

Why the Centipede Game Experiment Is Important for Political Science

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Putting the Centipede Game Experiments in Context

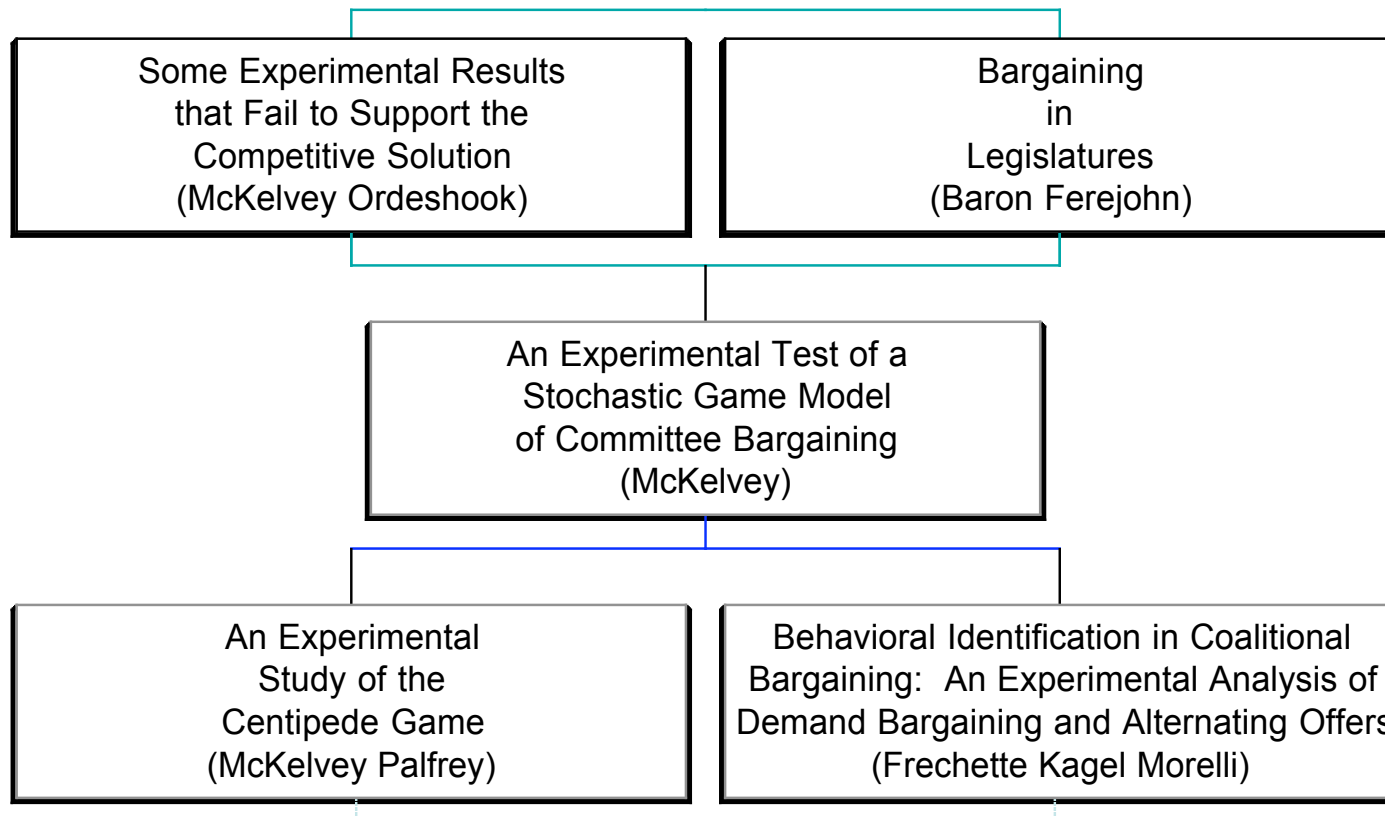
The centipede game is odd. It is hard to imagine a real world situation, particularly one in the world of politics, where two individuals would play such a stylized game. Furthermore, what are we to make of the results from the laboratory experiments—where undergraduates at Caltech were given monetary payoffs represented by such a game? What do these actions by highly intelligent subjects in an artificial environment in an unreal game have to tell us about politics? For example, suppose the research goal was to gain a better understanding of how legislatures operate. Wouldn't it be better to work with a much more realistic theory and to do empirical research using data from naturally occurring legislatures? Or, if we wanted to do experiments, maybe we could try to do something in the field—somehow manipulating the choices before legislators and seeing how that manipulation affects their actions. While doing field experiments in this case is probably undoable, that fact hardly seems enough to justify

doing a laboratory experiment on a game that seems so unrelated to real world legislatures with subjects who can hardly be viewed as representative of their members.

Using this sort of reasoning many political scientists dismiss the centipede game experiments of McKelvey and Palfrey. My goal in this short essay is to challenge that reasoning. I will do so by putting the experiments in the context of a general research program—by looking at the research that preceded those experiments and the research that has followed. The goal of the research program was indeed the study of how legislatures operate. In particular, the researchers desired to build a positive theory of coalition formation that would explain how voting led to outcomes in legislatures and other political bodies which used majority rule. Such a theory would be both logically consistent, have realistic assumptions, and make empirical predictions that were supported. I take it as a given that such a program is deeply important for political science.

Figure 1 summarizes how I put the centipede game experiments into the context of that research program. The figure presents a small slice of the program and highlights just five papers—McKelvey and Ordeshook (1983), Baron and Ferejohn (1989a), McKelvey (1991), McKelvey and Palfrey (1992), and Frechette, Kagel, and Morelli (2005). However, I contend by examining how the centipede game experiments fits into this slice shows how fundamental these experiments are to the research program and the importance of McKelvey's experimental contributions to that program and the value of laboratory experiments like his in general to political science.

Figure 1
Putting the Centipede Game Experiments in Context



Understanding Legislative Behavior Through Cooperative Game Theory

Deciding when this program began is arbitrary, but the seminal theoretical work that started much of the research I discuss was William Riker's *The Theory of Political Coalitions*, published in 1962. The approach taken by Riker was to model coalition formation as a cooperative game and use solution concepts to derive predictions about the payoffs in the coalitions. But in the late 1970s the solution proposed by Riker as well as other similar ones could not "be usefully applied to the empirical analysis of, e.g. legislative coalition formation" as Riker's students, McKelvey, Ordeshook, and Winer, hereafter MOW, (1978, p. 599) pointed out, because they assumed transferable utility—that side payments could be made. Moreover, the existing theories only predicted payoffs, not which coalitions would form, and the solution concepts did not have behavioral foundations—they were as MOW wrote (p. 600) "principally mathematical abstractions without behavioral rationale." As a consequence, MOW advocated a new idea, the competitive solution, which they put forward as a way of understanding coalition formation in legislatures without assuming the unreal idea of transferable utility. Furthermore, the competitive solution provided predictions about coalitions and payoffs and it had a behavioral foundation of coalition formation as a bargaining process (the competitive solution is discussed in more detail in the contribution to this volume by Peter Ordeshook).

Using Experiments to Test Theory

Although MOW's motives were to propose a more realistic, behavioral theory of legislative coalition formation that would be more useful for empirical analysis of real legislatures, they turned to laboratory experiments to test that theory. Why? Why not

go directly to legislatures? The advantage of going to the lab was that the researchers could use financial incentives to induce preferences for the subjects and thus more accurately test whether their proposed solution did predict accurately. If they had gone to a real legislature they would have had to estimate those preferences. This was before the important work of Poole and Rosenthal and others, which now provides us with a way of computing such estimates. However, even if MOW had had such data available, those estimates would still have had error. Moreover, the researchers would not have been able to vary those preferences to see if under different preference profiles, number of actors, and number of alternatives the solution concept worked—they would not have the control they had and used in the laboratory. Thus, the lab provided MOW with a strong test of their theory.

The experiments on the competitive solution were experiments that Alvin Roth (1995) labels as “speaking to theorists.” And they did. Although at first the results showed support for the competitive solution, the experiments also showed problems with the solution as discussed in McKelvey and Ordeshook (1983) and McKelvey (1991). Importantly, the experiments showed that the solution concept, because it was ordinal in nature, often did not explain the behavior of subjects. Specifically, the solution concept could not explain the fact that subjects chose alternatives with different probabilities and that subjects were influenced by differences in cardinal utilities in preference profiles that were ordinally equivalent. There were important disconnects between what the theory predicted and the behavior in the lab.

It is important to remember that the goal of the experimentalists was not to design a world that was like real world legislatures. The goal was to design a world that looked

like the theory and then see if indeed real individuals, placed in that world, behaved as predicted. But that makes the experiments seem like a trivial demonstration. The experiments were much more than that. In the experiments, the researchers were able to vary things—preference profiles, the number of alternatives, the number of actors—that they would not have been able to do using naturally occurring data from legislatures or field experiments. If there is some variation in these factors in naturally occurring legislatures it is possible to use statistical inference to posit how changes in these factors affect behavior. But generally there is little variation in these factors—Congress has not changed the number of members in over 50 years—or the variation is not random, forcing us to rely heavily on inference over observation. Field experiments that vary legislative preferences, number of alternatives, and number of legislators seem highly improbable.

As Gerber's essay in this volume points out (see especially p. x and footnote 18) many are skeptical of the results from laboratory experiments because they are seen as poor substitutes for empirical knowledge gained from examining naturally occurring legislatures. If that were the purpose, then these skeptics are justified in dismissing the laboratory experiments. But those who dismiss experiments for this reason show a fundamental lack of understanding of what can be learned from experiments that it is not possible to learn directly from the field. Laboratory experiments provide something unique—a chance to see if the theory works under variations and control that simply is not possible or highly difficult to observe in the field. There is no perfect substitute for the laboratory data, just as there is no perfect substitute for the data derived from naturally occurring legislatures or from field experiments when they are possible. Hence,

it is silly to debate whether data from the lab is superior or inferior to data from the field, either naturally occurring or manipulated. Such analyses should be seen as complements, each telling us something different and unique since each provides us with a different piece of information not available otherwise, which together can provide us with a fuller understanding of the usefulness of the theory.

The experiments on the competitive solution and other similar cooperative game theoretic solutions showed that when preference profiles were varied, behavior changed in a systematic fashion according to cardinal payoffs that was unpredicted by the theory. In this sense, as Roth (1995) discusses, the experiments brought to light new facts that were unknown before they were conducted. The experimentalists found that varying something that was not theoretically meaningful was empirically meaningful and thus discovered something new about behavior—something that showed that the theory was inadequate.

Noncooperative Legislative Bargaining Theory, Experiments, and Subgame Perfection

It is my belief that without those lab experiments, the limitations of cooperative game theory as an approach to studying legislatures would have not been manifested for some time. As a consequence of the experiments, researchers like McKelvey (1991) began to turn to noncooperative game theoretic models of coalition formations to understand legislatures. Noncooperative game theory could provide some explanations for the relationships between cardinal payoffs and voting choices made by the subjects and provide explicit microfoundations for observed behavior that could be empirically tested. McKelvey (1991) used a model like Baron and Ferejohn (1989a), hereafter BF.

In the BF model legislative bargaining is modeled as an infinitely repeated game where one individual makes an offer, the remaining individuals vote whether or not to accept the offer, and the game ends when an offer is accepted. Individuals are assumed to prefer bargains made earlier rather than later, the proposer is selected randomly each period, and a majority vote is needed for a proposal to be passed.

The predictions of the finite version of BF model rely heavily on the solution concept of subgame perfection. That is, suppose that there are three political parties, A, B, and C, choosing how to allocate a fixed number of ministerial portfolios. Assume that party A has 40 percent of the votes in the legislature, B has 35 percent, and C has 25 percent. Party A is chosen to make a proposal on how to divide the portfolios. Suppose that it is the last period of bargaining and if a proposal is not accepted the portfolios will be divided by vote shares. Thus party B should vote for a proposal that offers them more than 35 percent of the portfolios and party C should vote for a proposal that offers them more than 25 percent. Because A only needs a majority and C is cheaper, then A should propose that C gets slightly more than 25 percent of the portfolios, while A gets the remaining amount and B receives nothing. If we fold back the game to earlier proposal periods we find that whichever party is selected as the initial proposer should calculate for each party a reversion level using subgame perfection and propose an allocation that gives the party with the lowest reversion level just enough portfolios so that the party benefits over the reversion while keeping the majority of the portfolios to itself.

As Diermeier and Morton (2005) note the BF model is one of the most widely used formal frameworks in the study of legislative politics. Variants of the model have been used in the study of legislative voting rules (Baron and Ferejohn 1989a), committee

power (1989b), pork-barrel programs (Baron 1991a), government formation (Baron 1989, 1991b, Baron and Ferejohn 1989a), multi-party elections (Banks and Austen-Smith 1988, Baron 1991b), and inter-chamber bargaining (Diermeier and Myerson 1994, Ting and Snyder 200x).

Because the BF model does make precise predictions about voting choices and coalition formation that can be related to actual payoffs, has been subject to evaluation using both experimental and naturally occurring data (I am unaware of field experiments). McKelvey (1991) was the first to conduct laboratory experiments on BF (I discuss the evaluations of BF using field data below). McKelvey found that proposers offered too much. He speculated that the proposers were reluctant to give as small shares to coalition partners as predicted out of fear of retaliation should their proposal not be accepted. He suspected that the results showed a problem with assuming that individuals would follow subgame perfection.

How Centipede Game Experiments Inform Legislative Bargaining

The predictions of the centipede game, described in the accompanying chapters by McKelvey and Palfrey and Gerber in this volume, like the BF model, heavily depend on subgame perfection. Like the BF model, at each stage the game potentially ends. Like the BF model the players are predicted to look down the tree and using backwards induction make a choice in the first play of the game that effectively ends the game. Yet, unlike the BF model, the centipede game is not seen as representative of legislative bargaining. For one thing, it is a much simpler two-person game. Players do not have to choose proposals but the options before them are exogenous. Furthermore, calculating what a player expects to receive if later branches of the tree are reached is straightforward

rather than dependent on the probability that a player is selected to make a proposal and so on. Finally, the benefits to a player for violating subgame perfection are sizeable and increase the more willing the player is to do so.

Yet, the centipede game, because it is simpler and more straightforward, provides a more conclusive test of the assumption that players choose subgame perfect strategies than a test of the BF model. That is, the only reason why behavior may not be as predicted is if subjects do violate subgame perfection. The centipede game also allows for a careful investigation of what subjects anticipate about other subjects' behavior. In the centipede game, the first mover might pass if he or she is fairly confident that the second mover will pass and thus the first mover will be able to get a higher payoff for sure. But the first mover is assuming that the second mover may violate subgame perfection. In McKelvey's experiments on the BF model, he suspected that the tendency to give larger shares to coalition partners was because individuals were afraid that other subjects would violate subgame perfection and reject payoffs that they should accept. But the BF model had too many moving parts to be able to conclude that the subjects' choices were made for those reasons. In particular McKelvey could not observe rejections of equilibrium payoffs if payoffs were above equilibrium in anticipation of rejection. The centipede game, in contrast, allowed for the measurement of both non-equilibrium behavior and how anticipation of such behavior affected the choices of other players. By conducting experiments on the centipede game it was possible to learn something about behavior in other games, such as the BF model, which are more realistic, that an experiment on the BF model itself could not reveal. As discussed in Gerber, the centipede game experiments did show violations of subgame perfection and

the anticipation of violations, thus suggesting that McKelvey's suspicion that the failure of the BF model to predict well in the laboratory experiments was related to a tendency to violate subgame perfection.

Behavioral Game Theory, Experiments, and Legislative Bargaining

As discussed in the chapters by Gerber and Palfrey, the results from the centipede game experiments led McKelvey and Palfrey to derive a new equilibrium concept, quantal response equilibrium that would allow for subjects to violate subgame perfection. This concept was one of the first in a new approach to game theory, behavioral game theory, an approach that incorporates the fact that individuals may not always choose rationally in games. This concept has been applied to more specific questions in political science using naturally occurring data such as in the work of Signorino (1998) analyzing strategic interaction in international conflict. Hence, even if the centipede game experiments did not tell us something useful about legislative bargaining, they indirectly have informed our understanding of international conflict.

Although the centipede game experiments took the basics of the BF model and focused on those aspects that may be causing the results McKelvey (1991) found—fairer distributions within coalitions than predicted—other research on legislative bargaining took the alternative approach of testing the BF model directly on naturally occurring data, (see Warwick and Druckman 2001 and Ansolabehere et al. 2003). This analysis is also concerned with determining whether bargaining leads to unequal distributions of payoffs in coalitions as predicted by BF. However, the research contrasts the predictions of the BF model with an alternative model of bargaining called demand bargaining similar to that formulated in Morelli (1999). In the demand model actors make sequential demands

until every member has made a demand or someone forms a majority by demanding the residual payoff that is implicitly left by one short of a majority of other coalition members. If no majority coalition forms after all players have made a demand, a new first demander is randomly selected, all previous demands are void, and the game continues. Demand bargaining provides different predictions from the BF model in that the allocations of portfolios will be proportional to bargaining power and that proposers will not receive an undue share. Yet the results using naturally occurring data have been inconclusive—Warwick and Druckman find support for a proportional relationship and demand bargaining in legislatures while Ansolabehere et al. find evidence of proposal power, supporting the BF model.

What to make of the contrasting empirical results? The problem with the results is that it is difficult to determine what the nature of the underlying bargaining process within the legislature simply by looking at the what can be observed, proposal and bargaining power and portfolio allocations. Theoretically the two different models provide different predictions about the relationship between the observables. But the results from McKelvey (1991) and the centipede game experiments suggest that even when the underlying model is BF, the behavior of the individuals will lead to more equitable proposals, resembling demand bargaining. Thus, it might be the case that the predictions of the two models when behavioral violations of subgame perfection occur, will not be dissimilar enough for the naturally occurring data to distinguish between them.

In an innovative study, Frechette, Kagel, and Morelli (2005), hereafter FKM, investigate this hypothesis. First they tested to see if the methods used by Warwick and

Druckman and Ansolabehere et al. could distinguish between the two models if subjects behaved as the standard theory would predict (that is, without behavioral errors as discussed above). They generated simulated data and analyzed that data in the same way that the researchers using field data had. They found that the approaches using field data, if subjects make decisions as predicted by the standard game theoretic approach could distinguish between the two theories. Thus, in theory the methods used by the field researchers should work to determine how legislatures bargain.

But FKM also conducted experiments on both the BF and demand bargaining models—thus generating actual choices by real subjects. As with the simulated data they treated the data as if it they could only measure the same observables that a researcher with field data can measure/ FKM found that the empirical approaches used by Warwick and Druckman and Ansolabehere et al. could not distinguish between the two models using the data from the subjects in the experiments. Specifically, the regression analysis used on the field data, when used on the experimental data, cannot identify the underlying data generating processes and the regression results are similar to those found on the field data independent of whether the underlying data is generated with subjects participating in a BF game or a demand bargaining game. FKM (p. 6, italics in the original) contend that

there is a *behavioral identification* problem with the regression approach advocated for the field data, in that even though the specifications used are well identified with respect to theoretical behavior, the parameters of interest are not identified with respect to how agents actually behave. As such there is no clear mapping from the estimated parameters to the rules of the game that the

investigator is trying to infer given how people actually play these games. To fully address this behavioral identification problem, one would need to observe actual institutional differences and/or come up with other ways to distinguish between the two models given the available field data.

The analysis of FKM shows that laboratory experiments provide researchers who work with field data unique opportunities to test their methods of testing theory on field data. That is, the choices made by the subjects are better than simulated choices in that they incorporate differences between how individuals actually choose in games like BF or demand bargaining.

Concluding Remarks

The centipede game experiments when viewed in isolation may seem to be mainly of interest to theorists. But when put in context, we can see that the experiments were a direct consequence of a research program designed to understand legislative bargaining—a research program highly directed to building an empirically relevant theory. Experimental research on cooperative game theoretic models led to a more realistic noncooperative approach. Field data analysis is unlikely to have revealed the problems that the experimental research revealed. However, the assumptions about individual behavior in the noncooperative approach appeared to be violated in further experiments leading to a more careful study of those assumptions in the centipede game experiments and a new equilibrium concept that allows for more realistic behavior. The violations found in the centipede game experiments and McKelvey's BF experiments also imply, as FKM demonstrate, that tests of theories using field data must recognize that the predictions of the theory may not be distinguishable when violations are a possibility.

Laboratory experiments not only can lead to more realistic theories but can also be a testbed for methodologists who wish to evaluate formal theories on field data.

References

Austen-Smith, David and Jeffrey S. Banks. 1988. "Elections, Coalitions, and Legislative Outcomes." *American Political Science Review* 82:405-422.

Baron, David P. 1989. "A Noncooperative Theory of Legislative Coalitions." *American Journal of Political Science* 33:1048-84.

Baron, David P. 1991a. "Majoritarian Incentives, Pork Barrel Programs, and Procedural Control." *American Journal of Political Science* 35:57-90.

Baron, David P. 1991b. "A Spatial Theory of Government Formation in Parliamentary Systems." *American Political Science Review* 85:137-65.a

Baron, David P. and John A. Ferejohn. 1989a. "Bargaining in Legislatures." *American Political Science Review* 89:1181-1206.

Baron, David P. and John A. Ferejohn. 1989b. "The Power to Propose." in *Models of Strategic Choice in Politics*, ed. by Peter C. Ordeshook, Ann Arbor: University of Michigan Press, p. 343-366.

Diermeier, Daniel and Roger B. Myerson 1994. "Bargaining, Veto Power, and Legislative Committees. CMSEMS working paper No. 1089. Northwestern University.

Frechette, Guillaume, John Kagel, and Massimo Morelli, "Behavioral Identification in Coalitional Bargaining: An Experimental Analysis of Demand Bargaining and Alternating Offers," working paper, New York University Department of Economics.

- McKelvey, R. D. (1991): “An Experimental Test of a Stochastic Game Model of Committee Bargaining” in *Contemporary Laboratory Research in Political Economy*, ed. by Thomas R. Palfrey. Ann Arbor: University of Michigan Press.
- McKelvey, Richard D., Peter C. Ordeshook, and Mark D. Winer. 1978. “The Competitive Solution for N-Person Games Without Transferable Utility, With an Application to Committee Games,” *American Political Science Review* 72(2):599-615.
- McKelvey, Richard D. and Peter C. Ordeshook. 1983. “Some Experimental Results that Fail to Support the Competitive Solution.” *Public Choice* 40:281-91.
- McKelvey, Richard D. and Thomas R. Palfrey. 1992. “An Experimental Study of the Centipede Game” *Econometrica* 60:803-36.
- Morelli, M. (1999): “Demand Competition and Policy Compromise in Legislative Bargaining,” *American Political Science Review*, 93, 809—820.
- Riker, William H. 1962. *The Theory of Political Coalitions*. New Haven: Yale U. Press.
- Roth, Alvin E.. 1995. “Bargaining Experiments.” in *The Handbook of Experimental Economics*, ed. by John Kagel and Alvin Roth. Princeton: Princeton University Press, p. 253-348.
- Signorino. Curt. 1998. “Strategic Interaction and the Statistical Analysis of International Conflict.” *American Political Science Review*. 93(2):279-98.