BARGAINING AND PRICE FORMATION UNDER INCOMPLETE INFORMATION: THEORIES AND EXPERIMENTS[†]

Explicit Communication and Bargaining Outcomes

By VINCENT P. CRAWFORD*

Bargaining is a pervasive phenomenon in modern economies, and the leading examples of labor negotiations, trade agreements, and strategic arms limitation talks suggest that the potential welfare gains from improving the efficiency of bargaining outcomes are enormous. In recent years, there has been significant progress toward the kind of theoretical and empirical understanding of bargaining needed to realize some of those gains. However, in most of this work, it is assumed that bargaining is *tacit* in the sense that bargainers can communicate only by making offers and counteroffers that directly affect their payoffs. Real bargaining, by contrast, is usually *explicit*, in that bargainers can also communicate by sending nonbinding messages with no direct payoff implications. Such "cheap talk" messages evidently play an important role in coordinating bargainers' expectations so that they can reach agreement, and in determining how they share the resulting surplus.

This paper discusses theoretical and experimental work on explicit bargaining. Section I reviews the theory of tacit bargaining; Section II discusses the theory of explicit bargaining; and Section III reviews the experimental evidence on communication and bargaining outcomes, and discusses the gaps between theory and evidence that remain.

[†]*Discussants:* Robert Anderson, University of California-Berkeley; Preston McAfee, University of Western Ontario and California Institute of Technology; William Samuelson, Boston University.

*Department of Economics, University of California-San Diego, La Jolla, CA 92093. I am grateful to the NSF for research support.

I. Tacit Bargaining

The modern theory of bargaining originated in John Nash's (1953) analysis of the bargaining problem faced by two fully informed players who have an opportunity to meet before playing a game and make a binding agreement about how to play it. Nash's innovation was to construct a complete model of the players' interaction, including a model of the bargaining process, and then to use his notion of equilibrium to characterize their rational responses to its possibilities. He followed the pattern of his 1950 axiomatic bargaining analysis in summarizing the bargaining environment by the set of utility combinations associated with feasible agreements about strategy choices in the underlying game, here called the *utility-possibility set*, and players' utilities when they do not reach agreement, here called their *disagreement utilities*. In that analysis, he sought to express the utilities that bargainers could rationally "anticipate" as a function of the utility-possibility set and their disagreement utilities, and showed that one such function (now called the Nash bargaining solution) is uniquely characterized by four plausible axioms. These axioms extend the widely accepted principle of equally sharing the gains from agreement to bargaining problems with nonlinear utility-possibility frontiers and arbitrary disagreement outcomes, with the gains measured relative to disagreement.

In Nash's (1953) bargaining model, bargainers make simultaneous *demands*, expressed in utility terms. If their demands are *compatible* in the sense that they lie in the utility-possibility set, then bargaining ends with a binding agreement about how they will play the underlying game that yields

them the utilities they demanded. Otherwise, bargaining ends with no agreement and bargainers get their disagreement utilities, here assumed exogenous. Nash observed that any pair of demands associated with an efficient agreement that is at least as good as disagreement for each bargainer is an equilibrium in this game: If either bargainer made a lower demand, his payoff would be reduced with no compensating benefit; and if he made a higher demand, disagreement would result. Thus, although there are normally many such agreements, all are consistent with equilibrium (and its standard refinements) and, even when there is no uncertainty about the environment, the bargaining game is likely to generate a great deal of uncertainty about how players will respond to its multiplicity of equilibria. Unless bargainers find a way to resolve this *strategic uncertainty*, they may not realize any of the gains from reaching an agreement: At the heart of the bargaining problem lies a coordination problem.

Nash (1953) suggested two complementary resolutions of this coordination problem. In one, he noted that the normative force of his 1950 bargaining solution might focus bargainers' expectations on the associated demand-game equilibrium. In the other, he outlined a "smoothing" argument, showing that his solution is the "only necessary limit" of the equilibria in smoothed demand games as the amount of smoothing approaches zero.

A third resolution is due primarily to Ariel Rubinstein (1982). He replaced Nash's simultaneous-offers model with a sequential-offers model, in which fully informed bargainers take turns making offers to each other (with one exogenously assigned to the right to make the first offer). A bargainer can accept his partner's latest offer at any stage, in which case it becomes a binding agreement, taking effect immediately. But, a bargainer who rejects an offer must wait until the next stage before making a counteroffer. This process continues indefinitely until an offer is accepted; but delay is costly, in that bargainers prefer to reach agreement sooner rather than later.

Rubinstein showed that this model has a unique subgame-perfect equilibrium even when the time horizon is infinite: When bargainers are fully informed, his assumptions about the rules of bargaining completely eliminate the coordination problem. In this equilibrium, the bargainer who makes the first offer chooses it so as to extract all of his partner's surplus from accepting it, taking into account that the alternative is to make a counteroffer, chosen in the same way, but one stage later. In equilibrium, this first offer is always accepted, so the outcome is always efficient; and how bargainers share the resulting surplus in it is completely determined by the relationship between their delay costs. Although the right to make the first offer is an advantage, in the leading case in which bargainers discount the future at the same constant rate, this advantage disappears as their discount factors approach one (or as the time between offers approaches zero) and the unique subgame-perfect equilibrium outcome then approaches Nash's bargaining solution.

The choice between simultaneous-offers and sequential-offers specifications has important implications for the role of explicit communication. Although models like the demand game strike many people as too simple to reflect the dynamics of real bargaining, there is more to this choice than whether bargaining is static or dynamic. Suppose, following Thomas Schelling (1960, Appendix B) and John Harsanyi and Reinhard Selten (1988, pp. 23–26), that there is a fixed, known deadline, and that the only rules of bargaining are the stipulations that, if an agreement is reached by the deadline, it will be enforced, and, if not, the process ends in disagreement. (This rules out artificial constraints on the timing of offers like those in Rubinstein's model, but allows symmetric, physical constraints on the time it takes to make or transmit offers.) Then, if the costs of delay are negligible, for reasonable specifications of bargainers' strategic possibilities, there is an equilibrium that correspond to each of the efficient equilibria in Nash's demand game.

More generally, even with no fixed deadline, bargainers' strategies are dynamic decision rules that can be viewed as chosen simultaneously, and in any equilibrium in

which bargainers are certain to reach agreement, each bargainer's strategy must be such that the lowest utility his partner can make him accept is just compatible with the lowest utility he can make his partner accept. These lowest utilities function just as the demands in Nash's model, and the resulting agreements correspond precisely to its efficient equilibria. Thus, bargaining can pose a significant coordination problem even when bargainers are fully informed and approach agreement by a sequence of alternating offers. The give-and-take of real bargaining is surely, at least in part, a robust response to this coordination problem.

The choice between specifications therefore turns on the plausibility of the rules in sequential-offers models, and on whether the costs of delay are more important than the risk of coordination failure. In most contemplated applications, bargainers are free to choose the timing of their offers and counteroffers, within wide limits, and the costs of delay are small compared to the risk of coordination failure. It seems clear that this risk is not adequately modeled by the common practice of viewing delay costs as reflecting the chance that bargaining will be exogenously terminated before an agreement is reached.

There is also substantial experimental evidence that coordination is the essence of the bargaining problem, and that focal points based on the structure of the game, the context in which it is played, or the history of play in analogous games, as discussed by Schelling, strongly influence bargaining outcomes. Alvin Roth (1985) and his collaborators found, in environments designed to conform to the assumptions of models like those of Schelling and Harsanyi-Selten just discussed, that subjects' agreements were heavily influenced by which of two equal-sharing principles, equal probabilities of winning a subject-specific money prize, or equal expected money winnings, the information they had in common allowed them to use. (The structures of these environments, expressed in terms of the probabilities subjects bargained over, were always public knowledge; but, in some treatments, subjects were given private information about their money prizes and prevented from communicating it to their partners.)

There were few disagreements when subjects had enough information in common to use only the first principle, but there were significant numbers when they had enough to use either principle. In each case, the frequency of disagreements corresponded closely to a prediction based on the symmetric equilibrium of a coordination game in which bargainers choose independently between the principle or principles they can use; this suggests that the observed disagreements were due to the difficulty of coordination, not to irrationality. These results are especially informative because they were obtained in experimental environments with (except for a general prohibition against self-identification and the prohibition against messages about money prizes when these were not public knowledge) no artificial restrictions on subjects' bargaining strategies. In subsequent experiments, with subjects allowed to communicate only by two stages of simultaneous demands in environments otherwise like those just discussed, it was also found that manipulating subjects' prior expectations about each other's demands exerted a systematic, persistent influence on the agreements they reached.

Even in the experiments reviewed by Jack Ochs and Roth (1989), conducted in environments designed to conform to the assumptions of finite-horizon sequential-offers models, the unique subgame-perfect equilibria in these models predicted poorly. Subjects' behavior appeared to have been heavily influenced by equal-sharing principles, and this made it dangerous to try to extract all of the surplus, as those equilibria prescribe.

Although most of the experiments discussed in Section III used subjects fully informed about the structures of the games they were playing, most of the theoretical models of tacit bargaining that underlie the analyses of explicit bargaining discussed in Section II have incomplete information, typically about bargainers' reservation prices. Some of these have simultaneous-offers structures like the demand game; others have sequential-offers structures. Their

central theme is the use of the commitments allowed by the rules of bargaining, together with the risk of disagreement or the cost of delay, to sort bargainers by their reservation prices. Special cases aside, even the models with sequential offers have large sets of equilibria that satisfy standard equilibrium refinements. The usual practice is to study how bargainers learn about each other's private information *within* one of these equilibria. However, strategic uncertainty is unlikely to be less important here than with complete information, and it is unclear to what extent its effects can be captured in an equilibrium selected by applying refinements that are largely insensitive to it. In fact, John Kennan and Robert Wilson (1990) recently surveyed the literature on sequential-offers bargaining under incomplete information with applications in mind, finding significant, systematic differences between its predictions and U.S. and Canadian strike data.

II. Explicit Bargaining

This work builds on models of tacit bargaining like those discussed above, allowing bargainers one or more opportunities to communicate by sending nonbinding messages either before or during the exchange of binding offers and counteroffers. Because a nonbinding message has no direct payoff implications, it can affect outcomes only through the inferences the message receiver draws from the message sender's implied choice among his responses. This allows two roles for such messages in bargaining: signaling bargainers' private information and helping them to coordinate their expectations about how the underlying bargaining game will be played.

The signaling role was first explored, in more abstract settings, by myself and Joel Sobel (1982), and by Jerry Green and Nancy Stokey (1980). These papers showed that there are always uninformative equilibria, in which agents send nonbinding messages unrelated to their private information and these messages are ignored when received, but that there can also exist informative equilibria. A message sent in such an equilibrium means, in effect, "Given my private information, I like what you do when I say this better than anything I could get you to do by saying something else." Normally, equilibria in which the message sender's choice among responses conveys perfect information to the message receiver cannot exist unless their preferences are the same, and only uninformative equilibria can exist when their preferences are too far apart.

Schelling noted that the arguments for Nash's (1953) view that bargaining is primarily a coordination problem remain valid even when cheap talk is allowed, and his analysis of explicit bargaining emphasized its coordination role. He observed that fully informed bargainers have nothing to communicate except what shares of the surplus they expect to receive, and that whatever a bargainer expects, it is to his advantage to convince his partner that he expects more rather than less. It follows that, unlike in pure coordination games, cheap talk cannot coordinate bargainers' expectations *by itself*. Schelling observed that it might still influence bargaining outcomes, either by making it possible for bargainers to use new focal principles to coordinate their expectations, or by allowing them to coordinate their decisions more effectively, thereby expanding their opportunity set.

The coordination role was explored more formally by Joseph Farrell (1987), who studied the Battle of the Sexes game with complete information (which can be viewed as a discrete version of Nash's demand game) preceded by one or more rounds of nonbinding, simultaneous announcements about players' intended strategy choices. He identified a plausible equilibrium in which announcements that would be in equilibrium in the underlying game are accepted as the literal truth, and any other announcements are ignored. (The assumption that announcements are taken literally as long as they are consistent with players' incentives is a powerful equilibrium refinement in cheap-talk models; see, for example, Farrell and Robert Gibbons, 1988, and Roger Myerson, 1989.) In this equilibrium, players' randomized announcements give them a chance of achieving asymmetric coordination in the underlying game, even though they have no way to

distinguish between their roles *ex ante*, and are therefore effectively restricted to symmetric strategies in the game taken as a whole. They do better, *ex ante*, than without communication, and still better with additional rounds of communication; but the usefulness of cheap talk is again ultimately limited by the difference between their preferences, and even an unlimited number of rounds does not make coordination certain.

The signaling role of cheap talk has now been studied in bargaining games, by Steven Matthews (1989) in a two-stage sequential-offers model with one-sided private information (see also Farrell and Gibbons, 1988), and by Farrell and Gibbons (1989) and Matthews and Andrew Postlewaite (1989) in a one-stage simultaneous-offers model with two-sided private information, which can be viewed as an incomplete-information generalization of Nash's demand game. The models with two-sided private information allow one or more rounds of simultaneous messages before the underlying game is played; these messages also play a coordination role, in effect allowing bargainers to play different equilibria in the underlying game depending on their reservation prices. Matthews and Postlewaite show that this enormously expands the (already huge) set of equilibria in their model, allowing any outcome that is *ex post* individually rational and incentive compatible.

Finally, Thomas Palfrey and Howard Rosenthal (1990) studied the coordination and signaling roles of cheap talk in n-person games with incomplete information that otherwise closely resemble Nash's demand game, focusing on equilibria like the one studied by Farrell (1987) and obtaining results that generalize his in interesting, sensible ways.

III. Experimental Evidence

As suggested by the discussion above, experiments in which explicit communication was allowed throughout, not just "preplay," are included. Also included are experiments that used coordination games with the perfectly opposed preferences about how to coordinate characteristics of bargaining problems, even some not motivated as bargaining experiments and some conducted with more than two subjects. I have, however, excluded experiments with face-to-face communication. Although some of these have revealed interesting effects, including a suggestion that such communication has some power to bind players and is therefore not truly cheap talk, their results are difficult to interpret because subjects' preferences were evidently partly nonmonetary, hence not fully under experimental control.

The experimental results reported in Roth and J. Keith Murnighan (1982) (also summarized in Roth, 1985) strikingly illustrate the subtle interaction between bargainers' need to find a way to coordinate their expectations, and their strategic use of the information required by focal principles. The experimental environments were like the ones described in Section I that did not artificially restrict subjects' bargaining strategies, but with three significant differences: Some subjects now had an informational advantage over their partners, in that they knew their partners' money prizes as well as their own; the existence of this advantage was sometimes made public knowledge and sometimes not; and subjects were no longer prevented from communicating their private information about prizes to their partners. The results were determined mainly by whether the subject whose money prize was lower knew his partner's prize. When he did not, subjects' agreements closely approximated equal probabilities; but when he did, there was a significant shift toward the probabilities that implied equal expected money payoffs. (The only significant difference between the results for the public knowledge treatments and their non-public knowledge counterparts was a higher frequency of disagreements in the latter treatments when the subject whose money prize was lower also knew his partner's prize.)

These results suggest that most subjects expected to share the gains from their agreements equally according to the most "relevant" principle they could use, given the information they had in common plus whatever additional information they had an incentive to reveal, on the understanding that it would be used to determine the outcome

in this way. The transcripts suggest that when only the subject with the higher money prize knew both prizes, and this was public knowledge, the other subject often suspected that he would be treated unfairly. In this case, he knew that his partner could tell whether this was the case, but his partner typically refused to reveal his prize, and the subject then had little choice but to go along with the equal-probabilities agreement that he recognized as his best chance to coordinate, given the information he and his partner had in common.

Russell Cooper et al. (1990) studied the effect of explicit communication in the Battle of the Sexes game, sometimes with one subject allowed to make a single nonbinding announcement about his intended strategy choice before each play of the game, and sometimes with one or three rounds in which subjects were allowed to make simultaneous announcements. When only one subject could make an announcement, he almost always announced the strategy associated with his most preferred equilibrium, and subjects then almost always played the associated strategies. The results when both subjects were allowed to make announcements corresponded fairly closely to the equilibrium in the closely related game studied by Farrell (1987), with subjects doing significantly better than they did with no communication at all and slightly better with three rounds of announcements than with one, but stopping well short of achieving perfect coordination.

Palfrey and Rosenthal also found some support for this view of the coordination process in three-person public goods experiments with one round of simultaneous, nonbinding announcements, based on their incomplete-information generalization of Farrell's 1987 model. They found that subjects had considerable success in efficiently eliciting the contributions required for provision of the public good from the subjects whose privately known costs were lowest. Jeffrey Banks et al. (1988) obtained roughly similar results in experimental environments with similar structures. In each case, significant learning effects were observed in repeated play in tacit versions of the experiments, but not in their explicit counterparts, suggesting that it may be possible to design experiments to measure the effectiveness of cheap talk in reducing strategic uncertainty.

Much of the behavior observed in these experiments appears to have been driven by strategic uncertainty. By contrast, most of the theoretical analyses of explicit bargaining reviewed in Section II either focus on the signaling role of cheap talk, or study the coordination role within an equilibrium selected by refinements that are largely insensitive to strategic uncertainty. The growing experimental literature in this area offers the possibility of developing a theoretical and practical understanding of how strategic uncertainty and cheap talk interact (with or without private information) to determine bargaining outcomes. The theoretical analyses of experimental data in Roth-Murnighan and Roth (1985) show that it may be possible in many cases to model the effects of strategic uncertainty without giving up equilibrium analysis entirely; but, at the very least, this requires explicit attention to bargainers' need to coordinate their expectations, and probably also to the dynamics of the process by which they do so.

REFERENCES

Banks, Jeffrey, Plott, Charles and Porter, David, "An Experimental Analysis of Unanimity in Public Goods Provision Mechanisms," *Review of Economic Studies*, April 1988, *55*, 301–22.

Cooper, Russell et al., "Communication in the Battle of the Sexes Game," *Rand Journal of Economics*, forthcoming 1990, *21*.

Crawford, Vincent P. and Sobel, Joel, "Strategic Information Transmission," *Econometrica*, November 1982, *50*, 1431–51.

Farrell, Joseph, "Cheap Talk, Coordination, and Entry," *Rand Journal of Economics*, Spring 1987, *18*, 34–39.

_____ **and Gibbons, Robert,** "Cheap Talk, Neologisms, and Bargaining," Working Paper No. 500, MIT, July 1988.

_____ **and** _____, "Cheap Talk Can Matter in Bargaining," *Journal of Economic Theory*, June 1989, *48*, 221–37.

Green, Jerry and Stokey, Nancy, "A Two-Person Game of Information Transmission," Harvard Institute of Economic Research Discussion Paper No. 751, March 1980.

Harsanyi, John and Selten, Reinhard, *A General Theory of Equilibrium Selection in Games*, Cambridge: MIT Press, 1988.

Kennan, John and Wilson, Robert, "Strategic Bargaining Models and Interpretation of Strike Data," *Journal of Applied Econometrics*, forthcoming 1990, *5*.

Matthews, Steven, "Veto Threats: Rhetoric in a Bargaining Game," *Quarterly Journal of Economics*, May 1989, *104*, 347–69.

_____ **and Postlewaite, Andrew,** "Pre-Play Communication in Two-Person Sealed-Bid Double Auctions," *Journal of Economic Theory*, June 1989, *48*, 238–63.

Myerson, Roger, "Credible Negotiation Statements and Coherent Plans," *Journal of Economic Theory*, June 1989, *48*, 264–303.

Nash, John, "The Bargaining Problem," *Econometrica*, April 1950, *18*, 155–62.

_____, "Two-Person Cooperative Games," *Econometrica*, January 1953, *21*, 128–40.

Ochs, Jack and Roth, Alvin, "An Experimental Study of Sequential Bargaining," *American Economic Review*, June 1989, *79*, 355–84.

Palfrey, Thomas and Rosenthal, Howard, "Testing for Effects of Cheap Talk in a Public Goods Game with Private Information," *Games and Economic Behavior*, forthcoming, 1990, *2*.

Roth, Alvin, "Toward a Focal-Point Theory of Bargaining," in his *Game-Theoretic Models of Bargaining*, New York: Cambridge University Press, 1985.

_____ **and Murnighan, J. Keith,** "The Role of Information in Bargaining: An Experimental Study," *Econometrica*, September 1982, *50*, 1123–42.

Rubinstein, Ariel, "Perfect Equilibrium in a Bargaining Model," *Econometrica*, January 1982, *50*, 207–11.

Schelling, Thomas, *The Strategy of Conflict*, Cambridge: Harvard University Press, 1960; 2nd ed., 1980.