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ERC: A Theory of Equity, Reciprocity, and Competition

By GARY E BOLTON AND AXEL OCKENFELS*

We demonstrate that a simple model, constructed on the premise that people are motivated by both their pecuniary payoff and their relative payoff standing, organizes a large and seemingly disparate set of laboratory observations as one consistent pattern. The model is incomplete information but nevertheless posed entirely in terms of directly observable variables. The model explains observations from games where equity is thought to be a factor, such as ultimatum and dictator, games where reciprocity is thought to play a role, such as the prisoner's dilemma and gift exchange, and games where competitive behavior is observed, such as Bertrand markets. (*JEL* C78, C90, D63, D64, H41)

The various areas of inquiry that constitute experimental economics appear at times to be surveying distinct and isolated regions of behavior. What we see in experiments involving market institutions is usually consistent with standard notions of "competitive" self-interest. Other types of experiments appear to foster sharply different conduct. "Equity" has emerged as an important factor in bargaining games. "Reciprocity," of a type that differs from the standard strategic conception, is often cited to explain behavior in games such as the prisoner's dilemma. There is substantial controversy about what, if anything, connects these observations. The issue goes to the heart of what it is that experimental economics can hope to accomplish. If no connections can be found, we are left with a set of disjoint behavioral charts, each valid on a limited domain. But to the extent that common patterns can be established, laboratory research presents a broader, more valuable map of economic behavior.

In this paper, we describe a simple model called *ERC* to denote the three types of behavior reported from the lab that are captured by the theory: *e*quity, *r*eciprocity, and *c*ompetition. ERC is not a radical departure from standard modeling techniques. There are two important innovations. The first is the premise that, along with the pecuniary payoff, the relative payoff—a measure of how a person's pecuniary payoff compares to that of others—motivates people. While no model can hope to capture all facets of all experiments, ERC demonstrates that a simple model of how pecuniary and relative payoffs interact organizes data from a wide variety of laboratory games as one consistent pattern. Second, ERC is an incomplete-information model that is nevertheless posed entirely in terms of observables. The incomplete information reflects actual lab conditions, while the observability makes for straightforward testing of the model.

We have avoided inessential elaboration and generalization in favor of a very simple model—partly to impress upon the reader how well the basic idea fits with a large number of known facts; but also partly because, as experimentalists, we have become wary of speculating in areas where we have little data to guide us.[1] By identifying a common link among many known experiments, ERC points to new and innovative tests, the data from which then provides the grist for refining the existing model, or creating an entirely new one. In this sense, we think ERC is an important step

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[1] In this regard, Alvin E. Roth's (1995) review of the demise of numerous early, seemingly obvious hypotheses having to do with bargaining games can be read as a cautionary tale.

toward a broader, more valuable interpretation of experimental data.

I. Other Approaches and How ERC Compares

There are several approaches to modeling experimental games. Those closest to ERC are what might be called "motivation models." These posit motives that differ from the standard game-theory assumption that "more money is preferred to less." All embed motives in preferences, and all allow preferences to vary somewhat across individuals. Consequently, what players know about the preferences of other players becomes an important issue.

Matthew Rabin (1993) develops the concept of fairness equilibrium, based on the premise that people like to help those who help them and hurt those who hurt them. Hence the model emphasizes the role of intentions in behavior that deviates from standard theory. Rabin's model applies to two-person, normal-form games of complete information, and he shows that the model fits certain stylized facts. Most of the games we study here are played in the extensive form, some involve more than two players, and in all cases, preferences are necessarily private information. It is not immediately clear how to formally apply Rabin's model to these games; as a specific example, it is not clear how to reconcile fairness equilibrium with the competitive behavior we see in market games.[2]

David K. Levine (1998) studies an extensive-form model that classifies people as being to various degrees spiteful or altruistic. A person's type is treated as private information. Levine shows that a particular distribution of these types produces behavior that is consistent with the qualitative as well as some quantitative facts from several experiments, including ultimatum, auction-market, and centipede games. But this model (like Rabin's) does not accurately predict results from the dictator game, a game that we will argue is basic to an understanding of many other games.

Ernst Fehr and Klaus Schmidt (1999) study a model of inequality aversion in which individuals suffer negative utility as the distribution of payoffs moves away from the egalitarian distribution but may care differently about whether they are ahead of others or behind them. Some of the games they study are the same as ours, while others are different. Most of their results are derived in a complete-information context.

The approach most closely related to ERC is Bolton's (1991) comparative model. This complete-information model is consistent with a variety of phenomena in alternating-offer bargaining games, but it does not provide a satisfactory explanation for other types of games.

ERC is an incomplete-information model. We think this is important because most economics experiments are conducted anonymously; how a lab subject trades off pecuniary and relative payoffs is clearly private information. On the other hand, testing the model requires a reliable, preferably observable, measure of the underlying trade-offs. We have found that much of what we need to know has to do with the thresholds at which behavior deviates from the "more money is preferred to less" assumption. This information is readily recovered from dictator and ultimatum game data. We demonstrate throughout the paper that knowing the distributions of these thresholds is sufficient to characterize many phenomena.

ERC applies to games played in the extensive as well as the normal form. A subject's payoff is determined entirely by his *own* pecuniary and *own* relative payoff, making for a relatively parsimonious model. There is, of course, a cost to parsimony. For example, experiments that compare the relative-payoff explanation to the intentions explanation identify substantial evidence for relative payoffs but also often find evidence for intentions, something ERC does not capture.[3]

[2] Rabin (1993 p. 1296) notes that extending his model to multiperson, sequential, or incomplete-information games might be problematic or may even substantially change the implications of his model.

[3] Sally Blount (1995) finds evidence for the intentions explanation in the context of the ultimatum game, although she observes rejection behavior even in treatments that control for the intentions of the proposer. John Kagel et al. (1996 p. 100) observe "ample evidence that relative income shares entered players' utility functions, resulting in predictable variations in both rejection rates and offers," but at the same time they find that some of the phenomena in their ultimatum-game treatments require an intentions explanations. Gary Charness (1996) finds that the majority of above-minimal worker effort levels in the gift-exchange

We might conjecture that players care about the egalitarian distribution of payoffs across all players, instead of just their own relative payoff. The present paper demonstrates that we can go quite far with the coarser formulation. More importantly, some evidence runs contrary to egalitarian preferences. Werner Güth and Eric van Damme (1998) report on a three-player ultimatum-game experiment in which the proposer proposes a three-way split of the pie, and one responder can accept or reject. The third player, a dummy, does nothing save collect any payoff the other two agree to give him. Güth and van Damme find that proposers "only allocate marginal amounts to the dummy" (p. 242). Further, they find that "there is not a single rejection that can be clearly attributed to a low share for the dummy" (p. 230). Both observations cast doubt on egalitarian preferences. In an earlier paper, we demonstrated that ERC predicts both of these observations, as well as many related features of the data (Bolton and Ockenfels, 1998).[4]

Reinhard Selten and Ockenfels (1998) observe a similar phenomenon in the solidarity game. Each of three players independently rolls a die to determine whether she wins a fixed sum of money. Prior to rolling, each announces how much she wishes to compensate the losers, both when there is one loser and when there are two. Selten and Ockenfels find that most subjects give the same total amount independent of the number of losers.[5] In addition, gifts for one loser are positively correlated with the expectation of the gifts of others. Selten and Ockenfels demonstrate that neither the behavioral pattern nor the relation between decisions and expectations is easy to justify if subjects have standard altruistic preferences over income distribution. They conclude that: "The needs of the other players or the reduction of inequality do not seem to be the guiding considerations of these subjects" (p. 522).[6]

By confining our attention to own pecuniary and own relative payoffs, we leave the door open to a later refinement of motivation, one informed by a deeper understanding of an experiment like that of Selten and Ockenfels (1998).

Learning represents a distinctly different approach to these games. Roth and Ido Erev (1995) study a reinforcement-learning model that generates dynamic behavior consistent with ultimatum, best-shot, and auction-market games. Learning, however, does not easily explain why ultimatum second movers reject money, an observation that is central to ERC. On the other hand, motivation models are static and so cannot explain the learning observed in many games. For this reason, we view learning as complementary to the motivation approach.

II. Examples of What ERC Can Explain

At base, we want a model that is consistent with the known, robust facts. As it happens, most of the robust facts are qualitative in nature. The quantitative data for many of the games we study are known to be influenced by factors such as culture and framing, factors that often vary across experiments.[7] The results of these games are nevertheless robust in the sense that

game is attributable to relative payoffs, with the rest attributable to intentions. Bolton et al. (1998a) find that virtually all of the contributions they observe in a simple dilemma game are attributable to relative payoffs.

[4] For instance, ERC correctly predicts that responders never reject so long as their own share is ⅓ of the cake, regardless of the dummy's payoff.

[5] A related empirical phenomenon is the so-called "embedding effect" discussed in the contingent-valuation literature (see e.g., Daniel Kahneman and Jack L. Knetsch, 1992; Michael Hanemann, 1994). It suggests that the willingness to pay does not vary substantially with the number of projects to be valued.

[6] Other evidence that egalitarian distribution is not a primary concern: Bolton et al. (1998b) find that the total gift dictators leave multiple recipients is stable, but how dictators distribute gifts across recipients appears, in most cases, to be arbitrary. Joachim Weimann (1994) analyzes a public-goods experiment directed at the question of whether individual behavior of others or just aggregate group behavior influences the decision to contribute. He concludes that "Whether or not the individual contributions [to a public good] are common knowledge has no impact on subject's behavior" (p. 192).

[7] Roth et al. (1991), Roberto Burlando and John D. Hey (1997), and Ockenfels and Weimann (1999), among others, demonstrate that the quantitative data for ultimatum bargaining and dilemma games are significantly influenced by culture. Several of the types of the games we study here are known to be subject to framing effects (for dilemma games, see Dean G. Pruitt [1967] and James Andreoni [1995]; for equity games, see Richard P. Larrick and Blount [1997] and Bolton et al. [1998b]).

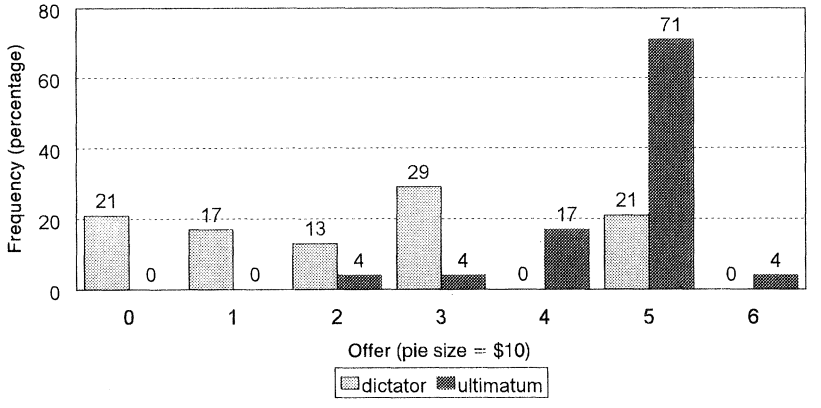

FIGURE 1. AMOUNTS OFFERED TO THE RECIPIENT IN DICTATOR AND ULTIMATUM GAMES (ONE OBSERVATION PER PROPOSER)

Source: Forsythe et al. (1994).

the qualitative pattern they exhibit is consistent across cultures and frames. It makes sense then to start by demonstrating that a model can handle the robust qualitative facts. That means, among other things, a lot of comparative statics. Of the quantitative facts that are robust, many are convergence results, and we show that ERC captures some of these too. Using a very simple version of ERC, we demonstrate, in the context of a dilemma-game experiment, that there is hope for a quantitative model (holding things like culture and framing fixed).

Three experiments provide a sense of what ERC can explain. First, Robert Forsythe et al. (1994) report an experiment involving both the ultimatum and dictator games. In the ultimatum game, the "proposer" offers a division of $10, which the "responder" can either accept or reject; the latter action leaves both players with a payoff of zero. The dictator game differs only in that the responder has no choice but to accept. The standard perfect-equilibrium analysis of both games begins with the assumption that each player prefers more money to less. Consequently, the responder in the ultimatum game should accept all positive offers. Given this, the proposer should offer no more than the smallest monetary unit allowed. In the dictator game, the responder has no say, so the proposer should keep all the money. Thus, in both games, the proposer should end up with virtually the entire $10.

Figure 1 displays the amounts proposers actually offered (each game played for one round). While there is a great deal of heterogeneity, average offers for both games are clearly larger than minimal. Various authors have given these results an equity interpretation (Roth [1995] provides a survey). But equity is insufficient to explain everything in Figure 1. Offers are plainly higher in the ultimatum game. This has to do with a fact well known to those who do ultimatum experiments: Responders regularly turn down proportionally small offers, and so proposers adjust their offers accordingly. Proposers may care about equity (they *do* give money in the dictator game), but it appears that it is responder concern for equity that drives the ultimatum game. Hence Figure 1 illustrates a subtle interplay between equity and strategic considerations, an interplay that ERC captures.[8]

The second experiment, performed by Roth et al. (1991), concerns a simple auction-market

[8] The results from dictator and ultimatum games have been shown to be remarkably stable along several dimensions. Forsythe et al. (1994) show that dictator giving is stable with respect to time. Elizabeth Hoffman et al. (1994) replicate the Forsythe et al. distribution. Bolton et al. (1998b) demonstrate that the amount the dictator gives is stable with respect to various game manipulations. Giving behavior is not restricted to people: capuchin monkeys give food in what is an animal version of the dictator game (see Frans de Waal, 1996 p. 148). Evidence on whether behavior is different when the experimenter can associate dictator actions with subject identities is mixed. Roth (1995) summarizes much of the research and suggests an alternative interpretation for what positive evidence there is. The same article surveys the many ultimatum-game experiments.

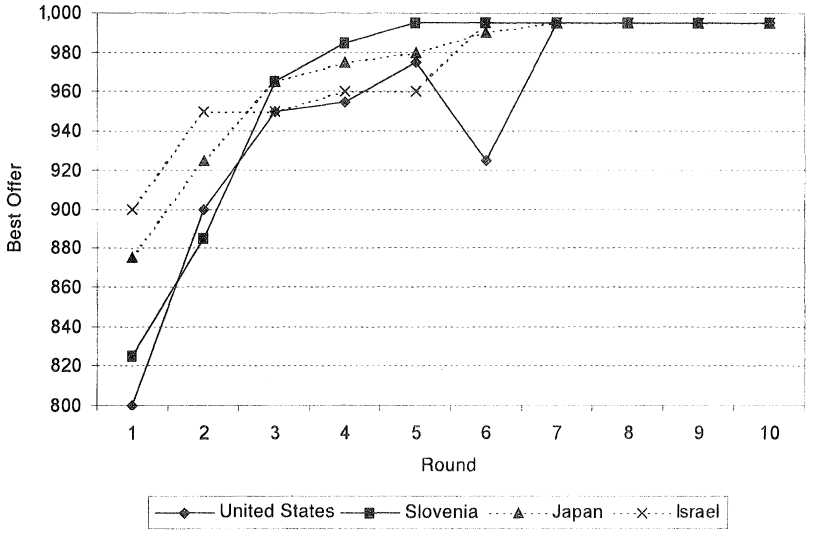

FIGURE 2. BEST OFFERS IN THE MARKET GAME (MINIMUM OF FOUR BEST OFFERS PER COUNTRY)

Source: Roth et al. (1991).

game. A single seller has one indivisible unit of a good to offer to nine buyers. Exchange creates a fixed surplus of 1,000. Buyers simultaneously submit offers. The seller is then given the opportunity to accept or reject the best offer. All subgame-perfect equilibria have the seller receiving virtually the entire surplus, namely, 995 or 1,000.

Ten rounds of the auction market were run in each of four countries. In each country, four markets were implemented. Figure 2 shows the minimum of the four best offers per round for each country.[9] In every case, the best bid rose to the subgame-perfect equilibrium offer no later than round 7 and did not fall below the equilibrium bid in any subsequent round. Hence the experiment produces behavior that is remarkably consistent with standard theory. The same study examined ultimatum-game play across the same countries. While there were some quantitative differences that can be attributed to culture, the qualitative pattern was the same in all cases: in all ten rounds of play, offers were generally higher than subgame-perfection predicts, and there were a significant number of rejections. Are the motives behind market behavior fundamentally different than those behind the ultimatum game? ERC answers, "No, the same motivation suffices to explain both games."

The third experiment, by Fehr et al. (1993), involves what is sometimes referred to as the "gift-exchange game." Subjects assigned the role of firms offer a wage to those assigned the role of workers. The worker who accepts the wage then chooses an effort level. The higher the level chosen, the higher the firm's profit and the lower the worker's payoff. The game is essentially a sequential prisoner's dilemma, in which the worker has a dominant strategy to choose the lowest possible effort. The only subgame-perfect wage offer is the reservation wage.

Figure 3 compares the effort level actually provided with the wage offered. Behavior is inconsistent with the horizontal line that indicates the workers' best response. (The data are aggregated over four sessions of 12 rounds each. Fehr et al. [1993] report that they found no tendency for convergence to equilibrium play.) In fact, there is a strong positive correlation between wage and effort, sometimes taken as evidence for reciprocity (Fehr et al. suggest this interpretation). It turns out that ERC can capture much of this behavior.

We next lay out the basic ERC model (Sec-

[9] The data are from Roth et al. (1991 pp. 1076–79 [table 1]).

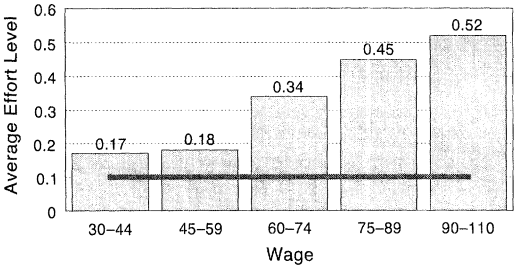

FIGURE 3. AVERAGE EFFORT IN RESPONSE TO WAGE (DATA AGGREGATED OVER FOUR SESSIONS OF 12 ROUNDS EACH)

Source: Fehr et al. (1993).

tion III). Our aim is to show consistency with a wide number of experimental results. We show that ERC can account for a variety of patterns reported for dictator, bargaining, and related games, including Forsythe et al. (1994) (Section IV). Next we explain why the model predicts competitive behavior for a class of market games including Roth et al. (1991) (Section V). We describe some basic results for one-shot dilemmas. We can say more with a parametric model. We fit the simplest possible version to the Fehr et al. (1993) data and then make some observations concerning the repeated prisoner's dilemma (Section VI). After describing what ERC can do, we discuss limitations and areas for refinement (Section VII).

III. The ERC Model

We concern ourselves with n-player lab games, $i = 1, 2, \ldots, n$, where players are randomly drawn from the population, and anonymously matched (face-to-face play is a known complicating factor). All game payoffs are monetary and nonnegative, $y_i \geq 0$ for all i. We assume that if a subject plays a game multiple times, she never plays with any particular subject more than once. We can therefore analyze each game as one-shot.

Each player i acts to maximize the expected value of his or her *motivation function:*

$$v_i = v_i(y_i, \sigma_i) \tag{1}$$

where

$$\sigma_i = \sigma_i(y_i, c, n) = \begin{cases} y_i/c & \text{if } c > 0 \\ 1/n & \text{if } c = 0 \end{cases}$$

is i's relative share of the payoff, and

$$c = \sum_{j=1}^{n} y_j$$

is the total pecuniary payout.

Motivation functions may be thought of as a special class of expected utility functions. We prefer the term "motivation function" because it emphasizes that (1) is a statement about the objectives that motivate behavior during the experiment. The weights individuals give these objectives may well change over the long term, with changes in age, education, political or religious beliefs, and other characteristics. However, it is sufficient for our purposes that the trade-off be stable in the short run, for the duration of the experiment.[10]

The following assumptions characterize (1):

ASSUMPTION 1: *The function v_i is continuous and twice differentiable on the domain of (y_i, σ_i).*

ASSUMPTION 2: *Narrow self-interest.—That is,*

$$v_{i1}(y_i, \sigma_i) \geq 0$$

$$v_{i11}(y_i, \sigma_i) \leq 0.$$

Also, fixing σ and given two choices where $v_i(y_i^1, \sigma) = v_i(y_i^2, \sigma)$ and $y_i^1 > y_i^2$, player i chooses (y_i^1, σ).

ASSUMPTION 3: *Comparative effect.—That is,*

[10] Vesna Prasnikar (1997) examines three large ultimatum-game data sets and concludes that the trade-off is stable even with repeated play. An objection sometimes raised to the motivation approach is that one "can explain anything by changing the utility functions." This objection implicitly assumes there is no way to test the functional specification. In the lab, however, we can and often do perform these types of validation tests.

$$v_{i2}(y_i, \sigma_i) = 0 \qquad \text{for } \sigma_i(c, y_i, n) = 1/n$$

$$v_{i22}(y_i, \sigma_i) < 0.$$

Assumption 1 is for mathematical convenience. Assumption 2 implies that *for a given relative payoff,* player i's choice is consistent with the standard assumption made about preferences for money. We do not assume that v_i is strictly increasing in the pecuniary argument, since this would rule out players who care more about the relative payoff than pecuniary payoff—players who, for example, divide fifty–fifty in the dictator game. Assumption 3 states that, holding the pecuniary argument fixed, the motivation function is strictly concave in the relative argument, with a maximum around the allocation at which one's own share is equal to the average share. This assumption implies that equal division has collective significance; hence we refer to equal division as the *social reference point.*[11]

Assumption 2 insures that, when a player presented with two alternative outcomes having the same relative argument, the one with the higher pecuniary payoff is chosen. An alternative way of handling this would be to assume that v_i is strictly increasing in the pecuniary argument and to allow a kink in the relative argument at $1/n$ (see Assumption 3). But in terms of explaining the experimental results dealt with here, it makes no difference, and the differential formulation is more convenient.

Behavior in many of the games we deal with is heterogeneous. The theory accounts for this by positing a tension, or trade-off, between adhering to the reference point (the comparative effect) and achieving personal gain (narrow self-interest). Individuals are distinguished by how this tension is resolved. Much of what we need to know about this tension is captured by the thresholds at which behavior diverges from "more money is preferred to less." Each player has two thresholds, $r_i(c)$ and $s_i(c)$, defined as follows [note that $y_i \equiv c\sigma_i(y_i, c, n)$]:

$$r_i(c) = \arg\max_{\sigma_i} v_i(c\sigma_i, \sigma_i), \qquad c > 0.$$

$si(c)$ is implicitly defined by

$$v_i(cs_i, s_i) = v_i(0, 1/n), \quad c > 0, \quad s_i \leq 1/n.$$

Both r_i and s_i are, technically speaking, functions of n, but for simplicity of exposition, we suppress this argument. For $n = 2$, r_i corresponds to the division that i fixes in the dictator game, and s_i corresponds to i's rejection threshold in the ultimatum game. Assumptions 1–3 guarantee that, for each c, there is a unique $s_i \in (0, 1/n]$ and a $r_i \in [1/n, 1]$. We will suppose that r_i is unique for each c.[12]

Assumption 4 provides an explicit characterization of the heterogeneity that exists among players. Let f^r and f^s be density functions.

ASSUMPTION 4: *Heterogeneity.—For all* $c > 0$,

$$f^r(r|c) > 0, \qquad r \in [1/n, 1]$$

$$f^s(s|c) > 0, \qquad s \in (0, 1/n].$$

Hence, we assume that the full range of thresholds is represented in the player population.

A. *A Useful Two-Player Game Example*

It will be useful to have an example motivation function to illustrate some key points as we go along. We emphasize that we will not use the example to prove any statements. Consider the additively separable motivation function for

[11] Assumption 3 runs counter to the hypothesis that people want high relative payoff for its own sake (i.e., status-seeking) (see e.g., James S. Duesenberry, 1949). If all people were status-seeking, we would always see dominant strategy play in prisoner's dilemma and public-goods games, since this strategy is best from both a pecuniary and status perspective. Many people, however, fail to play dominant strategy (see Section VI). Of course this does not rule out the possibility that *some* people are status-seeking, and to the extent that this is true, the model misses this aspect of these people's motivation. But we would also point out that introspective intuition that status matters is not necessarily at odds with the model, since it may be difficult to separate the desire for status per se from the pecuniary rewards that usually accompany status. Seeking status for pecuniary rewards is consistent with ERC.

[12] This would be the case, for example, if $v_i(c\sigma_i, \sigma_i)$ were strictly concave in σ_i for all $c > 0$.

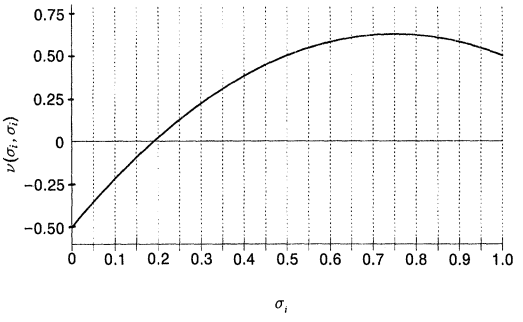

FIGURE 4. ADDITIVELY SEPARABLE MOTIVATION FUNCTION WITH $c = 1$ AND $a/b = 1/4$ ($r_i = 3/4$, $s_i = 1/5$)

player i, involved in a two-player game (we continue to write y_i as $c\sigma_i$):

$$(2)\quad v_i(c\sigma_i, \sigma_i) = a_i c\sigma_i - \frac{b_i}{2}\left(\sigma_i - \frac{1}{2}\right)^2 \qquad a_i \geq 0 \quad b_i > 0.$$

The component in front of the first minus sign is simply an expression of standard preferences for the pecuniary payoff. The component after the first minus sign delineates the influence of the comparative effect. In essence, the further the allocation moves from player i receiving an equal share, the higher the loss from the comparative effect. Figure 4 displays a particular parameterization of (2).

The functional form in (2) allows us to express heterogeneity in a very succinct way. A player's type is characterized by a/b, the ratio of weights that are attributed to the pecuniary and relative components of the motivation function. Strict relativism is represented by $a/b = 0$, which implies $r = s = 1/2$. Strict narrow self-interest is the limiting case $a/b \to \infty$, which implies $r = 1$ and $s \to 0$.

B. *ERC Equilibria*

As players gain experience with the game rules and the behavior of others, laboratory play tends to settle down to a stable pattern (see e.g., the discussion in Roth and Erev [1995]). ERC makes equilibrium predictions intended to characterize the stable patterns. Define an *ERC equilibrium* as a perfect Bayesian equilibrium solved with respect to player motivation functions in which each player's r and s are private information but the densities f^r and f^s are common knowledge.[13]

IV. Equity in Bargaining Games

For simplicity, we derive many of the results in this section assuming a continuous strategy space. Unless otherwise stated, all statements characterize ERC equilibria.

A. *Dictator and Ultimatum Games, and the Relationship Between Them*

First consider a dictator game in which the dictator (D) distributes a pie of maximum size $k > 0$ between himself and a recipient. We represent the dictator's division as the pair (c, σ_D) with $0 \leq c \leq k$. Thus, the dictator's payoff is $c\sigma_D$, and the recipient's payoff is $c - c\sigma_D$.

STATEMENT 1 (Dictator Game): *For all dictator allocations, $c = k$, and $\sigma_D = r_D(c) \in [1/2, 1]$. On average, dictator giving is positive: $1/2 < \bar{\sigma}_D(c) < 1$.*

PROOF:

The proof follows directly from Assumption 2, the definition of $r_i(c)$ given in Section III, and the heterogeneity assumption (Assumption 4).

The dictator game has been the subject of several studies (e.g., Forsythe et al., 1994; Hoffman et al., 1994; Bolton et al., 1998b). While the precise distribution of dictator giving varies with framing effects, Statement 1 appears equally valid for all cases: Dictators distribute all the money, (almost) always give themselves at least half, and on average, keep less than the whole pie. (Those taking less than half, like the one dictator in Figure 1, account for less than 1 percent of the data in the studies listed.)[14]

Now consider an ultimatum game between a proposer (P) and a responder (R). For the moment, we assume that the cake size, $k > 0$, is common

[13] For a precise definition of perfect Bayesian equilibrium see Robert Gibbons (1992 p. 180).

[14] For $k = 1$ and the example motivation function (2), the dictator decision is given by $r = \min\{0.5 + a/b, 1\}$ and directly reflects the player's type a/b.

knowledge. We represent the proposal by (c, σ_P), interpreted analogously to the dictator notation. To keep things as simple as possible, we assume that if a responder is indifferent between accepting and rejecting, that is, if $1 - \sigma_P = s_R(c)$, then the responder always accepts the proposal (c, σ_P). We further assume that $s_i(c)$ is differentiable. Statement 2 characterizes the responder's ERC equilibrium strategy, and Statement 3 characterizes the proposer's.

STATEMENT 2 (Ultimatum Responder Behavior): *For $c > 0$, the probability that a randomly selected responder will reject, $p(c, \sigma_P)$, satisfies the following: (i) $p(c, 1/2) = 0$ and $p(c, 1) = 1$; (ii) p is strictly increasing in σ_P over the interval $(1/2, 1)$; (iii) fixing a $\sigma_P \in (1/2, 1)$, p is nonincreasing in c.*

PROOF:

(i) By Assumption 2, for all responders, $\nu_R(c/2, 1/2) \geq \nu_R(0, 1/2)$. Hence, equal division is never rejected. The definition of $s_i(c)$ implies that the responder rejects the offer if $1 - \sigma_P < s_R(c)$, $s_R \in (0, 1/n]$. Therefore, $\sigma_P = 1$ offers are always rejected. (ii) This follows from integrating over the density $f^s(s|c)$. (iii) $s_i(c)$ is implicitly defined by $\nu_i(cs_i, s_i) = \nu_i(0, 1/2)$ for $s_i \leq 1/2$. Differentiating yields

$$s_i'(c) = -\frac{s_i \nu_{i1}(cs_i, s_i)}{c\nu_{i1}(cs_i, s_i) + \nu_{i2}(cs_i, s_i)} \leq 0.$$

STATEMENT 3 (Ultimatum Proposer Behavior): *For all ultimatum proposals, $c = k$ and $1/2 \leq \sigma_P < 1$.*

PROOF:

For any fixed $c > 0$, all proposers prefer $\sigma_P = 1/2$ to any $\sigma_P < 1/2$, and $\sigma_P = 1/2$ is never turned down. It follows that any ERC equilibrium proposal has $\sigma_P \geq 1/2$. Also, the unique standard subgame-perfect equilibrium proposal $\sigma_P = 1$ is always rejected so that any ERC equilibrium has $\sigma_P < 1$. By Statement 2, $p(c, \sigma_P)$ is nonincreasing in c, so by Assumption 2 the proposer will propose dividing all of k.

Many studies, beginning with Güth et al. (1982), confirm Statements 2(i) and 3. The experiments of Roth et al. (1991) and Bolton and Rami Zwick (1995) vividly illustrate that lower offers tend to have a higher probability of rejection [Statement 2(ii)]. Lisa Cameron (1995) and Hoffman et al. (1996) study ultimatum games played for one round, and find no cake-size effect with regard to rejection behavior [Statement 2(iii)]. Robert Slonim and Roth (1998) have subjects play the game over ten rounds. They find little difference in rejection behavior across cake sizes in the early rounds, but for the later rounds they find that rejections move in the direction consistent with Statement 2(iii). (The investigators note that there is no evidence that rejection thresholds change across rounds. They attribute their result to better statistical detection in later rounds due to a shift in proposer offers.)[15]

Forsythe et al. (1994) found that, on average, offers are higher in the ultimatum game than in the dictator game. ERC predicts this relationship. By Statements 1 and 3, we may assume that all proposals divide all of k, which we normalize to size 1.

STATEMENT 4 (Dictator vs. Ultimatum Proposer Offers): *On average, offers in the ultimatum game will be higher than offers in the dictator game ($\bar{\sigma}_D > \bar{\sigma}_P$). In fact, no one offers more in the dictator game, and the only players who offer the same amount are precisely those for whom $r_i(1) = 1/2$.*

PROOF:

That proposers who have $r_i(1) = 1/2$ offer the same in both games is obvious. Since the optimal σ_P is smaller than 1 (Statement 3), players with $r_i(1) = 1$ offer more in the ultimatum game. For all other proposers, $r_i \in (1/2, 1)$, we write out the first-order conditions (FOC) (normalize $\nu(0, 1/2) = 0$): the FOC for the dictator game is

$$\nu_{D1}(\sigma_D, \sigma_D) + \nu_{D2}(\sigma_D, \sigma_D) = 0,$$

[15] The additively separable motivation function in (2) suggests a negative relationship between s_i and r_i. As far as we know, there are no data on whether a relationship exists (let alone this one), although a relationship of some sort is plausible.

and the FOC for the ultimatum game is

$$\nu_{P1}(\sigma_P, \sigma_P) + \nu_{P2}(\sigma_P, \sigma_P) = \frac{p'(1, \sigma_P)\nu_P(\sigma_P, \sigma_P)}{1 - p(1, \sigma_P)} > 0.$$

By inspection, $\sigma_D > \sigma_P$. Hence, by Assumption 4, $\bar{\sigma}_D > \bar{\sigma}_P$.

B. *Unknown Pie-Size Games*

Suppose now that the responder must decide whether to accept or reject an offer of y monetary units without knowing the pie size, but knowing that the pie was drawn from some distribution, $f(k)$, with support $\lfloor \underline{k}, \bar{k} \rfloor$. Suppose $y < \underline{k}/2$. Michael Mitzkewitz and Rosemarie Nagel (1993), Kagel et al. (1996), and Amnon Rapoport and James A. Sundali (1996) have all shown that responders are more likely to reject y under these circumstances than if they know for certain that the pie is $\underline{k}$, and less likely to reject than if they know it is $\bar{k}$. The same is true in ERC. Let $p_u(y)$ denote the probability that y will be rejected by a randomly selected responder. Statement 5 supposes that the size of the offer does not convey any information about the pie size, the case we know how to solve for.

STATEMENT 5 (Incomplete Information): *For all* $y < \underline{k}/2$,

$$p\left(\underline{k}, \frac{\underline{k} - y}{\underline{k}}\right) < p_u(y) < p\left(\bar{k}, \frac{\bar{k} - y}{\bar{k}}\right).$$

PROOF:

Suppose $y < \underline{k}/2$. Then there exists a responder i who, if he knew the pie size was $\bar{k}$, is just indifferent between y and rejecting. Then, keeping in mind Assumption 3,

$$\nu_i\left(0, \frac{1}{2}\right) = \nu_i\left(y, \frac{y}{\bar{k}}\right) < \int_{\underline{k}}^{\bar{k}} \nu_i\left(y, \frac{y}{k}\right) f(k)\, dk$$

which indicates that i and players with similar rejection thresholds are less likely to reject when they do not know the size of the pie. A very similar argument shows that i is more likely to reject when he does not know that the pie size is $\underline{k}$.

TABLE 1—A COMPARISON OF PAYOFFS FOR THE MINI-GAMES

	Moves		Payoffs	
Mini-game	Proposer	Responder	y_P	y_R
Ultimatum	left	reject	0	0
		accept	2	2
	right	reject	0	0
		accept	3	1
Impunity	left	reject	0	0
		accept	2	2
	right	reject	3	0
		accept	3	1
Best shot	left	reject	1	3
		accept	1	1
	right	reject	0	0
		accept	3	1

C. *Impunity and Best Shot*

We concern ourselves with the "mini" versions of impunity and best-shot games and compare these to the mini-ultimatum game. In all three games, a proposer moves either "left" or "right." The responder observes the proposer's move and then either "accepts" or "rejects." The games differ only in the payoffs, which are listed in Table 1. Note that the standard subgame-perfect equilibrium is the same for all three games: the proposer plays "right," and the responder plays "accept." Applying ERC to the mini-ultimatum game is straightforward and yields results qualitatively equivalent to those for the full version. Application of ERC to the other games leads to markedly different predictions.

STATEMENT 6 (Impunity Game): *For the mini-impunity game: (i) Responders never play reject, so the only outcomes with a positive probability of occurring are* (2, 2) *and* (3, 1). *(ii) The probability of* (3, 1) *outcomes is equal to the proportion of proposers for whom* $\nu_P(3, \frac{3}{4}) > \nu_P(2, \frac{1}{2})$. *(iii) The probability of the* (3, 1) *outcome is higher than for the mini-ultimatum game.*

PROOF:

(i) For all responders, $\nu_R(2, \frac{1}{2}) \geq \nu_R(0, \frac{1}{2})$ and $\nu_R(1, \frac{1}{4}) > \nu_R(0, 0)$. (ii) Given responders' behavior, the proposer's choice is effectively $(y_P, y_R) = (2, 2)$ or $(3, 1)$. (iii) Obviously at least as many proposers play (3, 1) in impunity as in ultimatum, and by (i) the probability of rejection is strictly lower in impunity.

Bolton and Zwick (1995) study the mini-ultimatum and mini-impunity games, and the results are fully consistent with these predictions. Güth and Steffen Huck (1997) study ultimatum and impunity games with more complete strategy spaces. They find that responders are less likely to reject in impunity than in ultimatum, although they also find that the average impunity responder's rejection threshold, while small, is higher than zero. They find that proposers offer less in impunity than in ultimatum. Güth and Huck's study includes a dictator game. Statement 6(ii) implies that offers should not differ across dictator and impunity games, and this is what they report.

STATEMENT 7 (Best-Shot Game): *For mini-best shot: (i) The probability a* (3, 1) *offer is rejected is the same as in mini-ultimatum. (ii) For all proposers, the expected value of playing "right" is the same as in mini-ultimatum, while the expected value of moving "left" is smaller than in mini-ultimatum.*

PROOF:

(i) Note that, after an offer of (3, 1), responders in mini-best shot and mini-ultimatum have identical choices available to them. (ii) That the expected value of playing "right" is the same in both games follows immediately from (i). For moving left, let p be the probability a randomly chosen best-shot responder prefers (1, 3) to (1, 1); by Assumption 4, $p > 0$. Then for all proposers,

$$p\nu_P(1, \tfrac{1}{4}) + (1 - p)\nu_P(1, \tfrac{1}{2}) < \nu_P(2, \tfrac{1}{2})$$

for all $p \in (0, 1]$.

Supposing there is sufficient heterogeneity in the population, some proposers who choose moving left in the mini-ultimatum game will move right in mini-best shot in response to the lower value of moving left [Statement 7(ii)]. But Statement 7(i) implies that the mini-best shot responder accepts and rejects (3, 1) at the same rate as in mini-ultimatum. Consequently, mini-best-shot behavior should move toward, but not converge to, the standard subgame-perfect equilibrium. Prasnikar and Roth (1992) study both a best-shot and ultimatum game, each with a fuller strategy space than the mini game, each played over ten rounds. They observe standard ultimatum-game results. But for the best-shot game, by round 7, all proposers make the equilibrium offer. However, a significant proportion of the responders deviate from equilibrium in every round.[16] Qualitatively analogous observations are reported in John Duffy and Nick Feltovich's (1999) study of the evolution of 40 rounds of ultimatum play and 30 rounds of best-shot play: best-shot results are closer to perfect equilibrium, but on average, second-mover behavior clearly differs from the payoff maximizing best response. Unfortunately, in both studies, different payoffs and strategy spaces across games prevent a clean comparison of the rejection rates.

V. Competition in Market Games

In the last section, we showed that, if a game creates a trade-off between pecuniary and relative motivations, we can observe behavior that sharply contradicts standard theoretical predictions. But people do not always play fair. Many market institutions apparently induce competitive self-interested behavior of the type predicted by standard theory. In this section we show that typical market environments interact with ERC motivations in a way that aligns pecuniary and relative motives. As a consequence, traditional Nash equilibria are ERC equilibria.

Some well-known experimental results come from games with symmetric equilib-

[16] We refer in the text to the full-information treatments. Prasnikar and Roth (1992) also study incomplete-information games, as do Glenn W. Harrison and Jack Hirshleifer (1989), but the nature of the incomplete information renders the results incomparable to the theory.

rium payoffs, so we begin with the symmetric case. It turns out that ERC implies an interesting difference between Bertrand and Cournot games with respect to symmetry, and we turn to this issue at the end of the section.

Bertrand and Cournot games are the standard textbook examples of (oligopolistic) markets. Suppose demand is exogenously given by $M = p + q$, where M is a constant, p denotes the price, and q the quantity. Suppose $n \geq 1$ identical firms produce at constant marginal cost $\theta (< M)$. In Cournot games, firms choose quantities $q_i \in [0, M - \theta]$ yielding profits given by $y_i(q_1, q_2, \ldots, q_n) = (M - \theta - q_{-i})q_i - q_i^2$, where $q_{-i} = \sum_{j \neq i} q_j$. In Bertrand games, firms choose prices $p_i \in [\theta, M]$ yielding profits equal to $y_i(p_1, p_2, \ldots, p_n) = (p_i - \theta)(M - p_i)/\tilde{n}$ if i sets the lowest price along with $\tilde{n} - 1$ other firms, or equal to zero if there exists a firm $j \neq i$ that sets a lower price.

STATEMENT 8 (Bertrand and Cournot Game): *For $n \geq 1$, and for either price (Bertrand) or quantity (Cournot) competition, all Nash equilibria are ERC equilibria.*

PROOF:

For $n = 1$, $\sigma_i(y_i, c, 1) \equiv 1$ so that the ERC monopolist simply maximizes his profits. For $n > 1$, observe that all Nash equilibria in both the price and the quantity game yield equal equilibrium profits for all firms (see Kenneth G. Binmore, 1992). Hence, a firm that deviates from its Nash equilibrium strategy can neither gain with respect to pecuniary nor to relative payoffs.

The remaining statements in this section provide a stronger characterization of ERC equilibria. We will suppose that for some $\varepsilon > 0$ proportion of the population, r is approximately 1 for all possible total payoffs c, and for all number of players n. (How close the approximation need be will be made explicit in the relevant statements.) These people are highly self-interested in the standard sense. They will drive some (but not all) of the market results. We make two technical assumptions: First, we suppose that $v_i(0, 0)$ is, for a given pie size c and for all i, the worst possible outcome. Second, we suppose that the value of $v_i(y_i, 1/n)$ is bounded with respect to both i and n.[17]

We first show that, for n large enough, the competitive outcome is the unique ERC equilibrium for the Bertrand game. The intuition is quite simple: For large n, there is a high probability that at least one player cares sufficiently about his pecuniary payoff to undercut high bids in pursuit of pecuniary gain. Everyone knows that the probability of such a person is high, and so in equilibrium everyone undercuts, because this is what is necessary to preserve relative as well as pecuniary positions.

To keep the proof simple, we assume that the pure strategy space is finite. Furthermore, we assume that the interval between admissible price offers, Δ, is "small"; specifically,

$$(p - \Delta - \theta)(M - p + \Delta) > (1/n)(p - \theta)(M - p)$$

for all $p > \theta + \Delta$, and for all $n > 1$ (so there is a pecuniary incentive to undercut p, when all others bid p).

STATEMENT 9 (Bertrand Game in Large Markets): *For price competition and for n large enough, the market price in all* ERC *equilibria is equal to cost θ or to $\theta + \Delta$, the standard Nash equilibrium prices for $n > 1$ firms.*

PROOF:

Let γ be the probability that the composition of players in the game is sufficiently narrowly

[17] The first technical assumption simply implies that the worst thing that can happen to i is to have to watch others receive a positive payoff while receiving none himself. The second is also mild: that the value of $v_i(y_i, 1/n)$ is bounded with respect to i (fixing n) would follow immediately if we made the realistic (but less mathematically convenient) assumption that the population is finite; we simply impose boundedness on the infinite population (see Assumption 4). With respect to n, the assumption implies that, for a fixed pecuniary payoff, the value to i of achieving the social reference proportion is bounded with respect to the number of players in the game. We think that assuming the value of $v_i(y_i, 1/n)$ to be fixed with respect to n would be reasonable, but boundedness will suffice.

self-interested in the sense that, for all admissible $p > \theta + \Delta$,

$$\nu_i([p - \Delta - \theta][M - p + \Delta], 1) > \nu_i([1/n][p - \theta][M - p], 1/n)$$

for at least one i. Since an $r = 1$ player satisfies this condition, it follows that, as n increases, γ increases monotonically to 1. Choose n large enough, so that γ satisfies

$$\max_i\{(1 - \gamma)\nu_i([1/n][p_M - \theta][M - p_M], 1/n) + \gamma\nu_i(0, 0) - \nu_i(0, 1/n)\} < 0$$

where p_M is the monopoly price. A maximum exists because of the boundedness assumption.

Now suppose there is an ERC equilibrium in which the maximum bid that wins with positive probability is $p_H > \theta + \Delta$. Since transactions are never made at a price greater than p_H, bidding above p_H is strictly dominated by offering a price of p_H [recall that we assume that $\nu_i(0, 0)$ is the worst possible outcome for all i]. Therefore, in equilibrium, all prices bid with positive probability by any player must be p_H or lower. Hence p_H wins only if all n firms play it. It follows that the expected value to firm i of bidding p_H is

$$(3)\quad \beta\nu_i([1/n][p_H - \theta][M - p_H], 1/n) + (1 - \beta)\nu_i(0, 0)$$

where β is the probability that all firms other than i bid p_H. On the other hand, the expected value of firm i bidding $p_H - \Delta$ is

$$(4)\quad \beta\nu_i([p_H - \Delta - \theta][M - p_H + \Delta], 1) + (1 - \beta)[\cdots].$$

For sufficiently narrowly self-interested agents, (4) > (3). Therefore, sufficiently self-interested players always bid lower than p_H. Given this, the expected value of bidding p_H for any player is:

$$\begin{aligned} &\leq (1 - \gamma)\nu_i([1/n][p_H - \theta][M - p_H], 1/n) + \gamma\nu_i(0, 0) \\ &\leq (1 - \gamma)\nu_i([1/n][p_M - \theta][M - p_M], 1/n) + \gamma\nu_i(0, 0) \\ &< \nu_i(0, 1/n) \end{aligned}$$

which contradicts the assumption that p_H is a best response for at least some player (any player can guarantee himself $\nu_i(0, 1/n)$ by playing θ). Since a construction like (4) is always possible if $p_H > \theta + \Delta$, it follows that $p_H = \theta$ or $\theta + \Delta$ for sufficiently large n (to see that the latter can be supported as ERC equilibria, apply the reasoning in Statement 8).

In the guessing game, $n > 1$ players simultaneously choose a number z from an interval $[0, k]$. For simplicity, we assume (analogous to the Bertrand game) that the number of choices is finite and that the interval between any two consecutive choices Δ is "small." The winner is the player whose number is closest to $\omega\bar{z}$, $0 < \omega < 1$ and $\bar{z} = \sum_{j=1}^{n} z_j/n$. The winner receives a fixed prize; if there is a tie, winners share the prize equally. The guessing game is very similar to a Bertrand game, save that the cake to be distributed is fixed. Nagel's (1995) experiment shows that, after some rounds, play approaches the unique standard Nash equilibrium, $z_i = 0$ for all i. Teck-Hua Ho et al. (1998) study the game for several values of ω and also find that choices tend to converge toward the equilibrium.

STATEMENT 9a (Guessing Game): *For n large enough, the unique Nash equilibrium in the guessing game is equivalent to the (unique) ERC equilibrium $z_i = 0$ for all i.*

PROOF:

Showing that $z_i \equiv 0$ is an ERC equilibrium is straightforward. For the proof in the other direction, note that any outcome in which i wins has a payoff of at least $\nu_i(0, 1)$. Fix a strategy profile for the other $n - 1$ players, and let $\bar{x}$ be the arithmetic average implied by the distribution. If n is large enough, player i's influence on

the average is negligible (and so we can ignore it). Therefore, when n is large enough, by guessing $\omega\bar{x}$, player i can guarantee herself greater than

$$\frac{\Delta}{k}\,\nu_i(0,\,1) + \frac{k-\Delta}{k}\,\nu_i(0,\,0).$$

Substitute this value everywhere for $\nu_i(0,\,1/n)$, and the rest of the proof closely parallels that of Statement 9.

How large must n be? By the proofs of Statements 9 and 9a, the answer depends on the prevalence of "sufficiently narrowly self-interested" subjects in the population. In games with complete information, one sufficiently self-interested player is enough to induce competitive results. Hoffman et al. (1994) performed a dictator game in a buyer–seller frame similar to Bertrand games (with players being randomly assigned to buyer and seller positions). The proportion giving zero was about 45 percent.[18] Thus, the probability of at least one subject with $r = 1$ in a group of n subjects is $1 - 0.55^n$. Assuming that r is not too sensitive to the size of the pie or to the number of players, a lower bound on the probability of at least one sufficiently self-interested player in a group of three is over 83 percent. It appears, then, that n need not be very large for ERC equilibrium market prices to shrink to the standard Nash price. Charles A. Holt (1995) reports some evidence that outcomes of oligopoly games are less competitive with two players than with three or more, but there is no particular effect for numbers greater than two.

Interestingly, ERC implies that the auction-market game studied by Roth et al. (1991) (discussed in Section II) is sufficiently different from the Bertrand game to obtain competitive results independent of the number of buyers so long as there are at least two. Recall that, in this game, buyers simultaneously bid on an object owned by a single seller. The lowest bid is submitted to the seller, who either accepts or rejects; if the latter, all players receive a zero monetary payoff.

We normalize the surplus that can be shared from the transaction to 1, and we represent a *bid* by the proportion of the surplus that the buyer proposes *keeping* (defined this way, the relationship to Statement 9 will be transparent). A bid *wins* if it is both the lowest submitted and acceptable to the seller. Analogous to the Bertrand game, we suppose that the interval between permissible bids, Δ, is "small."

STATEMENT 9b (Auction-Market Game): *Consider an auction-market game having at least two buyers. Under the assumption that the seller accepts, all ERC equilibria for the market game have a winning buyer bid of* 0 *or* Δ, *the standard Nash equilibrium bids for* $n > 1$ *buyers.*

PROOF:

Given that the seller accepts, by applying the reasoning of Statement 8, standard Nash equilibrium bids are ERC equilibrium bids. Suppose, contrary to Statement 9b, that there is an equilibrium in which $z_H > \Delta$ is the highest bid that wins with positive probability. The proof that, in equilibrium, no one ever bids higher is analogous to the proof of Statement 9 if one substitutes "price (p)" for "bid (z)" and "firm" for "buyer." However, in contrast to the Bertrand game, in this market one buyer with the smallest bid is chosen randomly, and that buyer divides the surplus with the seller, who is an actual subject in the experiment. Consequently, (3) and (4) of the proof for Statement 9 become

$$(5)\quad \beta[(1/n)\nu_i(z_H,\,z_H) + (1-1/n)\nu_i(0,\,0)] + (1-\beta)\nu_i(0,\,0)$$

$$(6)\quad \beta\nu_i(z_H-\Delta,\,z_H-\Delta) + (1-\beta)[\cdots].$$

The inequality (6) > (5) holds for all players,

[18] We refer to Hoffman et al.'s (1994) buyer–seller dictator game with contest selection of roles. They also ran a buyer–seller dictator game with random selection of roles. The proportion giving zero was lower, but the proportion almost giving zero (10 percent or less) was about 40 percent, and in this sense our calculation is roughly consistent with both dictator treatments. We refer to these particular dictator treatments because they are approximately framed (buyer–seller) in the same way as Bertrand experiments. We nevertheless think of the resulting calculations as illustrations. A careful, meaningful calculation requires running dictator and Bertrand games in closely parallel frames.

regardless of type. This contradicts the assumption that bidding z_H is a best response.

The results demonstrate that the market behavior predicted by ERC is independent of the distribution of types, even if the equilibrium is inefficient as in the Bertrand game or unfair as in the market game. In this independence lies the power of market institutions.

As for the assumption concerning seller behavior, from the point of view of ERC, its validity is an empirical question. In fact, Roth et al. (1991 p. 1075) report that no best bid was ever rejected in a nonpractice round. The assumption is basically equivalent to positing that $v_i(\sigma_i, \sigma_i) > v_i(0, 1/n)\ \forall \sigma_i \in (1/n, 1]$,[19] which implies an asymmetry with respect to fairness: "I reject offers that are very unfair to me but accept offers that are very unfair to you." Asymmetry of this sort is suggested by George F. Loewenstein et al. (1989), and by Fehr and Schmidt (1999). While ERC has no problem accommodating this assumption, we have avoided it to highlight the fact that it is not relevant to any proof in this paper save that of Statement 9b, where it has but a very minor role. In particular, the assumption is not necessary to explain the competitive behavior of buyers in the Roth et al. (1991) game.[20] Is there a restriction we could place on the motivation function to guarantee the competitive results in Statements 9 and 9a for any sized group (greater than 1, of course)? The only one we can think of is a stronger asymmetry assumption: $v_i(c, 1) > v_i(c/n, 1/n)$ for all i, c, and n. But this is falsified by dictator-game experiments.

[19] Strictly speaking, Statement 9b requires that the seller accepts *all* bids, not just those greater than $1/n$. The proof, however, is easily extended. Suppose that the z_H in the proof gives the seller less than $1/n$. Revise both (5) and (6) to reflect the fact that undercutting increases the probability that the seller will accept.

[20] Moreover, asymmetry for *all* players is inconsistent with some empirical evidence. In experimental centipede games, for instance, it is observed that some subjects choose a payoff distribution that gives more money to the opponent if an egalitarian distribution is not feasible. Even if the proportion of such subjects in the population is small, the behavior of *all* subjects might substantially depend on the existence of such patterns (see Section VI).

Statement 8 shows that the standard Cournot-Nash equilibrium is an ERC equilibrium. The following proposition shows that, in addition, if we confine ourselves to pure strategies, the ERC equilibrium is unique. The proof extends the classic textbook graph-proof of duopoly Cournot equilibrium (e.g., Binmore, 1992 p. 290) to ERC motivations.

STATEMENT 10 (Cournot Duopoly): *In a Cournot duopoly, the unique ERC equilibrium in pure strategies is equivalent to the standard Nash equilibrium.*

PROOF:

In Figure 5, the x-axes show the quantity of firm j, and the y-axes show the quantity of firm i. The thick lines show the standard Nash reaction curves of player i (BE) and player j (CF). Two things need to be proved. First, observe that for all quantity combinations lying on the diagonal AD, the marginal utility with respect to relative payoffs is zero (Assumption 3). Since the probability of a player with $r_i(c) = 1/2$ is zero (Assumption 4), the marginal utility with respect to pecuniary payoffs on AD is strictly increasing [$r_i(c) > 1/2$ implies $v_{i1} > 0$ for $\sigma_i = 1/2$]. Hence, the only location on AD that can be an ERC equilibrium is point X, the Cournot equilibrium. Second, note that: (i) on the Nash reaction curves, $y_i'(q_i) = 0$ and $y_j'(q_j) = 0$, respectively; (ii) $y_i'(q_i) > 0$ if and only if (q_i, q_j) is within ABE, and $y_j'(q_j) > 0$ if and only if (q_i, q_j) is within ACF; (iii) $y_i < y_j$ if and only if (q_i, q_j) is within ADE, and $y_i > y_j$ if and only if (q_i, q_j) is within ACD; and (iv) $\sigma_k'(q_k) > 0$, $k = i, j$, everywhere in the interior of ACE. With these properties, it is easy to see that ERC reaction curves are bounded by the Nash reaction curves and the diagonal: j's ERC reaction curve must lie somewhere in the darkly shaded areas in Figure 5B, and i's ERC reaction curve must lie somewhere in the lightly shaded areas. The only possible point of intersection of ERC reaction curves is X.

The proof requires one sufficiently self-interested player in the market in a weaker sense than do the Bertrand statements, specifically, $r_i(c) > 1/2$ for one player. From dic-

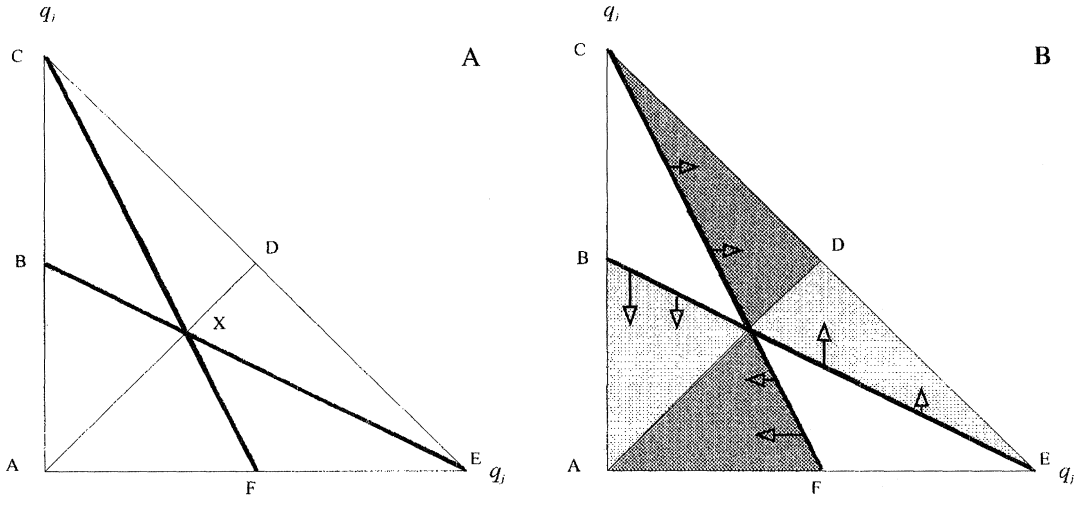

FIGURE 5. ERC REACTION CURVES IN A COURNOT DUOPOLY

tator games, we estimate the proportion of players for whom $r(c) > 1/2$ to be 80 percent. This is a conservative estimate: most dictator studies find a higher proportion than this. On this basis we estimate the probability of a standard Nash equilibrium to be at least 96 percent. However, the calculation ignores the pure strategy and the incomplete-information aspects of the proof.

Evidence for the standard Cournot-Nash equilibrium is less than conclusive. Holt (1985) conducted single-period duopoly experiments of the type we study here. While in the beginning some subjects try to cooperate, quantity choices tend ultimately to the Cournot level. Holt (1995) surveys a number of studies and reports some support for Nash equilibrium, but he also expresses reservations. Huck et al. (1997) experimentally study the stability of the Cournot adjustment process in a four-firm oligopoly with linear demand and cost functions. The authors report rough convergence to Nash equilibrium.

Finally, ERC implies that symmetric payoffs are important to Cournot outcomes in a way they are not to Bertrand outcomes. Consider a Cournot duopoly in which firm i has a cost advantage: $\theta_i < \theta_j$. The standard Nash equilibrium profit of firm i is greater than the profit of firm j. But this may not be an ERC equilibrium because firm i may choose a smaller quantity in order to boost relative payoff. On the other hand, consider cost heterogeneity in Bertrand games (i.e., each firm i is randomly assigned to costs $\theta_i \in \{\theta^1, \theta^2, \ldots, \theta^k\}$, $k < \infty$). Then, the competitive price is the lowest θ in the market, and it is also a standard Nash equilibrium.[21] It continues to be an ERC equilibrium if the market is large enough; the proof is analogous to that of Statement 9.[22]

VI. Reciprocity in Dilemma Games

In dilemma games, deviation by strictly narrowly self-interested players from their equilibrium strategy contributes to a higher joint (pecuniary) payoff for the group, and enough contributions produce an outcome that is Pareto superior to the equilibrium. In this section, we show that ERC is consistent with many of the

[21] This holds if there is more than one firm with minimum cost. If there is only one firm with minimum cost, there is a Nash equilibrium in which the price is the second-lowest cost, and the firm with minimum cost gets all the surplus.

[22] Roughly speaking, for n large enough there is one firm among the firms with minimum cost that is sufficiently self-interested so that it undercuts any price greater than minimum cost.

TABLE 2—PRISONER'S DILEMMA PAYOFF MATRIX

	Player 2	
Player 1	Cooperate (C)	Defect (D)
Cooperate (C)	$2m$, $2m$	m, $1 + m$
Defect (D)	$1 + m$, m	1, 1

Note: m = marginal per capita return (mpcr) $\in (0.5, 1)$.

reciprocal patterns observed in various dilemmas, including the prisoner's dilemma (PD), gift-exchange, and investment games.

A. *What Is Necessary to Induce Cooperation in Simultaneous and Sequential PDs?*

We demonstrate that, in ERC, the extent of cooperation can depend on the interaction between heterogeneity with respect to how players trade-off pecuniary for relative gains and the size of payoffs, especially the size of the efficiency gains that can be achieved through cooperation. These factors are important in both simultaneous and sequential PDs, although the factors interact in somewhat different ways across the two games.

Consider the PD payoff matrix in Table 2. To illustrate how trade-offs between pecuniary and relative payoffs matter to ERC predictions, we will suppose that individuals can be described by the motivation function given in (2):

$$v_i(c\sigma_i, \sigma_i) = a_i c\sigma_i - b_i(\sigma_i - \tfrac{1}{2})^2/2.$$

Then, a/b fully characterizes a subject's type. The population distribution of types will be denoted by $F(a/b)$.[23]

To see what influences cooperation in a one-shot simultaneous PD, examine the optimal decision rule for a subject with type a/b:

$$C > D \Leftrightarrow$$

$$\frac{a}{b} < \frac{p - \frac{1}{2}}{4(1 - m)(1 + 2m)^2} = g(m, p).$$

[23] Of course, the results we derive will be special to this class of motivation functions. But keep in mind that our goal here is to demonstrate that particular factors *can* play an important role in what ERC predicts.

Here p is the probability that the opponent cooperates. Thus, cooperation is influenced by the extent to which subjects are motivated by relative payoffs, the magnitude of the mpcr, m, and the proportion of cooperating subjects in the population. There is always an equilibrium in which nobody cooperates, but depending on the shape of $F(a/b)$, there may also be equilibria in which a proportion of subjects cooperate, while others defect.

We next consider the sequential PD, in which the second mover decides after being informed of the first mover's action. We obtain an interesting result: cooperation requires both subjects who are willing to sacrifice pecuniary for relative gains and subjects who are mostly interested in pecuniary payoffs. To see this, examine the optimal decision rules (the information assumptions laid out in Section III, subsection B, continue to apply):

Second mover:

$$C > D \Leftrightarrow \text{(i) first mover plays } C$$

$$\text{(ii) } \frac{a}{b} < g(m,1)$$

First mover:

$$C > D \Leftrightarrow \text{(i) } -1 + m(1 + \hat{p}) > 0$$

$$\text{(ii) } \frac{a}{b} > \frac{1 - \hat{p}}{8(m\hat{p} + m - 1)(1 + 2m)^2}.$$

Here $\hat{p} = \hat{p}(m) = F(g(m, 1))$ is the probability that the second mover responds cooperatively if the first mover cooperates. The second mover's optimal decision rule corresponds to the one applied in the simultaneous PD with $p = 0$ or 1, respectively. The second mover cooperates if and only if she is sufficiently motivated by the relative payoff, and the first mover cooperated. This means that the second-mover population can be partitioned into defectors and tit-for-tat players. The first mover cooperates if and only if she is sufficiently motivated by pecuniary payoffs and the expected monetary net return of cooperation $[-1 + m(1 + \hat{p})]$ is positive. The reasoning behind the

required first-mover motivation is simple: a first mover who is interested in relative payoff can guarantee equal payoffs by defecting, since in this case, the second mover will certainly defect. Only if a first mover is sufficiently interested in his pecuniary payoff will he take the chance of being exploited in an attempt to "trigger" second-mover cooperation.

Heterogeneity implies that the proportion of both first and second movers who cooperate increases with the mpcr ($\hat{p}'(m) > 0$ and $\partial[(1 - \hat{p}(m))/(8(m\hat{p} + m - 1)(1 + 2m)^2)]/\partial m < 0$). Even if $\hat{p}(m)$ is very small, a sufficiently high mpcr may induce the first mover to cooperate.

Several studies support the view that potential efficiency gains and the propensity of others to cooperate (measured in ERC by the marginal rate of substitution between pecuniary and relative payoffs) are major determinants of cooperation in both simultaneous and sequential PDs. In a well-known survey, Anatol Rapoport and Albert M. Chammah (1965) demonstrate that cooperation rates in PDs increase when the gains from cooperation increase, or when the "sucker" payoff decreases.[24] John Ledyard (1995) surveys the literature on public-good games and concludes that, besides communication, the mpcr is the only control variable that has a strong positive effect on cooperation rates. Many experiments show a strong relation between own and opponent decisions. Russell Cooper et al. (1996) found two behavioral types in one-shot PDs that are in line with the ERC decision rules in PDs derived above: "egoists," who always defect, and "best-response altruists," for whom C (D) is a best response to C (D).[25] Similarly, Rapoport and Chammah (1965 pp. 56–66) and Pruitt (1970) found strong positive interactions between cooperative choices of players. Several studies have manipulated the expectation about the cooperation behavior of the opponent and found a positive correlation between own defective choices and the probability that the opponent defects (e.g., Edwin Bixenstine and Kellog V. Wilson, 1963; Lave, 1965). Fehr et al. (1997) and Bolton et al. (2000) demonstrate that cooperation is sensitive to other-player strategy choice in sequential-dilemma games. While some of these studies involve repeated play, ERC implies that the particular behavior is not due to repetition.

B. *A Parametric Analysis of the Gift-Exchange Game: The α Model*

Fehr et al. (1993) investigated wage and effort decisions in an experimental labor market (the gift-exchange game discussed in Section II). In the first stage, a firm offers a wage w; and in the second stage, a worker who accepts chooses an effort level e.

What can ERC say about this game? First, since gift exchange is essentially the sequential-dilemma game analyzed in Section VI, subsection A, the qualitative type of cooperative outcome Fehr et al. observe (an above-minimal wage, followed by an above-minimal effort level) can be sustained in ERC equilibrium. Somewhat more substantively, ERC's most basic prediction is that all workers will try to give themselves at least half the pie (Statement 1). In three cases, workers had no option that gave them half or more. Consistent with ERC, all three chose the minimum effort. In 96 percent of the other 273 cases, the worker gave himself at least the same payoff as the firm. Hence, the very basic facts of the game are in line with the ERC model.

We would like to say more. To do so, we need a parametric model. We use the Fehr et al. (1993) data to construct a very simple, parameterized ERC. Quantitatively fitting firms comes down to the rather shallow claim that we can find a set of expectations and risk postures to justify their actions. We therefore confine ourselves to fitting a model of optimal worker responses. (One of the things we will find is that observed firm behavior is quite sensible, given worker behavior.) Fehr et al. (1993) report that they found no learning effect among workers over the 12 rounds of play, evidence that motivation functions are in fact stable.

[24] Rapoport and Chammah (1965 p. 39 [Figure 1]). Lester B. Lave (1965) reports similar results.

[25] The hypothesis that altruistic subjects cooperate unconditionally ("dominant strategy altruism") is clearly rejected in Cooper et al.'s study. Recently, an analogous "exploitation aversion" effect has been observed in symmetric one-shot public-goods experiments: while many subjects are ready to match the average contribution of others to a public good, only a few subjects are willing to contribute more than the average (cf., Fehr et al. 1998; Ockenfels, 1999).

We therefore fit the model to all 276 wage–effort pairs collected.

For reasons of tractability, we fit a simplified version of the model, one with a single parameter, α, to express worker heterogeneity. We use the end points to approximate the range. Suppose there are but two types of workers: a proportion α of relativists and a proportion $1 - \alpha$ of egoists. The egoist maximizes pecuniary payoff. The relativist "mitigates" payoffs; that is, the relativist minimizes $|u(w, e) - \pi(w, e)|$, where $u(w, e)$ and $\pi(w, e)$ are respectively worker and firm payoffs.

Both the data and the fuller ERC model imply that many people are somewhere in between the α model's egoist and relativist categories. Think of α as an approximation of the *population* propensity to reciprocate. We will show that the value of α obtained from the gift-exchange game is robust in the sense that it is quite similar to the value obtained from several other experiments. Moreover, this very spare model explains the Fehr et al. (1993) experiment in substantial detail.

For the Fehr et al. (1993) experiment, payoffs for the firm and the worker were $\pi(w, e) = (v - w)e$ and $u(w, e) = w - c(e) - c_0$, respectively. To keep the exposition simple, we assume continuous strategy spaces $e \in [e^{\min}, e^{\max}]$ where $0 < e^{\min} < e^{\max}$ and $w \in [c_0, v]$, and a continuous convex cost function $c(e)$.[26] The data analysis, however, accounts for the discontinuities in the experiment's strategy spaces.

Define $\underline{w}$ and $\bar{w}$ by

$$w \leq \underline{w} \Leftrightarrow$$

$$e = e^{\min} \text{ minimizes } |u(w, e) - \pi(w, e)|$$

$$w \geq \bar{w} \Leftrightarrow$$

$$e = e^{\max} \text{ minimizes } |u(w, e) - \pi(w, e)|.$$

[26] Fehr et al. (1993) set $v = 126$, $c_0 = 26$, $e \in \{0.1, 0.2, \ldots, 1\}$, and $w \in \{30, 35, 40, \ldots, 125\}$; the convex cost function $c(e)$ was given by $(c(0.1), c(0.2), \ldots, c(1)) = (0, 1, 2, 4, 6, 8, 10, 12, 15, 18)$. The Fehr et al. design involved an excess supply curve, but Charness (1996) replicated the experiment without one, and so we will not consider supply conditions here. Charness set $v = 120$, $c_0 = 20$, and $w \in [c_0, v]$ with all other variables the same. The results of our analysis are valid for both designs.

Then the best-response functions for the workers are:

$$e^{\mathrm{E}}(w) \equiv e^{\min}$$

for egoists; and

$$e^{\mathrm{R}}(w) = \begin{cases} e^{\min} & w \leq \underline{w} \\ e^*(w) & \underline{w} < w < \bar{w} \\ e^{\max} & w \geq \bar{w} \end{cases}$$

for relativists. Here, $e^*(w)$ is implicitly defined by equating $u(w, e)$ and $\pi(w, e)$:

$$(v - w)e^*(w) = w - c(e^*(w)) - c_0.$$

The average effort level is $\bar{e}(w) = (1 - \alpha)e^{\min} + \alpha e^{\mathrm{R}}(w)$.

We state three hypotheses concerning how efforts and payoffs relate to wages and provide a rough sketch of the proofs. The formal derivations are in the Appendix. We compare each hypothesis with the Fehr et al. (1993) data.

STATEMENT 11 (Effort Hypothesis): *For all $\alpha \in (0, 1)$, a higher wage induces a higher average effort level; specifically, $\bar{e}'(w) \geq 0$ with strict inequality for $w \in (\underline{w}, \bar{w})$.*

SKETCH OF PROOF:

For $w \in (\underline{w}, \bar{w})$, an increase in the wage leads to an increase in workers' payoff, which relativists mitigate through higher effort. Since egoists' effort levels are constant, average effort levels increase. For $w \notin (\underline{w}, \bar{w})$, the model predicts constant effort levels for both egoists and relativists.

The effort hypothesis is clearly confirmed by the data. Fehr et al. (1993 pp. 447–48) report strongly significant correlation measures for highly aggregated data. On a somewhat less aggregated level, the Spearman rank correlation coefficient between wages and average effort levels calculated over all 17 values of wages actually chosen ($w \in [30, 110]$) shows a clear correlation ($\rho(\bar{e}, w) = 0.965$, two-tail p value < 0.00012). The α model predicts that the wage–effort correlation is less prominent on the individual level since the egoists do not respond

at all to different wage offers. The Spearman rank correlation coefficient between efforts and wages on the disaggregated data is $\rho(e, w) = 0.495$, a lower value than what is observed on the aggregate level, but nevertheless one that is highly significant (two-tail $p < 10^{-14}$).

STATEMENT 12 (Worker-Payoff Hypothesis): *For all $\alpha \in (0, 1)$, higher wages increase the worker payoff.*

SKETCH OF PROOF:

The statement is true for egoists since $u(w, e^{E}) = w - c(e^{\min}) - c_0$. Let $u^{R}(w) = u(w, e^{R}(w))$. Then the payoff for a relativist is

$$u^{R}(w) = w - c(e^{R}(w)) - c_0$$

$$= \begin{cases} w - c(e^{\min}) - c_0 & w \leq \underline{w} \\ w - c(e^{*}(w)) - c_0 & \underline{w} < w < \bar{w} \\ w - c(e^{\max}) - c_0 & w \geq \bar{w}. \end{cases}$$

Thus, $u^{R}(w)$ is increasing for small and large wages ($w \notin (\underline{w}, \bar{w})$). In the middle range, it increases because increases in wage and effort lead to higher total payoffs that relativists share equally.

The Spearman rank coefficient between wages and the worker payoff using individual data is $\rho(u, w) = 0.94$ (two-tail $p < 10^{-52}$), consistent with the worker-payoff hypothesis.

STATEMENT 13 (Firm's Payoff Hypothesis): *The average profit, $\bar{\pi}(w) = \pi(w, \bar{e}(w))$, is decreasing on $[c_0, \underline{w}]$. For $\alpha > 12$ percent, the average profit is increasing from $\underline{w}$ up to some maximum $w^{*} \leq \bar{w}$ and is decreasing for $w > w^{*}$.*

SKETCH OF PROOF:

The average payoff to a firm within the α model is given by

$$\bar{\pi}(w) = (v - w)\bar{e}(w)$$

$$= \begin{cases} (v - w)e^{\min} & w \leq \underline{w} \\ (v - w)((1 - \alpha)e^{\min} + \alpha e^{*}(w)) & \underline{w} < w < \bar{w} \\ (v - w)((1 - \alpha)e^{\min} + \alpha e^{\max}), & w \geq \bar{w}. \end{cases}$$

Since effort levels are constant for very small and very high wages, the α model predicts a negative relationship between $\bar{\pi}(w)$ and w for $w \notin (\underline{w}, \bar{w})$. For $w \in (\underline{w}, \bar{w})$, $\bar{\pi}(w)$ is strictly concave, because marginal total payoffs are decreasing in w. Relativists are willing to share total payoffs equally so that the marginal expected profit $\bar{\pi}'(w)$ is decreasing. The exact shape of $\bar{\pi}(w)$ in the middle wage interval (and whether it pays for firms to deviate from the minimum wage) depends on the value of α. If $\alpha > \underline{\alpha} \approx 12$ percent, which is reasonable in view of other experimental results (see Section VI, subsection C), $\bar{\pi}(w)$ is increasing in at least part of the middle range of w.[27]

In order to compare the firm's payoff hypothesis to the data, we need the value of α. We obtain an estimate in the most straightforward manner possible. We calculate the average effort level for each wage level actually offered and then calculate $\alpha(w)$ by solving $\bar{e}(w) = (1 - \alpha)e^{\min} + \alpha e^{R}(w)$. Then

$$\alpha = \sum_{w > \underline{w}} \frac{\#(w)}{273}\, \alpha(w)$$

(for $w \leq \underline{w}$, all subjects chose minimum effort, as predicted). Calculating α in this way yields (exactly) $\alpha = 0.5$.[28]

Figure 6 shows that the estimated model fits the data very closely. Note that ERC predicts no variance in the effort levels and payoffs for $w \leq 35 = \underline{w}$. In fact, all three observations in this range are at the minimum effort level $e^{\min} = 0.1$. There is only one observation for $w = 110$.

[27] Twelve percent is the value calculated with the discrete strategy spaces and cost function used in the experiment. With the continuous strategy spaces and cost function, the corresponding value is 10 percent (see Appendix).

[28] The described estimation technique is somewhat crude, but it has the advantage of being transparent. A somewhat more sophisticated method is minimizing the weighted deviations from actual and predicted payoffs:

$$\sum_{w} \frac{\#(w)}{276} \left(\left|\bar{\pi}^{\text{actual}}(w) - \bar{\pi}^{\alpha\ \text{model}}(w, \alpha)\right| + \left|\bar{u}^{\text{actual}}(w) - \bar{u}^{\alpha\text{model}}(w, \alpha)\right|\right).$$

Doing so, we obtain the value $\alpha = 0.46$, very close to the value from the simpler estimation method.

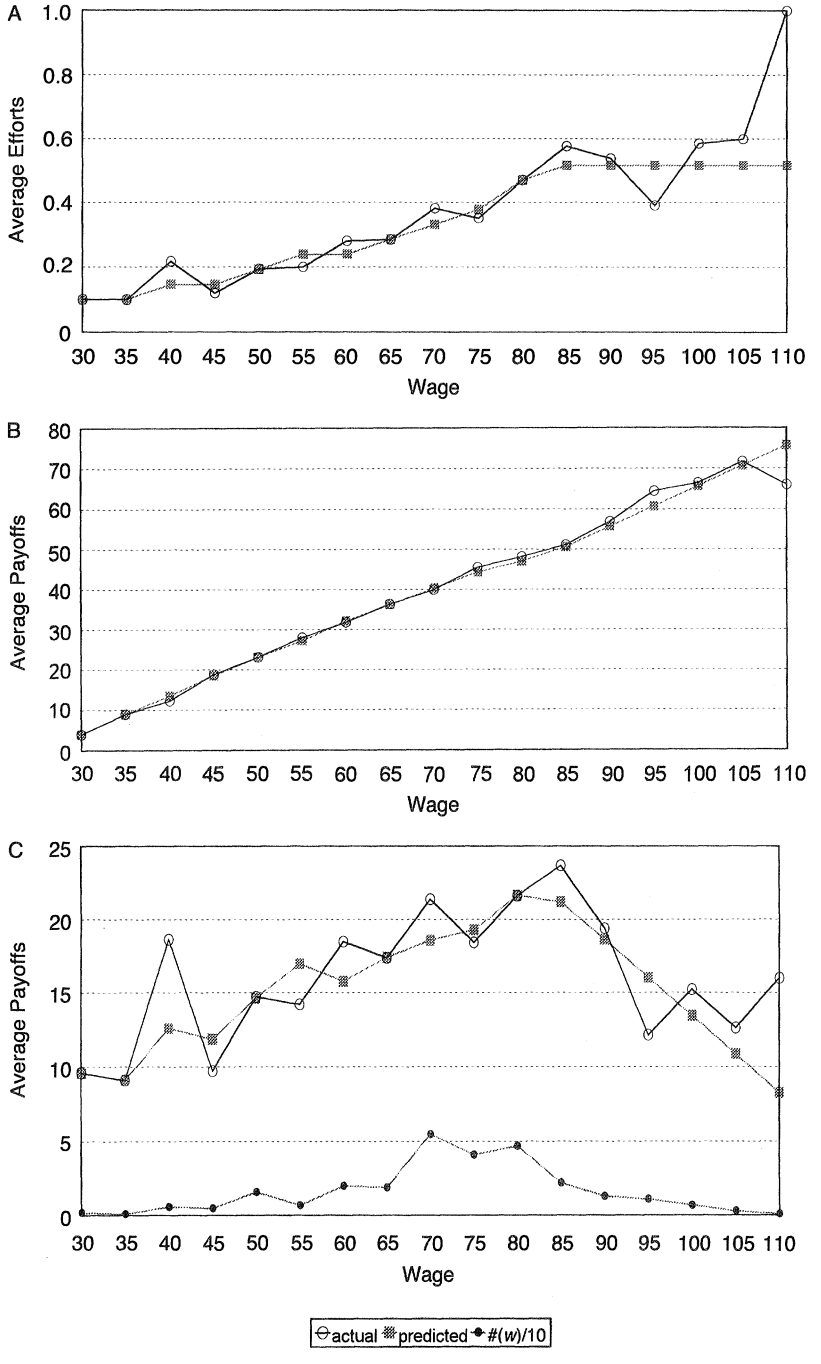

FIGURE 6. (A) ACTUAL AND PREDICTED AVERAGE EFFORT LEVELS; (B) ACTUAL AND PREDICTED AVERAGE PAYOFFS OF THE WORKERS; AND (C) ACTUAL AND PREDICTED AVERAGE PAYOFFS TO THE FIRMS, AND ACTUAL WAGE OFFERS

Since $\bar{w} = 85$, the corresponding actual effort ($e^{\max} = 1$) and actual payoffs are within the range permitted by the model. Note from Figure 6C that actual wage offers cluster around the optimal wage offer.

Finally, the "fair-wage–effort hypothesis"

that Fehr et al. (1993) studied posits a correlation between wages and efforts. As we have indicated, this is confirmed in the data. But Figure 6C shows that higher wages are not always met by higher *profits*. If we think that higher than minimal effort indicates reciprocal behavior beyond a concern for relative payoffs, we might have expected a strictly positive relation; that is, we might have expected that workers and firms share the efficiency gains that are obtained by mutual cooperation. In contrast, the correlation between payoffs is mildly but significantly negative: $\rho(u, \pi) = -0.16$ (two-tail $p = 0.0065$).[29]

C. *Checking the Robustness of the α Model*

One quick way to check the robustness of our α estimate is to compare it to dictator-game experiments. The rates of giving reported in dictator games vary due to framing effects and design differences. Nevertheless, the Forsythe et al. (1994) experiment has an average rate of giving of 0.23, one of Hoffman et al.'s (1994) dictator games (buyer–seller frame, random selection of roles) has a rate of 0.27, Andreoni and John H. Miller (1998) obtained a value of 0.25, and Ockenfels (1999) has a value of 0.23. Within the context of a dictator game, a strict egoist gives 0, and a strict relativist gives half. Hence the mentioned average rates of giving imply $\alpha \approx 0.5$, very similar to the gift-exchange estimate.

Joyce Berg et al.'s (1995) investment game is similar to the gift-exchange game. An investor may send some of his endowment to a responder. Whatever is sent immediately triples in value. The responder then decides how much, if any, of the money to return to the investor.[30] We denote the investment by x and the return by z. Both players start with a \$10 endowment. From the general ERC model, we would expect $z(x) \leq 2x$. In fact, the inequality holds for 30 out of 32 observations.

We compute the responder α in precisely in the same manner as for the gift-exchange game: egoists choose $z^E(x) \equiv 0$ and relativists choose $z^R(x) = 2x$. The resulting α value is 0.42, very close to the gift-exchange estimate.[31]

Looking for evidence of reciprocity, Berg et al. (1995 p. 127) posit that, $\bar{z}(x)/x$ and x are positively correlated. But since $\bar{z}(x)/x = 2\alpha$, the α model implies that $\bar{z}(x)/x$ is constant for all x. The data confirm the α model: the Spearman rank correlation coefficient is 0.01 (Berg et al., 1995 p. 131).

The α model can also be used to explain why counting on reciprocity paid off in one game, but not in the other. In the gift-exchange game, marginal efficiency gains are extremely high for small wages, so that self-interested firms should cooperate even if α is much lower than the 0.5 we estimated.[32] In an expected-value sense, it pays to offer a higher than minimal wage (see Figure 6C), and in fact more than 99 percent of wage offers were higher. In the investment game, any investment is multiplied by a fixed factor of 3. The factor 3 needs be matched with an α of at least 0.5 just for an investment to break even. Given our estimate of α, we are not surprised that investments in the investment

[29] One might ask to what extent second-mover behavior is triggered by a desire to reward "friendly" intentions. To reveal the underlying motivations, Charness (1996) ran a gift-exchange experiment with three treatments. The first essentially replicated the experiment of Fehr et al. (1993). In the second treatment, wages were determined by an unpaid third party. In the third, wages were randomly drawn from a bingo cage. Charness identifies some evidence that intentionality plays some role. However, strong evidence for what is usually thought to be the telltale sign of reciprocity in gift-exchange games, positive correlation between offers and second-mover actions, is found in all three treatments. Moreover, as predicted by ERC, the correlation coefficients are very similar in all three treatments. The range of the (highly significant) Spearman rank correlation coefficient between wages and effort is from 0.404 (random) to 0.491 (standard game), and between wages and *average* effort the range is from 0.905 (random) to 1 (third party); see also Bolton et al. (1998).

[30] Berg et al. (1995) studied two treatments: a no-history treatment in which the investment game was played without any information about how others play, and a history treatment in which subjects were informed about the no-history results as part of their instructions. In order to ensure comparability to the dictator and gift-exchange games, we confine ourselves to the observations in the no-history treatment.

[31] The more sophisticated estimation technique mentioned in footnote 28 is, for the investment game, equivalent to the simpler technique.

[32] If one of the players sacrifices one payoff unit in the subgame-perfect equilibrium, total payoffs are increased by about ten payoff units. This is a much higher efficiency gain than in most experimental dilemma games.

game failed by just a bit to generate a positive net return: the average net return was −$0.50.[33]

D. *Some Observations on the Finitely Repeated Prisoner's Dilemma*

Defection in all rounds is the unique standard subgame-perfect equilibrium for the finitely repeated prisoner's dilemma (PD). Subjects in experiments, however, systematically cooperate, although typically they fail to reach full efficiency. In a famous paper, David M. Kreps et al. (1982) present two models of the finitely repeated PD. The second model demonstrates that, if each player assesses a (small) positive probability that his partner is "cooperative" (i.e., he prefers to cooperate [defect] if the other cooperates [defects]), then sequential equilibria exist wherein purely money-motivated and perfectly rational players cooperate until the last few stages.

By ERC, cooperative subjects of this type actually exist.[34] The models differ on two other points. First, in ERC, the proportion of cooperative subjects is not exogenous, but depends on the stage-game payoff matrix (see Section VI, subsection A). Second, ERC predicts that cooperation rates may be positive even in the last round of a repeated PD (consider two players who are mostly interested in the relative payoff and believe with a high degree of certainty that their partner is too) and even among experienced players (experience teaches that some people *are* willing to cooperate until somebody defects on them).

Andreoni and Miller (1993) test the sequential-equilibrium prediction of Kreps et al. (1982). The experimental conditions included "partners" (each subject partners with another for a 10-period game, repeated 20 times, each time rotating partners) and "strangers" (each subject plays 200 iterations of a single-shot PD, with a new partner in every iteration). Andreoni and Miller find substantial evidence for reputation-building. However, they conclude: "Several findings in the experiment suggest that, rather than simply believing that some subjects may be altruistic, many subjects actually are altruistic" (Andreoni and Miller, 1993 p. 582).[35] Among the findings that lead the authors to this conclusion is that the mean round of first defection in the partners treatment increases across games, whereas strangers quickly develop a stable pattern of cooperation. Assuming that subjects update their beliefs about the proportion of cooperative subjects, this contradicts the rationality hypothesis but is consistent with ERC.

Likewise, Cooper et al. (1996) conclude that the reputation model fails to explain positive cooperation rates observed in their one-shot PD's, whereas altruism alone, without reputation-building, cannot explain the significantly higher cooperation rates and the path of play in their finitely repeated PDs. By ERC, it is the *interplay* of strategic triggering behavior of egoists and reciprocal responses of cooperative subjects that drives repeated and sequential dilemmas (Section VI, subsection A).

VII. Summary

ERC demonstrates that many facets of behavior, over a wide class of games, can be deduced from two of the most elementary games: ulti-

[33] John B. Van Huyck et al. (1995) study a peasant–dictator game, similar to the investment game. The authors observe that "subjects are concerned about relative earnings" (p. 159) and that "the strategic variables are highly correlated with the data" (p. 165). For instance, if the factor by which the investment is multiplied is increased, efficiency increases.

[34] See, for instance, the decision rules derived in Section VI, subsection A, with the help of the example motivation function. In the general ERC model, we have that for a subject with $r = \frac{1}{2}$,

$$u\left(\frac{c}{2}, \frac{1}{2}\right) > u\left(\frac{1+m}{4m}c, \frac{1+m}{4m}\right).$$

Since

$$\frac{1+m}{1+2m} > \frac{1+m}{4m} > \frac{1}{2},$$

$$u\left(\frac{c}{2}, \frac{1}{2}\right) > u\left(\frac{1+m}{4m}c, \frac{1+m}{1+2m}\right).$$

Hence, a subject who prefers the equal split in a dictator game also prefers to cooperate if (and only if) the PD partner cooperates.

[35] Richard D. McKelvey and Thomas R. Palfrey (1992) show that, allowing for a small number of altruists (whose behavior, while extreme, is consistent with ERC motivations; see footnote 20), data from the centipede game can be rationalized as a sequential equilibrium. Colin Camerer and Keith Weigelt (1988) find evidence that sequential equilibrium approximates aggregate data, save that the actual proportion of cooperative subjects exceeds that induced. John Neral and Jack Ochs (1992) find that changes in the payoff matrix influence the amount of cooperative behavior.

matum and dictator. These games expose the thresholds, the flash points, at which the pull of narrow self-interest is subjugated to a concern for relative standing. These flash points, together with the specific structure of equity, market, and dilemma games influence strategic play. The success of ERC equilibrium implies that people do indeed behave strategically.

The success of the rudimentary fitting of the gift-exchange game suggests that a more formal quantitative model is worth exploring. The first step would be to check whether the flash points that are the key to parameterizing the theory are reasonably stable when considerations like framing and culture are held fixed. This requires new data.

In its present form, ERC has some clear limitations. ERC is a theory of "local behavior" in the sense that it explains *stationary patterns* for relatively *simple games,* played over a *short time span* in a *constant frame.* Many important challenges for extending ERC have to do with the italicized phrases. Incorporating learning requires a dynamic theory (although the present version of ERC helps us to understand some of what people need to learn). We suspect that an analysis of more complicated games will require solution concepts that recognize bounded rationality. Longer time spans will require dealing with the influence of age and experience on people's goals.

The present definition of the social reference point is perhaps too simple. Consider a two-person ultimatum game in which all payoffs between 60–40 and 40–60 are infeasible, rendering the 50–50 split implied by the social reference point infeasible. Under these conditions we might think that the probability of an offer of 40 percent being rejected is lower than in the usual game. But it also seems plausible that removing the social reference allocation may lead people to focus on another outcome as a reference point, such as 60–40. In this form, the argument is rather arbitrary. Better data may lead us to a more systematic and sophisticated social reference point.

ERC also raises the question of what constitutes the appropriate reference group. While in the experimental games considered here the identification of one's reference group seems to be rather obvious, the same need not be true in more complex experimental or social environments.

Why do people care about relative standing? As we explained in Section I, several studies find that people are willing to sacrifice little to defend egalitarianism. The same experiments cast doubt on the notion that people care about payoff distribution in a way we would expect a purely unselfish altruist to care. People appear self-centered, albeit in a way that differs from received theory.

The answer may have to do with evolutionary biology. For a vast time, people lived in small groups. People may have a propensity to contribute because a successful group was necessary to individual success. A propensity to punish noncontributors might be the way evolution (partially) solves the free-riding problem inherent in such an arrangement. Güth (1995), Tore Ellingsen (1997), Huck and Oechssler (1999), and Levent Koçkesen et al. (2000) all study evolutionary models that produce conclusions along these lines.

Appendix

To complete the proof of Statement 11 we show that $\bar{e}'(w) > 0$ for $\underline{w} < w < \bar{w}$. From the best-response functions the following is true for $\underline{w} < w < \bar{w}$: $e^{*\prime}(w) > 0 \Rightarrow \bar{e}'(w) > 0$. From the implicit definition of $e^*(w)$, we have

$$\nu e^{*\prime}(w) - e^*(w) - w e^{*\prime}(w) = 1 - c'(e^*) e^{*\prime}(w).$$

Hence,

$$e^{*\prime}(w) = \frac{1 + e^*(w)}{\nu - w + c'(e^*)} > 0.$$

To complete the proof of Statement 12, we show that $u^{\mathrm{R}}(w) = u(w, e^{\mathrm{R}}(w))$ is increasing in w for $\underline{w} < w < \bar{w}$. We have

$$\frac{\partial u^{\mathrm{R}}(w)}{\partial w} > 0 \Leftrightarrow c'(e^*) e^{*\prime}(w) < 1 \Leftrightarrow c'(e^*) \frac{1 + e^*(w)}{\nu - w + c'(e^*)} < 1.$$

In Fehr et al.'s (1993) design, $c'(e) \leq 30$ for all e, $e^*(w) \leq 1$ for all w, $\nu = 126$, and $\bar{w} = 85$. Hence,

$$c'(e^*)\frac{1 + e^*(w)}{\nu - w + c'(e^*)} < 0.85 < 1.$$

To complete the proof of Statement 13, we show that $\bar{\pi}''(w) < 0$ for $\underline{w} < w < \bar{w}$. We have

$$\bar{\pi}'(w) = -(1 - \alpha)e^{\min} + \alpha e^{*\prime}(w)(\nu - w) - \alpha e^*(w) \text{ and}$$

$$\bar{\pi}''(w) = \alpha e^{*\prime\prime}(w)(\nu - w) - 2\alpha e^{*\prime}(w).$$

From the implicit definition of $e^*(w)$ we have

$$\nu e^{*\prime\prime}(w) - 2e^{*\prime}(w) - we^{*\prime\prime}(w) = -c''(e^*)[e^{*\prime}(w)]^2 - c'(e^*)e^{*\prime\prime}(w).$$

Hence,

$$e^{*\prime\prime}(w) = -\frac{e^{*\prime}(w)[c''(e^*)e^{*\prime}(w) - 2]}{\nu - w + c'(e^*)}.$$

This yields

$$\bar{\pi}''(w) = -\alpha(\nu - w)\frac{e^{*\prime}(w)[c''(e^*)e^{*\prime}(w) - 2]}{\nu - w + c'(e^*)} - 2\alpha e^{*\prime}(w) < 0 \Leftrightarrow$$

$$-c''(e^*)e^{*\prime}(w)(\nu - w) < 2c'(e^*)$$

which is true by the convexity of $c(e)$ and the proof of the effort hypothesis.

We can calculate $\underline{\alpha}$ with the help of the implicit equation $\bar{\pi}'(\underline{w}; \underline{\alpha}) = 0$ where the derivative is evaluated from the right-hand side. We have

$$\bar{\pi}'(\underline{w}; \underline{\alpha}) = -(1 - \underline{\alpha})e^{\min} + \underline{\alpha}e^{*\prime}(\underline{w})(\nu - \underline{w}) - \underline{\alpha}e^*(\underline{w}) = 0.$$

Since $e^*(\underline{w}) = e^{\min}$,

$$\underline{\alpha} = \frac{e^{\min}}{(\nu - \underline{w})e^{*\prime}(\underline{w})} = \frac{\nu - \underline{w} + c'(e^{\min})}{(\nu - \underline{w})(1 + e^{\min})}e^{\min}.$$

Using the numbers from the Fehr et al. (1993) experiment, the formula yields $\underline{\alpha} = 10.1$ percent.

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