counterbalance population disparities as well as systems in which larger districts elect proportionately more legislators. Federal and state courts then confronted the question: When do these systems satisfy the requirements of fair and effective representation?

In 1954, Shapley and Shubik [1954] offered an interpretation of the Shapley value as an index of voting power. They interpreted the Shapley value as measuring the chance a voter would be critical to the passage of a bill. These ideas influenced John Banzhaf III who, as a law student, proposed a related index in Banzhaf [1965].[40] Banzhaf also interpreted his index as a measure of the chance a voter would be critical. Banzhaf [1965] used this index to analyze weighted voting schemes and Banzhaf [1968] applied the index to the problem of multi-member districts. In each article, Banzhaf acknowledged the influence of the Shapley value on his

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[39]Of course, as the Court was soon forced to learn, there are many ways to divide a population into roughly equal districts.

[40]The Banzhaf index is equivalent to a measures independently proposed by Coleman [1973], Dahl [1957], and Rae [1969]. On this equivalence, see Dubey and Shapley [1979].

thinking.[41]

Banzhaf [1965] had a substantial impact on litigation; even while in draft, it was introduced into the deliberations of the state and federal courts considering a plan for the temporary reapportionment of the New York Legislature in which weighted voting would be used. (For a discussion of the plan see Glinski v. Lomenzo [1965] and WMCA, Inc. v. Lomenzo [1965].) After he published his articles, Banzhaf continued to intervene in reapportionment litigation; the courts thus frequently considered his view. Before we examine Banzhaf's influence on the case law, we define the two power indices mentioned and briefly discuss the relation between them. Straffin [1994] provides a comprehensive survey of the technical literature.

Consider a simple, proper voting game (N,v). Let $\Theta(i)$ be the number of coalitions S in which i is a swing voter; that is, the number of coalitions S such that v(S) = 1 and v(S-{i}) = 0. The unnormalized Banzhaf power index β_i is given by:

$$\beta_i = \Theta_i / 2^{n-1}$$

while the normalized Banzhaf index is:

$$\beta_i' = \Theta_i / \Sigma_i \Theta_i.$$

The Shapley-Shubik power index is defined as:

$$\sigma_i = \Sigma_{S \text{ is a swing for } i}[1/n!](s-1)!(n-s)! \text{ where } s = |S|;$$

An individual's (unnormalized) Banzhaf index gives the probability that she will be a

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[41]Footnote 32 to Banzhaf [1965] begins, "Although the definition presented in this article is based in part on the ideas of Shapley-Shubik, their definition is rejected because. . . [it] has not been shown that the order in which votes are cast is significant; . . . Likewise it seems unreasonable to credit a legislator with different amounts of voting power depending on when or for what reasons he joins a particular voting coalition." Footnote 55 of Banzhaf [1968] thanks Shapley.

swing voter under the assumption that all coalitions are equally likely to form. An individual's Shapley-Shubik index gives the probability she will be a swing voter under the assumption that it is equally likely that a coalition of any size forms.[42] Although these two indices often give similar measures of power, they need not. Indeed, they may differ radically both in the relative weights they assign and in the rank order they place players. (See Straffin [1988] for examples.)

Straffin [1988] derives the indices within a probabilitistic model in which there are n voters and each voter i has probability p_i of voting "yes" on a given issue, and a probabilty $(1-p_i)$ of voting "no" on the issue. Voter i's power is given by the probability that her vote will affect the outcome of the election. Thus, a voter's power depends on the joint distribution from which the p_i's are drawn. Straffin shows that (a) σ_i measures i's power if, for all voters i, $p_i = p$ and p is drawn from the uniform distribution on [0,1] and (b) β_i measures i's power if, for each voter i, p_i is drawn independently from the uniform distribution on [0,1]. Equivalently, β_i measures i's power on the assumption that each voter independently has a %50 chance of voting "yes" on the issue.[43]

We turn now to the judicial reception of these ideas. The maxim of "one person, one vote" was articulated in the context of a political structure in which legislators are elected from single member districts and each legislator has one vote within the legislature. The early reapportionment cases therefore identified one political structure -- equal-sized, single-member

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[42]More precisely the Shapley-Shubik index assumes that it is equally likely that a coalition of any size forms, and that all coalitions of a given size are equally like to form. An equivalent characterization is that the Shapley-Shubik index gives the probability that as an individual joins a coalition she will be a swing under the assumption that all orders of coalition formation are equally likely.

[43]For an axiomatic characterization of the two indices see Dubey and Shapley [1979].

districts -- that satisfies the constitutional requirement that each citizen's vote have equal influence on political outcomes.[44] Other political structures, however, were soon challenged. These challenges required the judiciary to elaborate a conception of "equal voting power."

Two political structures were of particular interest. Suppose that districts vary in size. In systems of weighted voting, each district elects one legislator, but the elected representatives of larger districts are given more votes within the legislature. What set of voting weights, if any, yield equal influence of each citizen's vote? In the second political structure, larger districts elect more representatives. How should representatives be allocated among the districts to satisfy the constitutional mandate?

The Banzhaf index (and Shapley-Shubik index) suggests answers to these questions. Citizens in a representative democracy play a compound voting game. They elect representatives, and these representatives then pass legislation. There are three ways that the Banzhaf index could be used in this context. Firstly, it could be used to measure the power of the elected representatives voting in the legislature. Secondly, it could be used to measure the power of citizens when voting for representatives. Finally, it could be used to measure the net power of citizens in the compound voting game. Since the probability that a citizen is a swing voter for the final passage of legislation equals the probability that her vote is crucial to getting her legislator elected times the probability that the legislator's vote is crucial, this last measure of

[44]The case law focuses on the formulation of the conception of right articulated in Reynolds v. Sims [1964]. There the U.S. Supreme Court stated that "each and every citizen has an inalienable right to full and effective participation in the political processes of his State's legislative bodies." [at 565] Moreover, "full and effective participation by all citizens in state government requires . . . that each citizen have an equally effective voice in the election of members of his state legislature." (at 565)

Banzhaf power is simply the product of the first two.

From roughly 1967 through 1990 the Banzhaf index served as a judicially accepted criterion for the determination of the power of representatives at the legislative level in weighted voting schemes. The Banzhaf index had particular importance in New York State where many county boards elected supervisors from towns with widely varying populations.[45]

Indeed, Banzhaf's first article analyzed the striking case of the Nassau County Board of Supervisors in 1958 and 1964. Voters in different municipalities elected a total of six representatives. Since the municipalities differed in size, the elected representatives were given different voting weights, presumably to equalize the power of the citizens in the different municipalities. Incredibly, the weights were distributed among the representatives in such a way that three representatives had no swings - their votes could never influence the outcome (see Table 1). In fact, the complicated weighting scheme masked the fact that both in 1958 and 1964 the six representatives were actually playing a game of three-player majority rule; three of the representatives had power 1/3 and three had power 0 under both the Shapley and the normalized Banzhaf index.

Table 1
Board of Supervisors-Nassau County

1958				
Municipality	Population	Weight of Representative	Unnormalized Power	Normalized Power

[45]Imrie [1973] and Lucas [1983] provide brief accounts of the use of the Banzhaf index in New York state.

Hempstead1	618,065	9	1/2	1/3
Hempstead2		9	1/2	1/3
N. Hempstead	184,060	7	1/2	1/3
Oyster Bay	164,716	3	0	0
Glen Cove	19,296	1	0	0
Long Beach	17,999	1	0	0
1964				
Hempstead1	728,625	31	1/2	1/3
Hempstead2		31	1/2	1/3
N. Hempstead	213,225	21	0	0
Oyster Bay	285,545	28	1/2	1/2
Glen Cove	22,752	2	0	0
Long Beach	25,654	2	0	0

Subsequently, in Iannucci v. Board of Supervisors of Washington County [1967] the New York Court of Appeals, the highest court in New York State, endorsed the Banzhaf index as the appropriate standard for determining the weights accorded to representatives of districts of varying sizes. The Court stated that the principle of one-person-one vote was satisfied as long as the "[Banzhaf] power of a representative to affect the passage of legislation by his vote . . . roughly corresponds to the proportion of the population of his constituency." (at 252) Interestingly, the Court explicitly endorsed the abstract nature of the power calculus, ruling that "the sole criterion [of the constitutionality of weighted voting schemes] is the mathematical voting power which each legislator possesses *in theory* (emphasis added) . . . and not the actual voting power he possesses in fact . . . " (at 252). In (Franklin v. Kraus [1973]) the New York Court of Appeals again approved a weighted voting system that made the Banzhaf power index of each representative proportional to his district's size.

In both these cases the court used the Banzhaf index to determine the voting power of the legislators. The courts, however, did not carry the Banzhaf reasoning through to the citizen level. It can be shown that the probability that an individual is a swing voter in the election of her legislator is (approximately) inversely proportional to the *square root* of the population of her district. Thus, equalizing each citizen's net Banzhaf power in the compound voting game would require that a legislator be given power proportional to this square root. Nonetheless, the courts decided that a legislator's power should be proportional to the population itself.

How do we account for the failure of the courts to consider the citizen's power in the compound game? Apparently, the courts adopted a different view of the relation between representative and citizen than that implicit in Banzhaf.[46] The swing voter analysis assumes that citizens disagree about which candidate would best represent the jurisdiction and that the prevailing candidate acts in the interests of those citizens *who voted for her*. On a different conception of representation, however, once elected a candidate represents the interests of *all* citizens within her constitutency. Each citizen in a district then exerts an equal influence upon the district representative, so that a citizen's influence is inversely proportional to the district population. Hence, under this conception, a representative's power should be proportional to the number of constituents in her district, as the courts ruled.

We now consider judicial treatment of multimember districts. In Abate v. Mundt [1969], the New York Court of Appeals upheld a system of multi-member districts that allocated

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[46]Banzhaf(1965) is noncommital about the relationship between a citizen and his representative. Banzhaf(1968) explicitly endorses the compound voting computation suggested above.

supervisors to election districts in proportion to district populations. The court again ignored the compound game analysis. It should be noted, however, that unlike Banzhaf's analysis of weighted voting schemes, his analysis of multi-member districts is seriously flawed. His assertion that voters in districts should be given representatives in proportion to the square root of the size of the population is unwarranted.

First of all, it is clear that no recommendation on the number of representatives in a multimember district can be made independently of the voting method being used to elect these representatives. Is each voter being given one vote or the same number of votes as there are representatives or is some other method in use? Second, if individuals are given many votes, then what is the proper assumption to make on the way these votes are cast? Clearly, the assumption that an individual is casting her own votes independently of each other is absurd. Finally, what assumption is being made about the correlation of the voting behavior of representatives voted for by a single individual? If the correlation is perfect, then, in effect, the multimember districting scheme results in a weighted voting game in the legislature. Of course, the ratios of voting powers in such a game are not neccessarily equal to the ratios of voting weights. On the other hand, if these representatives are voting differently from each other, in what sense are they all representing the same individual? There may well be such a sense, but it is ill-captured by the Banzhaf conception, which considers the probability that a voter will be decisive on an issue.

A few years after Abate, the United States Supreme Court (in Whitcomb v. Chavis [1973]) rejected the Banzhaf index in the judicial evaluation of multi-member districts. The Court argued that the index offered only a theoretical measure of the voter's power while constitutional considerations had to rest on disparities in actual voting power.[47] Thus, the theoretical character of the power index which had pleased the New York Court of Appeals, moved the United States Supreme Court to reject the index.

In 1989 the U.S. Supreme Court explicitly carried out a compound voting game analysis when considering the weighted voting scheme used by the Board of Estimate of New York City.[48] The court rejected the Banzhaf index, again citing its "theoretical" nature. On the basis of this decision, one federal district court struck down as unconstitutional the weighted voting scheme that then prevailed in Nassau County.[49] A second federal district court approved a weighted voting system in the New York county of Roxbury which assigned *weights* proportionally to population.[50] Thus, for the time being at least, the Banzhaf index appears to have been discredited for all United States legislative apportionment purposes.

This brief history illustrates both the potential significance and difficulties of judicial use of game-theoretic (or other formal) concepts in the articulation of legal rules. The Banzhaf index governed the shape of weighted voting systems for roughly twenty years and partially shaped the judicial treatment of voting systems that consisted of unequal sized districts. Unfortunately, however, the courts and the community of political scientists and game theorists failed to engage

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[47]Banzhaf was an expert witness for plaintiffs at trial and signed the plaintiff-appellee's brief to the United States Supreme Court. Interestingly, plaintiffs sought single-member districts as a remedy in <u>Whitcomb v. Chavis</u>.

[48]Morris v. Board of Estimate of New York City [1989]

[49]Jackson v. Nassau County Board of Supervisors [1993]. The weights at issue in the litigation had been allocated so that the Banzhaf power of each representative was proportional to the population of the representative's district.

[50]Roxbury Taxpayers Alliance v. Delaware County Board of Supervisors [1995].

in a constructive dialogue that would have enabled the courts to formulate a coherent conception of equal and effective representation for each citizen. The courts never clearly articulated or resolved three important questions. First, as we remarked earlier, the courts had to choose whether to focus attention on the game constituted by voters electing representatives, the game played by the elected representatives in the legislature, or the compound game. The role of citizens in the compound game seems normatively the correct one for the courts to consider, but they were never clear on this point. Second, and as a consequence of their failure to consider the compound game explicitly, the courts did not articulate a theory of representation that would allow analysis of the compound game. Finally, the courts did not question whether power was the appropriate concept for expressing equality of representation. The indices of voting power measure the probability that an individual will be a swing voter under various assumptions; the related concept of satisfaction measures the probability that the outcome will be the one that the voter desires. In a town with like-minded citizens each one will have zero voting power since decisions will always be unanimous and no individual voter will be crucial. On the other hand, each citizen will have a satisfaction of one. The courts should have at least considered whether satisfaction was a more appropriate concept on which to construct the rights to fair and effective representation than power.

The analytic community on the other hand bears some responsibility for the judicial failure to confront these three questions. Neither Banzhaf himself nor other commentators on the judicial efforts clearly framed the question in terms of the compound game. Moreover, discussions of the importance of the concept of representation to the analysis of the game were sparse. Finally, although a voter's satisfaction is arguably more important than a voter's power, the former concept has received comparatively little attention from game theorists.[51]

5.2 Fair Allocation of Losses and Benefits.

Adjudication resolves disputes among parties. Courts are thus often more concerned, at least superficially, with the fair resolution of the dispute between the parties before the court than with the ex ante behavior that may avoid similar disputes in the future (or reshape them). Many classes of disputes, in fact, seem explicitly directed at the fair division of property among disputing claimants. The most obvious area of law in which questions of this type arise is bankruptcy where the court must allocate the assets of the bankrupt among its creditors in a way that distributes the loss--i.e., the difference between the (valid) claims of creditors and the value of the estate--fairly.[52] Other areas include: the interpretations of wills that divide more assets among the heirs than are actually available; the rules of contribution when the share of an insolvent tortfeasor must be allocated among the remaining joint tortfeasors; rate proceedings for common carriers such as telecommunications or electricity providers when the common costs of service provision must be allocated among different classes of customers; the determination of fee awards to class action attorneys when the common costs of representation must be allocated among different classes of plaintiffs.

One might reasonably ask what conception of fairness is embodied in legal rules

[51]On satisfaction see Brams and Lake [1978] and Straffin, Davis, and Brams [1982]

[52]In fact bankruptcy law must balance other concerns with fairness. In particular, the rules of bankruptcy may affect the pre-bankruptcy behavior of both debtor and creditors. Moreover, even after bankruptcy, the value of a debtor corporation is generally greater as an on-going concern than liquidated; capturing this surplus may entail creating incentives to some parties such as managers or specific creditors that otherwise seem unfair. Finally, we have ignored concerns about priority of claims of different types of creditors.

governing these allocations? What explains variation, if any, in these rules? In the case of common law, a judge confronted with a dispute consults the decisions in analogous, previously decided cases and attempts to articulate a principle or set of principles that rationalizes these outcomes. Here, answering the above questions is particularly important and difficult.

Talmudic law, like anglo-american law, is a form of common law adjudication. Aumann and Maschler [1985] and O'Neill [1982] have deployed game theoretic tools to explicate in part the rules implicit in two areas of Talmudic law that concern the fair allocation of property among disputing claimants.

Aumann and Maschler consider the following bankruptcy problem from the Talmud. There are three creditors on an estate. Creditor 1 is owed 100; creditor 2 is owed 200, and creditor 3 is owed 300. The estate is worth less than the 600 total claim. The Talmud states that when the estate is valued at 100, the creditors should each receive $33\frac{1}{3}$; when the estate is valued at 200, the creditors should receive, respectively, 50, 75, and 75; when the estate is valued at 300, the allocation should be (50, 100, 150). What principle underlies the prescribed allocations? How should these three examples be extended to other bankruptcy cases?

As a preliminary, consider "the contested-garment problem" from the Mishnah: one individual claims an entire garment; a second individual claims one-half of the same garment. The Talmud allocates the garment (3/4, 1/4) to the two claimants respectively. Here, the underlying principle is well understood by Talmudic scholars. The second claimant implicitly concedes half the garment to the first, while the first claimant concedes nothing. Each claimant is given the amount that is conceded to him, and the remainder is divided equally. However, this principle is articulated only for the case of two claimants. How can this principle for the two-claimant case be extended to the n-claimant case?

Define a general claim problem $P = (A; c_1, c_2, \ldots, c_n)$, where A is the total amount of assets to be distributed and c_i is i's claim on A. Aumann and Maschler call a distribution x of the amount A "contested-garment consistent" if (x_i, x_j) is the contested garment solution to the claim problem $(x_i+x_j; c_i, c_j)$ for all claimants i and j. There is a unique contested-garment consistent solution and this solution gives the allocations prescribed by the Talmud for the above three bankruptcy problems.

Note that while the notion of contested-garment consistency does not appear elsewhere in the game-theory literature, this "consistency" approach is certainly game-theoretic in spirit. For instance, Harsanyi has characterized the product solution to the n-person Nash bargaining problem as the unique solution which is Nash-consistent for all pairs of bargainers.

Aumann and Maschler turn the claim problem into a cooperative game by associating the following characteristic function game with it:

$$v(S) = \max(A - \Sigma_{i \in N-S} c_i, 0) \quad \text{for } S \subseteq N.$$

This characteristic function is constructed on the assumption that claims are satisfied in full as they arrive and that a coalition can only *guarantee* itself what it would receive if it were the last to make a claim on the assets A. Alternatively, a coalition's worth is what it obtains when it concedes the claims of the other claimants. The contested-garment consistent solution (and hence the Talmudic division to the three bankruptcy problems) is the nucleolus of this coalitional game.

While this result is remarkable and Aumann and Maschler's discussion is insightful and revealing, various objections can be raised. These objections pertain to the limitations of the game-theoretic approach in general.

A difficulty in applying game theory is that "real world" situations are not presented as games. Rather a game must be defined. While the characteristic function Aumann and Maschler associate with the claim problem is a reasonable one, other specifications are also reasonable. For instance, we could define a coalition's worth to be its expected payment assuming that the other claimants do not form coalitions, that all claimants are paid off as they arrive, and that all orders of arrival are equally likely.

Similarly, while consistency notions are interesting, several can be defined. Thus, call a solution x to a claim problem "CG2-consistent" if for all $S \subset N$, $(\sum_S x_i, \sum_{N/S} x_i)$ is the contested-garment solution to $(A; \sum_S c_i, \sum_{N/S} c_i)$. As the claim problem (500; 100, 200, 300) shows, there is no CG2-consistent solution.[53] This non-existence might be taken as evidence that CG2-consistency is the wrong notion of consistency, but it might just as well indicate that the contested garment example should not be extended to more than two people.[54]

As noted earlier, two questions arise in the analysis of a body of common law cases. What is the general rule that is to be derived from the disposition of particular cases, and what is the conception of fairness embodied in this law? These two questions are related because a rule that rationalizes a set of cases must both "fit" those cases and offer an

[53]Solving for x_i by taking $S = \{i\}$ for each claimant one at a time yields (50,150,250) as the putative CG2-solution but this does not sum to 500.

[54]Aumann and Maschler consider a principle similar to CG2-consistency. They show how a modification of this principle can be used to again derive the CG-consistent solution.

attractive rationale for them. After all, many rules will be consistent with the decisions in the set of cases.

Aumann and Maschler explicitly address the first question. Implicitly, they address the second as well. The nucleolus of a bankruptcy problem minimizes the maximum loss suffered by any coalition. Thus, it has an egalitarian spirit, but one in which coalitions and not just individuals are taken as objects of concern.

O'Neill considers a problem in which a testator bequeaths shares in his estate, valued at 120, that total to more than one. The entire estate is bequeathed to heir 1, half the estate to heir 2, one third the estate to heir 3 and one quarter the estate to heir 4. According to O'Neill, the 12th century scholar Ibn Ezra claimed that the division (97/144, 25/144, 13/144, 9/144) is the appropriate one.

Ibn Ezra reasoned that heir 4 lays claim to a fourth of the estate, but that all four heirs make equal claim to this quarter and so this quarter is split evenly. Next heir 3 claims one third of the estate. He has already received his share of 1/4 of the estate, so now he and the two larger claimants receive an addtional 1/3(1/3-1/4) for a total of 13/144. Proceeding in this manner yields the above numbers.

In contrast to the earlier bankruptcy problem, here the reasoning underlying the division is given explicitly. O'Neill is interested in both extending this reasoning and proposing alternative, albeit related, solutions. Notice that while each heir only makes a claim for himself, this claim can be taken as implicitly imputing a division of the remainder of the assets to the other heirs. Indeed, given a specific heir's claim and an allocation rule, use the rule to impute a division of the remainder of the assets to each of the other heirs. Since no heir has any greater legitimacy than any other, compute the allocation that results from averaging the various divisions obtained in this manner. O'Neill calls a rule consistent if the allocation thus obtained is the same as the allocation the rule prescribed for the initial problem. Ibn Ezra's solution is not consistent in this sense.

Again associate the characteristic function $v(S) = \max(A-\Sigma_{i\varepsilon N-S}c_i, 0)$ with this claim problem. The Shapley value yields an allocation which is consistent in O'Neill's sense. Furthermore, the Shapley allocation affords an interesting interpretation. Suppose that each heir is simply paid off in full as he presents his claim until the estate is exhausted. The allocation which results from averaging over all possible orders in which the claims could be presented is the Shapley value. This allocation method shares some of the spirit of Ibn Ezra's method in that each heir's claim is taken equally seriously.

When making allocations, courts might want to balance practical considerations with ethical ones. For instance, courts may not want to give claimants the incentive to combine their claims. Thus, they might require that if $(x_1,..., x_i,..., x_j,..., x_n)$ is the solution to $(A; c_1..., c_i\ . . c_j\ .. ., c_n)$ then $(x_1,..., x_i + x_j,...x_n)$ is the solution to $(A; c_1..., c_i + c_j\ ..., c_n)$. The only anonymous such rule is proportional allocation.[55]

One should note that American law generally does not resolve claims problems similarly to the Talmudic solutions that inspired O'Neill and Aumann and Maschler. In bankruptcy law, the assets A are, in fact, allocated among claimants proportionally to their claims. American law presumably adopts this approach because creditors may freely transfer claims on the debtor-in-bankruptcy. With inheritances the problem is considered one of

[55]See Moulin [1988], O'Neill [1982] and Young [1994].

interpreting the intent of the testator. If no clear intent can be inferred, the will is invalid, the individual dies intestate, and the state's default rules of inheritance govern. Determination of intent depends critically on the precise wording of the document. See, e.g. Estate of Heisserer v. Loos, (1985), In re Vismar's Estate, (1921), Rodisch v. Moore, (1913).

The shares of insolvent defendants among joint tortfeasors are generally allocated using one of two rules. Under legal contribution, the tortfeasor against whom the plaintiff chooses to execute the judgment must bear entire share of the insolvent parties. Under equitable contribution, these insolvent shares are divided among the solvent tortfeasors either equally or proportionally to their own shares. (Kornhauser and Revesz [1990] summarizes the law in this area.)

6. Concluding Remarks.

Law pervades daily life. Legal rules structure relations among individuals, institutions, and government. The theory of games provides a framework within which to study the effects these legal rules have on the behavior of these agents. In a legal culture that considers law a means to guide behavior to specified goals, this framework will interest not only legal scholars but also lawmakers directly as they attempt to design rules that forward their goals. In the last decade, analysts have deployed increasingly sophisticated models to an ever-widening range of legal rules. Our discussion has merely scratched the surface of this literature. Many analyses of legal rules focus not on the behavioral effects of these rules but on their conceptual and normative foundations. The tools of game theory have also offered insights into these areas.

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