LEARNING LIABILITY RULES

DONALD WITTMAN, DANIEL FRIEDMAN, STEPHANIE CREVIER,
*and AARON BRASKIN**

Abstract

We conduct experiments regarding the equilibrium and convergence properties of three different liability rules: negligence with contributory negligence, comparative negligence, and no-fault. Our experimental results show that, in comparison to contributory negligence, comparative negligence promotes a faster and more reliable convergence to the efficient equilibrium. Furthermore, as predicted by theory, the no-fault equilibrium yields suboptimal amounts of effort. Along the way we also test various hypotheses regarding learning and other adjustment dynamics. Thus our article extends the traditional static notion of institutional choice—liability rules with efficient equilibria are chosen—to a more dynamic perspective—rules that rapidly achieve efficient equilibria are chosen.

Economic theorists have long argued that, in the presence of perfect information (and in the absence of court costs), negligence-based liability rules are superior to other liability rules because the former lead to efficient outcomes while the nonnegligence rules do not.[1] But the extensive literature on liability rules has two major lacunae: (1) there have been virtually no

* We are indebted to LeighAnne Jarvis for helping to conduct a pilot experiment and to David Wright for helping us analyze the data. The National Science Foundation partially supported our research under grant SES 9023945. Details of our research are found in Learning Liability Rules (University of California, Santa Cruz, Department of Economics Working Paper No. 306, 1995). We received many useful comments from Jennifer Arlen, Michael Bergman, the referee, and audiences at the March 1994 Public Choice Society meetings and at the May 1994 American Law and Economics Association meetings and at economics department seminars at Arizona, Lund, University of California, San Diego, and Wisconsin.

[1] John P. Brown, Toward an Economic Theory of Liability, 2 J. Legal Stud. 1 (1973), demonstrated the efficiency properties of negligence, negligence with contributory negligence, and strict liability with contributory negligence. William Landes & Richard Posner, Joint and Multiple Tortfeasors: An Economic Analysis, 9 J. Legal Stud. 517 (1980), demonstrated the efficiency of comparative negligence. Steven Shavell, Strict Liability versus Negligence, 9 J. Legal Stud. 1 (1980), argued that negligence rules are inefficient when the level of activity is ignored; Michelle J. White, An Empirical Test of the Comparative and Contributory Negligence Rules in Accident Law, 20 Rand J. Econ. 308 (1989), established the same conclusion when the standard is uncertain or too high.

[*Journal of Legal Studies*, vol. XXVI (January 1997)]

empirical tests of these propositions, and (2) the extant theory has provided little guidance regarding the best choice among the various-negligence based liability rules. This article seeks to rectify both problems.

We argue that the choice between comparative negligence and negligence with contributory negligence, both of which theoretically lead to the same efficient equilibrium, depends on their relative speed of convergence to equilibrium. The social costs arising from slow or erratic convergence can be very high. Our message is that liability rules shape the learning process and thus determine the speed of *convergence* to equilibrium.

We undertake an experimental test of three liability rules. Negligence with contributory negligence, comparative negligence and no fault represent, respectively, the past, present, and possible future of accident law in most states.[2] As predicted, the laboratory tests show that no fault leads to suboptimal levels of care. Both comparative negligence and negligence with contributory negligence yield mean care levels close to the optimal, but convergence is much more rapid and reliable under comparative negligence. Learning behavior in our experiment is shown to be better approximated by an extension of the fictitious play model than by several alternative learning models.

In the last section we briefly discuss the implications of our results for the historical choice of liability rules for torts involving automobile and other sorts of accidents.

I. Equilibrium Theory

We construct a basic equilibrium model with perfect information and symmetric damages. Automobile accidents, where either party may be the injurer or the injured, are the classic example of symmetric damages. The model does not address all questions of possible interest—for instance, we neglect transaction costs, risk aversion and insurance motives, and inefficient choices of the legal standard—but the model does provide an adequate basis for later discussion of learning behavior.

Damage $D(x, y) \geq 0$ to the first party X is a decreasing function of the care levels or prevention costs $x \geq 0$ and $y \geq 0$, undertaken respectively by X and by the second party Y; that is, $D_x, D_y < 0$.[3] It is also assumed

[2] In approximately three-fourths of the states, comparative negligence is the operative liability rule for automobile accidents. In most of these states, negligence with contributory negligence had previously been in force.

[3] The value $D(x, y)$ implicitly refers to expected rather than realized damage. One could work explicitly with a stochastic damage function, but that would complicate the notation without providing any additional insight into the equilibrium results. We suspect that stochastic damage would slow down the rate of learning considerably for all liability rules but would not alter the ranking across rules.

that D_{xx}, D_{yy}, $D_{xy} > 0$ and $D_{xx}D_{yy} > D_{xy}D_{xy}$. The symmetry assumption is that $D(x, y) = D(y, x)$. That is, a priori X and Y have equal ability to mitigate damages and they suffer equally in an accident. The total damage to both parties is $D(x, y) + D(y, x) = 2D(x, y)$.

Society wishes to minimize the sum total of damage and damage prevention costs $C^s = x + y + 2D(x, y)$. It is easy to show that there is a unique symmetric social optimum $x^\Omega = y^\Omega$.

We now consider the portion C^r of the total cost borne by the first party X under each liability rule r. The cost to Y then is the cost to society minus the cost to X. The first two rules use the concept of negligence, the degree to which the care level x or y falls short of a known normative level x^N. We assume throughout our analysis that the normative level is efficient, that is, $x^N = x^\Omega$.

Under comparative negligence, $r = \text{CN}$,[4] both sides share in the liability according to their relative negligence, or care shortfall: $x_s = \max\{0, x^\Omega - x\}$ and $y_s = \max\{0, y^\Omega - y\}$. Thus $C^{\text{CN}} = x + 2D(x, y)x_s/(x_s + y_s)$ is the cost to X under CN. For example, if Y is twice as negligent as X, then Y is liable for two-thirds of the damages, $2D(x, y)$, and X is liable for one-third. If neither party is negligent we use the convention $0/(0 + 0) = 1/2$, so the formula says that each party is liable for its own damage, that is, half the damage costs.

Under negligence with contributory negligence ($r = \text{NCN}$), total costs are split in the same way as under CN if only one party is negligent (that party pays full damages $2D(x, y)$) or if neither party is negligent (both pay their own damage $D(x, y)$). The split is different when both X and Y are negligent. In this case X and Y will be liable under NCN for their own damage only.[5] The rule can be expressed concisely using the negligence indicators $x_n = 1$ if $x < x^\Omega$ and $= 0$ otherwise, and $y_n = 1$ if $y < y^\Omega$ and $= 0$ otherwise. Then the cost to X under NCN is $C^{\text{NCN}} = x + 2D(x, y)x_n/(x_n + y_n)$.

[4] David Haddock & Christopher Curran, An Economic Theory of Comparative Negligence, 14 J. Legal Stud. 49 (1985); Daniel Rubinfeld, The Efficiency of Comparative Negligence, 16 J. Legal Stud. 375 (1987); Daniel Orr, The Superiority of Comparative Negligence: Another Vote, 20 J. Legal Stud. 119 (1990); and Tai-Yeong Chung, Efficiency of Comparative Negligence: A Game-Theoretic Analysis, 22 J. Legal Stud. 395 (June 1993) have analyzed comparative negligence in the context of one side being the injurer and the other being the victim. See William Landes & Richard Posner, The Economic Structure of Tort Law (1987), for a discussion of the symmetric case. There are many variations of comparative negligence.

[5] See Jennifer Arlen, Re-examining Liability Rules When Injurers as Well as Victims Suffer Losses, 10 Int'l Rev. L. & Econ. 233 (1990); and Jennifer Arlen, Liability for Physical Injury When Injurers as Well as Victims Suffer Losses, 8 J. L. Econ. & Org. 411 (1992), for an earlier analysis of NCN where either party may be the injured or the injurer. With symmetric damages, a simple negligence rule is equivalent to NCN.

Under no fault (r = NF) each party is liable only for the damage to herself.[6] That is, the cost to X under no fault is $C^{NF} = x + D(x, y)$.

The following proposition summarizes the static efficiency and uniqueness results for all three rules.

PROPOSITION. There is a unique Nash equilibrium in pure strategies for r = CN, NCN, and a unique symmetric Nash equilibrium in pure strategies for r = NF. For r = CN and NCN, the Nash equilibrium is the social optimum (x^{Ω}, y^{Ω}). For r = NF, the symmetric Nash equilibrium calls for a lower level of care than the social optimum.

Proof. See the papers already cited and/or our working paper.[7]

II. Learning

Few if any economists or game theorists really believe that humans always achieve Nash equilibrium instantaneously. Most implicitly believe that some adjustment process guides human behavior so that (under favorable circumstances, eventually) it closely approximates Nash equilibrium. Such an adjustment process occurs, for example, whenever the court or legislature ratifies changes in the efficient standard of care or whenever there are new entrants and exiters from the driving population. Granted that there is some adjustment process, it then becomes natural to ask which circumstances speed the process and which impede it. In particular, which liability rules promote rapid and reliable convergence to the efficient Cournot-Nash Equilibrium (NE) and which allow at best slow and erratic convergence?[8]

The adjustment process is crucial. For some applications, for example, asset market behavior, one might focus on entry and exit or on wealth redistribution. In other applications, adjustment mainly takes the form of *learning* or changes in individual behavior in response to experience, including imitation of apparently successful individuals. We regard learning as the main adjustment process for liability rules because the population and wealth distribution remains more or less constant over the time periods when motorists adjust to changes in the efficient care level.

Our view is that, just as equilibrium thinking is based on Cournot behavior, so is out-of-equilibrium behavior. That is, if other players are undertak-

[6] Given the symmetry of damages, the analysis is identical to that of strict liability.

[7] Daniel Friedman & Donald Wittman, Learning Liability Rules, (Working Paper No. 306, Univ. California, Dep't Economics, 1994).

[8] Samuel Rea, The Economics of Comparative Negligence, 7 Int'l Rev. L. & Econ. 149 (1987), points out that some individuals may not choose the Nash effort level because they are judgment proof or because they misperceive risks or costs. We regard these as reasons for slow adjustment to equilibrium. Rea argues that, in comparison to NCN, comparative negligence is more robust to the presence of these ''unresponsive'' individuals.

ing nonequilibrium behavior, the person will treat this behavior as a given and choose her best response. If X has undertaken a nonoptimal degree of care (that is $x \neq x^{\Omega}$), Y's best response may be for her to also take a nonoptimal degree of care. It can be shown mathematically (see our working paper for the proofs) that, whenever the best response under NCN differs from that under CN, it turns out that the CN best response is the efficient equilibrium level, x^{Ω}. So Cournot response to out-of-equilibrium behavior is more likely to be equilibrium behavior under CN than under NCN. Otherwise their Cournot behavior is identical. This suggests that, if people engage in best response behavior, then convergence to the equilibrium should be more rapid under CN because more players are likely to choose the equilibrium behavior as their best response to out-of-equilibrium behavior, and with more people choosing equilibrium behavior, other players' best response is then to choose the equilibrium level, also.

Do humans really engage in best response behavior? Other aspects of the interaction may also be important. To assess the value of our approach, we need a fully specified empirical model of the learning process. The good news is that there are many such models in the literature. The bad news is that none of them is canonical.

We need a learning model that can represent best responses as well as other factors influencing human choice. Perhaps the simplest such model is

$$x_t = \alpha x_{t-1} + \beta B(\hat{x}_{t-1}). \tag{1}$$

Here x_t is the current state (the care level chosen by a player, the mean care level or perhaps the distribution of care levels in the current population), B is the best response function, and $\hat{x}_{t-1}$ is a forecast of the current state using information available at time $t - 1$.

The main explanatory variable, of course, is the best response $B(\hat{x}_{t-1})$. It can be specified in several ways, depending on the interpretation of the state and the assumed forecasting procedure. The two most popular forecast specifications are Cournot—$\hat{x}_t = x_t$, so players expect the next period to be the same as the present period—and fictitious play—$\hat{x}_t = t^{-1} \sum_{s=1}^{t} x_s$, so players expect the next state to be the average of previous states (for example, they regard states as independent draws from a distribution whose mean is estimated by the sample mean of states observed so far).

The other explanatory variable is the previous state, x_{t-1}, a proxy for all other influences that vary slowly. The model allows for the possibility that players immediately best respond ($\beta = 1$) and allows for some inertia ($\alpha > 0$). To the extent that the model captures systematic behavior, we can use it to compare the learning process across the different liability rules. The model also can compare rival specifications of the predicted state.

We have looked at several parametrizations of the damage function and numerous variants on (1) and other parametric learning models. We have yet to find a case where the NCN rule promotes faster convergence to the efficient NE than does the CN rule. But the real test is with humans. We use the ideas developed in this section to structure some laboratory experiments with the three liability rules and to help analyze the data. Let us now turn to those procedures and results.

III. Experiments

A. *Previous Work*

Despite the extensive theoretical work on liability rules, there has been very little experimental work. Lewis Kornhauser and Andrew Schotter[9] compared strict liability with negligence liability in the context of a single-actor model. In a single-actor model, the subjects are injurers and the outcome depends only on their care level. They found that the participants chose care levels that were excessively high in the early rounds of the strict liability experiment. As the experiment progressed the level of care used by the subjects began to decrease. At the end of the experiment, care levels were less than the optimal care level. These latter results are consistent with our results for no fault (no fault and strict liability are equivalent under the assumption of symmetric damages). Under the negligence rule, the participants' behavior was more economically efficient and converged to the optimum.

LeighAnne Jarvis and Stephanie Crevier[10] ran two pilot experiments (only eight subjects over five periods in a noncomputerized classroom setting) comparing the NCN and CN liability rules. The parametrizations and instructions were roughly similar to those used here. The data appeared to favor CN, but the number of observations were insufficient to draw reliable conclusions.

In 1991, Kornhauser and Schotter[11] compared negligence to negligence with contributory negligence in the context of two-actor accidents. (Unlike our work, they had one set of subjects be the injurers and another set be the victims.) Both liability rules were found to be optimal when the standard of

[9] Lewis Kornhauser & Andrew Schotter, An Experimental Study of Single-Actor Accidents, 19 J. Legal Stud. 203 (1990).

[10] LeighAnne Jarvis & Stephanie Crevier, Comparing Two Liability Rules: Negligence with Contributory Negligence and Comparative Negligence (Term Paper No. 165W92, Univ. California, Dep't Economics, Winter 1992).

[11] Lewis Kornhauser & Andrew Schotter, An Experimental Study of Two-Actor Accidents (Working Paper No. 91-60, New York Univ., Dep't Economics, 1991).

care was set to the socially optimal level.[12] Information levels were also varied and found to have a relatively minor effect.[13] In view of these conclusions we decided in our experiments not to vary the level of information and not to consider a simple negligence rule (which is also quite rare in automobile accident law).

B. Present Design

We designed three computerized sessions, each lasting 36 periods or about 100 minutes in a networked Macintosh computer lab. Twelve inexperienced subjects were to participate in each session and use each liability rule for 12 consecutive periods in balanced sequences.[14] Subjects were recruited from University of California, Santa Cruz, undergraduate classes. After all subjects arrived and were seated, they received written instructions that were publicly reviewed (see App. A), got answers to their questions, and ran several practice periods. Care levels appeared as headings for the 10 columns of the payoff matrix displayed on the screen.

Each period each subject chose a care level which then was highlighted; after all subjects confirmed their choices, they were randomly matched and the row corresponding to the partner's choice was highlighted. The payoff at the intersection of highlights then was automatically copied to a computerized record sheet that displayed the subject's previous choices, previous partners' choices, and the resulting payoffs. The instructions (see App. A) used neutral language to explain the payoffs as ''net values'' (''income'' less ''care level'' and ''cost'') and made clear that partners were randomly rematched each period.

Entries in the payoff matrix were based on the damage function $D(x, y) = d - a(x + y)^b$ with parameters $a = 9$, $b = .6$, $d = 350$, the usual social cost function $C^s = x + y + 2D(x, y)$, and the rules $r =$ CN, NCN, NF for allocating social cost. The payoff matrix for rule r then was a discrete approximation to $700 - C^r(x, y)$. The actual payoff matrices for each liability rule are included in Appendix B. The reader can confirm that the sym-

[12] *Id.* at 40. When actors were allowed to vary their frequency of activity (number of car trips) as well as their level of care, the results demonstrated that neither rule was very successful in predicting activity level although levels of care remained close to the optimal (*id.* at 31–33). We did not vary the activity level in our experiments since it only introduced more noise into their results.

[13] *Id.* at 38.

[14] For example, CN then NF then NCN in one session, NF/NCN/CN in another, and NCN/CN/NF in the third session. The execution was not precisely as planned. Two sessions ran with 10 rather than 12 subjects because of no-shows. Due to a computer glitch, the last CN run was only 9 periods. We found no evidence that these glitches had any effect on our results.

metric Nash equilibrium care levels are at column 9 for NCN, column 7 for CN, and a mixture of columns 2 and 3 for NF.[15] The optimal care level for NF is column 9; of course, for the other rules the optimal level coincides with NE. At the end of the session, one period was randomly selected, and all subjects received the payoff earned that period in cash. The average cash payment was about $15.00.

IV. Results

Figure 1 shows how average care level changed over time. Panel *c* gives the clear impression that actual care levels converge closely to the efficient NE level ($z^{\Omega} = 7$) under the CN liability rule.[16] From an initial mean care level (and standard deviation) of 6.75 ($\pm$1.55) in the first period, the subjects attained 7.09 ($\pm$0.29) by the last period. Panels *b* and *c* show roughly similar patterns, but one gets the impression that convergence to NE is slower and perhaps biased under the NCN rule. We will put this impression to the test in the next two subsections.

A. Deviations from Equilibrium

Table 1 confirms that care level choices converge more closely to the efficient level under CN than under the other liability rules. For example, the second line shows that of the 192 care level choices made in the last six periods under CN, only 12 were above the NE level, while 28 were below and $192 - 12 - 28 = 152$ were exactly at the efficient NE care level $z^{\Omega} = 7$. The mean level of care was only 0.35 below z^{Ω} (SD = 1.35).

For the NF liability rule, the difference between the mean level of care and the predicted NE level of 2 or 3 was not much larger in absolute value, but had the opposite sign. Departures from the efficient care level were, as expected, much larger, averaging almost -4.0.

The NCN liability rule produced a mean level of care about 2.0 below the efficient NE care level. The gap hardly narrowed in the last 6 periods, remaining at -1.93 (SD = 3.17).

The mean care levels under CN imply ultimate cash rewards about 5 per-

[15] No fault has a unique (symmetric pure strategy) NE, but it is between columns 2 and 3. The discretized NF game (where choices are restricted to the 10 columns) has a mixed strategy NE. The efficient NE level of care, x^*, is 192 for both CN and NCN, but the Nash equilibrium column choices, z^*, are different; thus for NCN a care level of 192 is achieved by choosing column 9, while for CN the same care level is achieved by choosing column 7. We used a slightly different discretization for CN to avoid confounding possible inertia by the player from one liability rule experiment to the next with their optimizing behavior.

[16] We use z^* to express the equilibrium column choice and x^* to express the equilibrium care level.

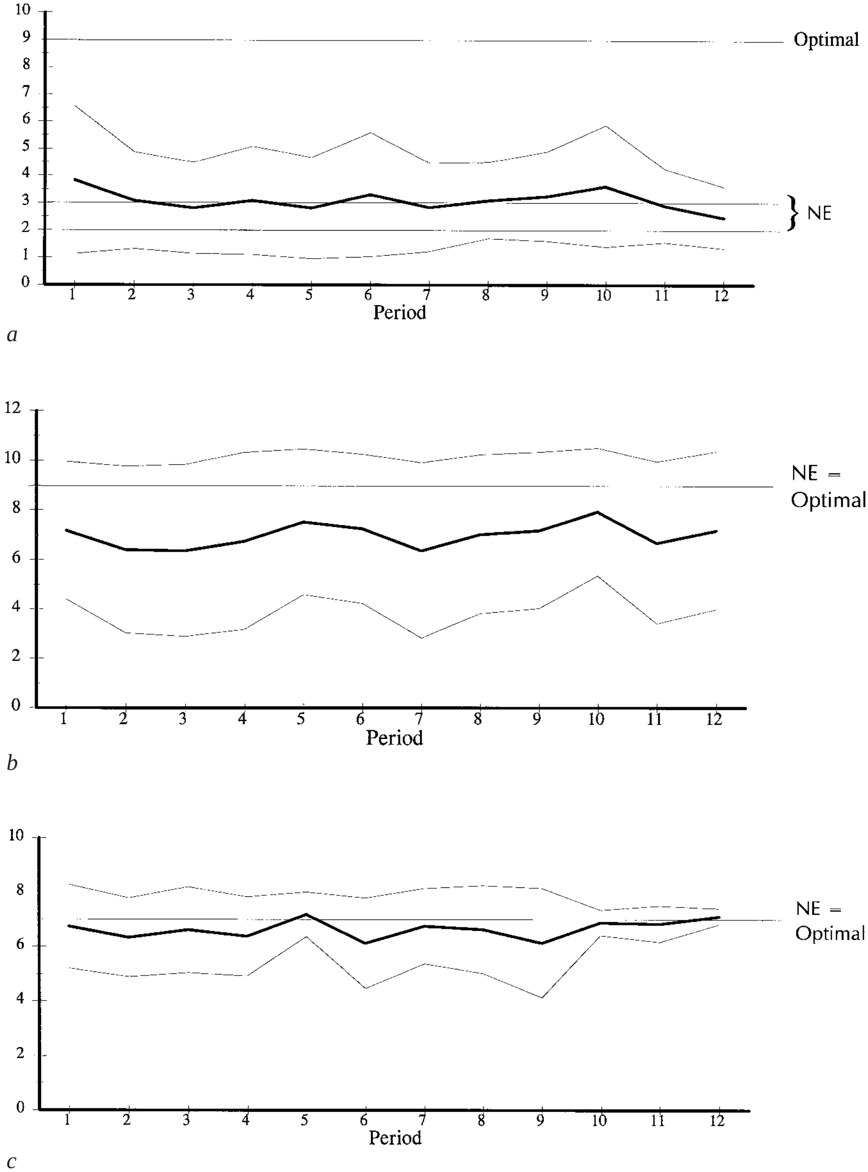

FIGURE 1.—Actual mean care level ±1 SD. *a,* No fault. *b,* Negligence with contributory negligence. *c,* Comparative negligence.

TABLE 1

DEVIATIONS FROM EFFICIENT AND NE CARE LEVELS

Sample	No. of Observations	No. at Zero	No. Positive	No. Negative	Mean	SD
		Mean Actual minus NE Care Level				
CN, all periods	384	267	23	94	−.38	1.42
CN, last six periods	192	152	12	28	−.35	1.35
NCN, all periods	384	239	13	132	−2.01	3.18
NCN, last six periods	192	128	4	62	−1.93	3.17
NF, all periods	384	170	135	79	.49	1.56
NF, last six periods	192	91	67	34	.40	1.32
		Mean Actual minus Efficient Care Level				
NF, all periods	384	2	16	364	−3.90	1.87
NF, last six periods	192	5	4	185	−3.97	1.62

NOTE.—The efficient care level equals the NE care level for comparative negligence (CN) and negligence with contributory negligence (NCN); in terms of columns, the NE is $z^* = 7$ for CN and is $z^* = 9$ for NCN. For no fault (NF), the efficient column choice is $z^\Omega = 9$, and the NE care level is $z^* = 2$ or 3. In the last case, the deviation is defined to be $z - 2$ for $z < 2$, 0 for $2 \leq z \leq 3$, and $z - 3$ for $z > 3$, where z is the actual column choice.

cent below those at the efficient NE, versus about 12 percent under NCN, and about 8 percent under NF. (The mean NF care level implies about 3 percent *higher* cash reward than at its inefficient NE.)[17] Most observers will regard such behavioral differences across liability rules as ‘‘economically significant.’’ But are they statistically significant?

Table 2 compares absolute deviations from NE under the two alternative rules to absolute deviations under CN. The comparisons are all on a ‘‘matched pair’’ basis, comparing deviations under CN and an alternative rule for a given player in a given period. We lose some data when we cannot find a match, but the procedure largely eliminates the effects of interperiod learning and of group idiosyncrasies that can bias the usual pooled comparisons. Therefore we believe the very significant test statistics reported in the table (the matched-pair Student’s t and the standard nonparametric binomial and Wilcoxon) should be taken at face value. We conclude that CN indeed produces significantly smaller deviations from NE than the alternative rules and that its advantage persists in the last six and even in the last three periods.

[17] The calculation for each rule takes the expected payoff for the mean care level against the distribution of care levels chosen in each session and compares this expected payoff to the payoff at NE (and, for NF, also to the payoff at the social optimum). Expressed in terms of social costs, the percentages would be about twice as large.

TABLE 2

MATCHED PAIR TESTS FOR THE CN LIABILITY RULE

	Matched Pair Differences							
Sample	No. of Observations	No. Positive	No. Negative	Mean	SD	t	Binomial	Wilcoxon
NF, all periods	384	155	59	.29	1.79	3.06	6.56	7.08
NF, last six periods	192	85	25	.23	1.57	2.02	5.72	5.40
NF, last three periods	96	43	10	.34	1.65	2.04	4.53	4.46
NCN, all periods	384	123	42	1.49	3.20	8.79	6.31	5.41
NCN, last six periods	192	60	20	1.45	3.19	6.28	4.47	3.90
NCN, last three periods	96	27	7	1.35	2.98	4.45	3.43	3.13

NOTE.—See Table 1 for definitions. For each player and each period, the matched pair difference is the absolute deviation $|z - z^*(\mathrm{CN})|$ of actual column choice from NE column choice ($z^* = 7$) under CN, subtracted from the corresponding absolute deviation $|z - z^*(\mathrm{r})|$ for the alternative liability rules r = NF and r = NCN.

TABLE 3

PARAMETER ESTIMATES FOR $\ln d_t = a + bt + e_t$

A. PARAMETERS			
Rule	Restrictions	a	b
CN	none	.64 (3.08)	−.77 (.44)
NF	none	−.64 (3.41)	−.60 (.49)
NCN	none	.79 (.29)	−.05 (.04)
CN	$b_{NF} = b_{CN}$	.19 (2.33)	−.69 (.30)
NF	$b_{NF} = b_{CN}$	−.10 (2.43)	−.69 (.30)
NCN	$b_{NF} = b_{CN}$	.80 (.29)	−.05 (.04)

B. χ^2 TESTS		
Restriction	$\chi^2(1)$	p Value
$b_{NF} = b_{CN}$	.05	.82
$b_{NCN} = b_{CN}$	2.57	.11
$b_{NCN} = b_{NF}$	1.29	.26
$b_{NCN} = [b_{NF} = b_{CN}]$*	4.62	.03

NOTE.—The dependent variable is the logarithm of the absolute deviation of the mean state from its NE value. Standard errors for a and b coefficient estimates are in parentheses.

* Reject at the 5 percent level.

B. Adjustment Dynamics

A learning model offers a deeper explanation of the data than an equilibrium model if the learning model can predict behavioral change due to an environmental change (for example, in the liability rule) that does not affect the equilibrium.

Before estimating the parametric learning model, we look at a simple descriptive model of the adjustment process. Its purpose is to give the reader some perspective on the data from which to judge the subsequent analysis. The descriptive model assumes that convergence to NE is exponential for each liability rule, but the rate and the starting point may differ for different rules. That is, we assume that, apart from random noise, the absolute value d_t of the deviation of the mean care level from the NE level converges to zero as t approaches infinity according to $d_t = A_r \exp(-c_r t + e_t)$, where c_r and A_r are the rate and initial absolute deviation for rule r. The relevant regression for each rule is $\ln d_t = a_r + b_r t + e_t$, where $c_r = -b_r$ is the rate constant and $A_r = e^{a_r}$ is the initial absolute deviation. Using the seemingly unrelated regression modification of ordinary least squares where necessary we obtain the parameter estimates listed in Table 3. Negligence with contributory negligence has the largest initial deviation (.79 compared to .64 for NF and CN) and the slowest convergence rate (.05 compared to .60 for

NF and .77 for CN). We cannot reject the hypothesis that CN and NF have the same convergence rate, but we can reject the hypothesis that NCN has the same rate as CN and NF at the 3 percent/2 = 1.5 percent level in favor of the one sided alternative that, as predicted, it is slower.

The rest of our dynamic analysis is based on the parametric learning model, $x_t = \alpha x_{t-1} + \beta B(\hat{x}_{t-1}) + e_t$, introduced earlier at the end of Section II. Table 4 reports fits for several alternative specifications of the best response variable and the state variable. First, take the state variable x_t to be the mean care level chosen by players in period t and consider Cournot expectations. The more aggregated version of Cournot regards players as best-responding to *last* period's *mean* care level; a less aggregate version regards players as best-responding to the *distribution* of care levels chosen last period. The first four columns of the table report regressions for both versions. The remaining four columns in the upper part of the table report corresponding regressions for fictitious play expectations.[18] Again we have two versions: players may best-respond to the mean of all care levels chosen over *all* periods since the current liability rule was instituted, or they may best-respond to the entire distribution.

The lower part of Table 4 reports our most fine-grained analysis. The learning model now predicts each individual player's care level as a function of that player's most recent care level and of the best response to care levels chosen by that player's *actual* opponents. Here ''Cournot-Mean'' and ''Cournot-Distribution'' coincide; we are simply looking at the best response to the previous opponent's care level. ''Fictitious-Mean'' and ''Fictitious-Distribution'' now refer to the mean and full distribution of care levels chosen by that player's actual opponents in all previous periods using the current rule.

We have three major questions: (1) Which specification of the learning model works best—Cournot-mean, Cournot-distribution, fictitious-mean, or fictitious-distribution? (2) Which specification is most consistent across liability rules? (3) Is learning explained by best response behavior?

We first answer question 1. Imposing the assumption that learning is the same under all liability rules, that is, there are no dummy variables for NCN or CN (αD_{NCN}, αD_{CN}, βD_{NCN}, $\beta D_{\mathrm{CN}} = 0$), fictitious-distribution provides the best fit whether we estimate the population care level ($\bar{R}^2 = .791$) or the individual care level ($\bar{R}^2 = .292$). When we relax this consistency assump-

[18] Recently Cournot and fictitious play have become popular empirical learning models for fitting laboratory data from simple bimatrix games; see R. Boylan & M. El-Gamal, Fictitious Play: A Statistical Study of Multiple Economic Experiments, 5 Games & Econ. Behav. 205 (1993); and Yin-Wong Cheung & Daniel Friedman, Learning in Evolutionary Games: Some Laboratory Results (Working Paper No. 303, Univ. California, Santa Cruz, Dep't Economics, 1994), and the citations therein.

TABLE 4

LEARNING MODEL REGRESSIONS

A. DEPENDENT VARIABLE: POPULATION-MEAN CARE LEVEL; $N = 96$

	B Is Best Response To:							
	Cournot-Mean		Cournot-Distribution		Fictitious Play–Mean		Fictitious Play–Distribution	
Coefficient	All *D*'s	No *D*'s	All *D*'s	No *D*'s	All *D*'s	No *D*'s	All *D*'s	No *D*'s
α	.63	.67	.71	.57	.44	.95	.41	.46
	(.09)	(.07)	(.13)	(.09)	(.18)	(.03)	(.19)	(.10)
αD_{NCN}	−.45	. . .	−.52	. . .	.52	. . .	−.23	. . .
	(.17)		(.20)		(.19)		(.24)	
αD_{CN}	−.36	. . .	−.44	. . .	−.17	. . .	−.15	. . .
	(.24)		(.28)		(.32)		(.30)	
β	.56	.29	.22	.37	.87	.07	.45	.45
	(.16)	(.06)	(.12)	(.08)	(.31)	(.04)	(.16)	(.08)
βD_{NCN}	.08	. . .	.42	. . .	−.70	. . .	.20	. . .
	(.20)		(.17)		(.33)		(.20)	
βD_{CN}	.13	. . .	.47	. . .	−.18	. . .	.25	. . .
	(.27)		(.26)		(.40)		(.27)	
F-statistic	90	338	80	339	63	265	85	362
$\bar{R}^2$	.824	.780	.805	.781	.767	.735	.815	.791

B. DEPENDENT VARIABLE: INDIVIDUAL CARE LEVEL A_{irt}; $N = 1{,}026$

	B Is Best Response To:					
	Cournot		Fictitious Mean		Fictitious-Distribution	
Coefficient	All *D*'s	No *D*'s	All *D*'s	No *D*'s	All *D*'s	No *D*'s
α	.47	.34	.44	.69	.61	.32
	(.05)	(.03)	(.07)	(.02)	(.05)	(.03)
αD_{NCN}	−.23	. . .	.31	. . .	−.54	. . .
	(.06)		(.07)		(.06)	
αD_{CN}	−.25	. . .	−.27	. . .	−.49	. . .
	(.10)		(.13)		(.11)	
β	.62	.56	.75	.27	.39	.58
	(.08)	(.03)	(.12)	(.03)	(.08)	(.03)
βD_{NCN}	−.02	. . .	−.58	. . .	.33	. . .
	(.08)		(.12)		(.09)	
βD_{CN}	.12	. . .	.03	. . .	.44	. . .
	(.12)		(.16)		(.12)	
F-statistic	97	411	26	76	116	422
$\bar{R}^2$	.319	.286	.108	.069	.360	.292

NOTE.—Standard errors are in parentheses. α is the coefficient of the lagged dependent variable; β is the coefficient of the best response variable B; and D_r is a dummy variable for rule r = NCN and CN. Thus in the last specification, b is .39 for NF but is .39 + .44 = .83 for CN.

tion, then fictitious-distribution again provides the best fit for estimating individual care levels, but Cournot-mean yields the best fit for estimating population care levels.

The second question asks whether a specification is consistent in the sense that the fitted parameters are invariant as the liability rule changes. An obvious test is to see whether any of the interactive dummy variables (αD_{NCN}, αD_{CN}, βD_{NCN}, βD_{CN}) are significantly different from zero, which would imply inconsistency. Only the fictitious-distribution for population mean care levels passes this test.[19] In every other specification at least one (and usually two or three) of the dummy coefficients is significantly different from zero.

Finally, we turn to the third and possibly most important question, whether players best-respond. That is, is β large and significantly different from zero? Starting off again with fictitious mean, the β coefficient is quite large (.45 for the population care level and .58 for the individual care level) and very significant. With the exception of fictitious mean under population care levels, all the other specifications yield large (ranging from .27 to .56) and significant β. Hence our answer is in the affirmative.

V. Discussion

Even when two rules have the same (efficient) equilibrium, the rules may differ for practical purposes because they are not equally effective in promoting learning and convergence to the efficient equilibrium. Heretofore, there have been precious few tests of any sort regarding liability rules in general and none involving symmetric games. Our experiments compared convergence and equilibrium across three liability rules. These experiments also enabled us to compare variants of a learning model in the context of an *n*-person symmetric game.

Our laboratory results strongly confirm both equilibrium and learning theory. We do get at least rough convergence to the equilibrium in every case, whether the equilibrium is efficient (as it is for the comparative negligence rule and the negligence with contributory negligence rule) or inefficient (as it is for the no fault rule). Deviations from efficient behavior are significantly smaller, statistically and economically, under the comparative negligence rule than under the negligence with contributory negligence rule or the no fault rule. A ''reduced-form'' adjustment model suggests that convergence to equilibrium is slower under NCN than under either CN (to the

[19] If we employ a joint test, then even the fictitious distribution specification is not consistent. Note that, because observations in the experiments are not independent, the significance levels are overstated and we risk finding inconsistency where none exists.

equally efficient equilibrium) or NF (to the inefficient equilibrium). More important, we found plausible parametrizations of a simple learning model that could account for behavior across all three liability rules. The fictitious play (or ''long memory'') expectation scheme generally produced better fits to our data than alternative specifications involving Cournot (''short memory'') and the mean state. In all characterizations best response behavior played a major explanatory role.

What are the legal implications of our findings? We have shown that comparative negligence promotes faster convergence to the efficient Nash equilibrium level of care than negligence with contributory negligence (and that both have superior equilibrium properties to no fault).[20] Thus we have an explanation for an outstanding ''mystery'': why comparative negligence has supplanted negligence with contributory negligence in so many states.[21] The question then becomes, Why did we not always have comparative negligence? We believe that we have a partial answer. In symmetric situations, such as automobile accidents, it is easier to measure relative negligence $x_s/(x_s + y_s)$ and hence to determine comparative negligence. For example, if one party was going 40 mph in excess of the speed limit and the other 20 mph in excess, then it is easy to ascertain that the first party is twice as negligent as the second. In comparison, other torts such as product liability lack such symmetry and do not have any natural measure of relative negligence. Symmetry makes a comparative negligence rule more workable. Thus it is not surprising that, as automobile accidents came to dominate the

[20] Of course, our theoretical analysis and experiments do not deal with court transactions costs, which are likely to be smaller with NF.

[21] Richard Posner, Economic Analysis of Law 255 (1992), characterizing comparative negligence in a different way from his earlier paper with Landes (*supra* note 1), states that ''the modern movements to substitute comparative for contributory negligence'' is one of the three ''most important counterexamples to the efficiency theory of the common law.'' Christopher Curran, The Spread of the Comparative Negligence Rule in the United States, 12 Int'l Rev. L. & Econ. 317 (1992), also argues against his earlier coauthored paper (with Haddock, *supra* note 4) and claims that CN is inferior to NCN but provides an interest group explanation for its spread—those states with more lawyers implemented CN earlier.

Other explanations for the choice of CN over NCN generally rely on the insurance motive: damages apparently are shared more often under CN in practice, so it may be less risky than NCN. Given the availability of other forms of insurance, we did not find this explanation compelling. Robert Cooter & Thomas Ulen, An Economic Case for Comparative Negligence 61 N.Y.U. L. Rev. 1067 (1986); and White, *supra* note 1, consider situations where there is uncertainty about the court's standard of due care, x^{Ω}. They show that risk-averse drivers may then choose too much caution, especially so under negligence with contributory negligence which is more risky than comparative negligence. But Aaron Edlin, Efficient Standards of Due Care: Should Courts Find More Parties Negligent under Comparative Negligence? 14 Int'l Rev. L. & Econ. 21 (1994), argues that the standard of care can be adjusted so that negligence with contributory negligence does not create excessive care. He provides still another explanation for the rise of comparative negligence—an optimal response to a presumed increase in jury standards for due care.

tort system,[22] the beneficial aspects of comparative negligence demonstrated in this article encouraged courts and legislatures to switch to this more efficient rule. In California, the courts first applied comparative negligence to automobile accidents and only later expanded it into other areas. In the United States, an important exception to the long-time dominance of negligence and negligence with contributory negligence was admiralty law which always employed comparative negligence. Here too the damage is often symmetric (ship collisions).[23]

The implications of our analysis are not confined to liability rules. Most contemporary economic analysis centers on equilibria and their properties, and much of recent cognitive psychology is concerned with learning rules, but the focus in this article is on still a different question: which institutions create faster learning or convergence? The answer may be very important in a variety of applications. For example, the Vickrey (second price sealed) auction and the English (ascending open) auction have the same dominant (truth-telling) strategy in a private values environment,[24] but convergence to the efficient equilibrium is much faster in the English auction.[25] The English auction indeed is much more common in practice. Legal and economic institutions of all sorts, not just liability rules and auction procedures, may be chosen for their quick learning or convergence properties as much as for their efficient equilibria.

APPENDIX A

Instructions

Thank you for joining us today. You are about to participate in an experiment in the economics of group decision making. The funding for this project has been provided by campus research grants. If you follow these instructions *carefully* and make good decisions, you can earn a considerable amount of money which will be paid to you in cash at the end of the experiment.

If at any time you have a question, please raise your hand and one of the lab assistants will assist you. We also ask that you refrain from making any comments out loud or to other participants during this experiment. PLEASE keep your eyes on your own screen at all times.

[22] Peter Huber, Liability: The Legal Revolution and Its Consequences (1988), states that traffic accidents account for approximately 40 percent of all tort cases.

[23] From the mid-nineteenth century to the early part of the twentieth century, CN was applied to industrial accidents, but this application of the rule dwindled as workers gained the ability to get restitution via other means. In 1950, only five states had a general comparative negligence rule; by 1986, forty-four states employed comparative negligence.

[24] William Vickrey, Counterspeculation, Auctions, and Competitive Sealed Tenders, 16 J. Fin. 37 (1961).

[25] John Kagel, R. M. Harstad, & D. Levin, Information Impact and Allocation Rules in Auctions with Affiliated Private Values: A Laboratory Study, 55 Econometrica 1275 (1987).

The idea is as follows. You start each round with a ‘‘salary’’ and you will spend part of that on a ‘‘care level.’’ You will have ten ‘‘care levels’’ to choose from. You will be paired with another participant at random, who faces the same conditions as you and has also chosen a care level. The care level chosen by you and the other participant will affect the costs that occur after both of you have chosen. The computer will then determine who will pay what part of the ‘‘costs’’ according to a rule. The rule will stay the same for several rounds and then may change. You will notice the change by a change in the numbers on your chart.

To see how this works, look at the chart below [Table A1], which is similar to the chart you will see on your screen. You are represented by the numbers across the TOP (X) of the chart. Some other participant is represented by the numbers down the SIDE (Y). Those numbers are the ‘‘care levels’’ you are going to choose from. The numbers in the middle of the chart are ‘‘net values.’’ It is the amount you will have left over after ‘‘care level’’ and ‘‘costs’’ have been paid for.

For example, if you chose ‘‘35’’ and another random participant chose ‘‘20,’’ your net on this chart [Table A2] below would be 700.

Before we start we want you to have a little fun testing out the chart. These first five test rounds will not be recorded. Go ahead and try a few rounds by using the mouse to click on care levels. Now is a good time to ask questions if you have any.

Final Instructions

We are ready to begin now. One round will be picked at random to be your payment round. You will be paid for this round at the end of this experiment. Remember that your earnings for the experiment depend on your choice of care level and that of another participant, so choose carefully each round.

NOTE.—The numbers that appear on the chart are ‘‘FRANCS,’’ not dollars. The conversion rate is __ Francs per $. We expect the average participant to walk away with at least $8.

TABLE A1

CARE LEVELS AND RESULTING NET VALUES

X

		5	10	15	20	25	30	35	40	45	50
	5	25	50	75	100	125	150	175	200	225	250
	10	50	100	150	200	250	300	350	400	450	500
	15	75	150	225	300	375	450	525	600	675	750
	20	100	200	300	400	500	600	700	800	900	1000
	25	125	250	375	500	625	750	875	1000	1125	1250
Y	30	150	300	450	600	750	900	1050	1200	1350	1500
	35	175	350	525	700	875	1050	1225	1400	1575	1750
	40	200	400	600	800	1000	1200	1400	1600	1800	2000
	45	225	450	675	900	1125	1350	1575	1800	2025	2250
	50	250	500	750	1000	1250	1500	1750	2000	2250	2500

TABLE A2

NET PAYOFF WHEN YOU CHOOSE ‘‘35’’ AND ANOTHER PARTICIPANT CHOOSES ‘‘20’’

X

		5	10	15	20	25	30	35	40	45	50
	5	25	50	75	100	125	150	175	200	225	250
	10	50	100	150	200	250	300	350	400	450	500
	15	75	150	225	300	375	450	525	600	675	750
	20	100	200	300	400	500	600	700	800	900	1000
	25	125	250	375	500	625	750	875	1000	1125	1250
Y	30	150	300	450	600	750	900	1050	1200	1350	1500
	35	175	350	525	700	875	1050	1225	1400	1575	1750
	40	200	400	600	800	1000	1200	1400	1600	1800	2000
	45	225	450	675	900	1125	1350	1575	1800	2025	2250
	50	250	500	750	1000	1250	1500	1750	2000	2250	2500

APPENDIX B

TABLE B1

PAYOFF MATRICES

A. NEGLIGENCE WITH CONTRIBUTORY NEGLIGENCE

	0	24	48	72	96	120	144	168	192	216
0	350	387	394	395	393	389	384	377	508	484
24	411	418	419	417	413	408	401	393	508	484
48	442	443	441	437	432	425	417	408	508	484
72	467	465	461	456	449	441	432	423	508	484
96	489	485	480	473	465	456	447	437	508	484
120	509	504	497	489	480	471	461	451	508	484
144	528	521	513	504	495	485	475	464	508	484
168	545	537	528	519	509	499	488	477	508	484
192	422	429	434	439	442	445	446	447	478	466
216	453	458	463	466	469	470	471	472	490	477

B. COMPARATIVE NEGLIGENCE

	0	32	64	96	128	160	192	224	256	288
0	350	415	443	464	480	494	508	476	444	412
32	397	427	449	466	480	494	508	476	444	412
64	411	434	451	466	479	493	508	476	444	412
96	419	437	452	465	477	491	508	476	444	412
128	423	438	450	462	473	486	508	476	444	412
160	424	436	446	455	464	477	508	476	444	412
192	422	431	437	442	445	447	478	462	445	428
224	463	469	474	477	479	480	494	477	460	442
256	501	506	509	511	512	511	509	492	474	456
288	538	541	543	544	543	542	524	506	488	470

C. NO FAULT

	0	24	48	72	96	120	144	168	192	216
0	350	387	394	395	393	389	384	377	369	360
24	411	418	419	417	413	408	401	393	384	375
48	442	443	441	437	432	425	417	408	399	389
72	467	465	461	456	449	441	432	423	413	403
96	489	485	480	473	465	456	447	437	427	416
120	509	504	497	489	480	471	461	451	440	429
144	528	521	513	504	495	485	475	464	453	442
168	545	537	528	519	509	499	488	477	466	454
192	561	552	543	533	523	512	501	490	478	466
216	576	567	557	547	536	525	514	502	490	477