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Abstract This paper considers whether game theory can be tested, what difficulties experimenters face in testing it, and what can be learned from attempts to test it. I emphasize that tests of game theory rely on fallible assumptions concerning particular features of the strategic situation and of the players. These do not render game theory untestable in principle, but they create serious problems. In coping with these problems, experimenters may use game theory to learn what games experimental subjects are playing.

Keywords: game theory, experimentation, prisoner's dilemma, testing

1 INTRODUCTION

This paper considers whether game theory can be tested, what difficulties experimenters face in testing it, and what can be learned from attempts to test it. I emphasize that tests of game theory rely on fallible assumptions concerning particular features of the strategic situation and of the players. These do not render game theory untestable in principle, but they create serious problems. In coping with these problems, experimenters may use game theory to learn what games experimental subjects are playing.

2 IS GAME THEORY TESTABLE?

Although the words, 'game theory' can refer to several different things, most mathematicians, economists and evolutionary biologists regard game theory as a branch of mathematics. A game is defined by a set of 'players', a set of strategies for each player, and a set of 'payoffs' for each player for each strategy combination. Players need not be people; they may, for example, be plants or animals or even an agent called 'chance.' A pure strategy picks out one alternative at each 'information set', but information sets need have nothing to do with knowledge. Similarly, payoffs need not involve preference or utility. In some biological applications payoffs might be death or survival. Game theory consists of axioms and definitions that are

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employed to reach conclusions concerning what strategies players will adopt given specifications concerning the number of players, their strategy sets, and the payoffs.

Although the distinction between purely mathematical claims and contingent empirical claims is not as clear or as strict as one might imagine, it is clear enough to justify the conclusion that there is no way to test game theory without interpreting it. Without some interpretation, sentences within game theory cannot be true or false except in virtue of their logical form. Without knowing what counts as a player, a strategy, a payoff or a choice is, one cannot sensibly consider the truth or falsity of claims about the number of players, what strategies they can play, what the payoffs of strategy combinations are, or which strategies will be chosen. One can still sensibly ask 'meta-language' questions concerning whether, for example, some sentence is syntactically well formed or whether it is deducible from some other sentences. But without interpretations, syntactic objects such as inscriptions and utterances are not the sort of thing that could be true or false. Game theory is not testable until it is interpreted.

Experimental economists thus do not test game theory, full stop. They test some particular empirical interpretation of game theory, which usually takes 'players' to be human beings, 'choice nodes' to be occasions when people might make choices, a player's pure strategy as a specification of a choice for each information set where the person gets to choose, payoffs to be utilities (as indices of preference), and so forth. When game theory is interpreted this way, let us call it 'human premeditated game theory' or for short 'HP game theory' – 'human' because the players are human beings and 'premeditated' to distinguish it from evolutionary game theory.

HP game theory is an interpreted theory, but it does not follow that it makes any testable claims. 'If anything is a red apple then it is red' is fully interpreted, but it is not testable, and it is apparently empirically empty. It is true, because any interpreted sentence with the form 'If anything is F and G, then it is F' is true. Analytic claims, such as 'round balls are not square' are true by virtue of the meaning of their terms rather than their logical form, but they are also irrefutable. Similarly (though not so simply), 'If s is a strongly dominant strategy for a rational player P, then P prefers s to any other strategy' appears to follow from the definitions of rationality and of a strongly dominant strategies. A good deal of game theory takes the form of theorems, and no matter how the terms in a theorem are interpreted, there is no point to testing a theorem (as opposed to testing its axioms or its conclusion). For example, Nash *proved* that if bargaining solutions satisfy four specific conditions, then the solution will maximize the product of the individuals' gains from bargaining. So there is no point to testing to see whether when the axioms are satisfied the solution maximizes the product of the individual's payoffs. If any other solution is observed, the axioms cannot all be satisfied. Sensible tests of Nash's bargaining theory are not devoted to determining whether logical impossibilities happen. Experimental studies of Nash bargaining theory (such as Roth and Malouf 1979) instead probe whether people satisfy his four conditions or whether people in fact come to the solutions to bargaining problems that are implied by these conditions.

Insofar as HP game theory confines itself to making proven conditional claims, it is pointless to test it. One can prove that if an individual satisfies the axioms of rational choice theory, knows what game he or she is playing, and has a strongly dominant strategy, then the individual will choose that strategy. If one takes HP game theory to make only conditional claims such as this one, then observing that individuals often do not play what appear to be their dominant strategies in what appear to be prisoners' dilemma games does not and cannot reveal any mistake in HP game theory. It shows instead that the antecedent conditions in the above conditional claim are not all satisfied – that is, the players are not rational, or they do not know what game theory are playing, or they do not have strongly dominant strategies. Game theory is not testable if it is restricted to theorems. To make testable claims, game theorists must assert their axioms or the conclusions proved by their theorems.[1]

Although empirically empty, the proven conditional claims of HP game theory may still be useful, because theorems can help people, who are certainly not logically omniscient, to recognize consequences and make predictions. For example, thanks to Ariel Rubinstein's theorem, I am able to predict what rational and (very) intelligent players will do in his famous bargaining problem. By drawing out the implications of claims concerning the preferences, beliefs, rationality and intelligence of players, the strategies among which they can choose, and the outcomes of those strategies, the theorems of game theory can facilitate testing them. For example, the results of dictator games help to falsify the hypothesis that experimental subjects care only about their own financial payoffs.

Although the point is controversial, I maintain that HP game theory does and should do more than make proven conditional claims. Game theorists do not and should not only explore the consequences of rationality: they also assert or suppose that humans are, to some reasonable approximation, rational. They do not only calculate what the consequences would be if humans cared only about their own monetary payoffs; some also assert that it is often a good approximation to assume that humans in fact care only about their own payoffs. Game theorists do not only explore the consequences of salience; they also propose hypotheses concerning the importance of salience and the sorts of things that humans find salient. In my view, game theory is committed to contingent and testable axioms concerning human rationality, preferences, and beliefs. The theory is not without empirical content.

HP game theory 'sticks its neck out' as soon as it goes beyond proving theorems. If game theory is (as I believe) committed to claims about individual rationality and self-interest, then observing cooperation in an experiment in which subjects are supposed to be playing a prisoners' dilemma game may disconfirm game theory rather than demonstrating only that the antecedent conditions for the argument for mutual defection are not satisfied. If game theory is interpreted and offers empirical hypotheses or asserts some of the antecedents in its theorems, then game theory is testable.

But even in this case, game theory will not be testable *by itself*. (This claim obviously depends on distinguishing those propositions that belong to game theory from those that do not.) As Pierre Duhem famously argued (1906), significant scientific claims cannot be tested by themselves. Consider something as simple as Galileo's law: that bodies near the surface of the earth fall with a constant acceleration, unless their fall is somehow impeded, as for example by a barrier or by air resistance. Galileo's law can be formulated as a conditional, 'If there are no other forces acting besides gravity, then bodies near the surface of the earth will fall with a constant acceleration'. Unlike the conditionals I discussed above, this one is not a mathematical truth.[2] It is an empirical claim, which can be and has been tested. Galileo tested it using inclined planes to slow up the acceleration and make the time measurement easier. Nowadays, we can build precise timers and create extremely good vacuums. Each of these tests bears on the correctness of Galileo's law only if claims about the respective test apparatus are true. A test using an inclined plane might find that different bodies accelerate at different rates because Galileo failed to grease the plane between trials. A test using an evacuated chamber might find a decreasing acceleration, because the chamber was leaking air in. Any test of Galileo's law is simultaneously a test of other claims the experimenter has to rely on in carrying out the test. Moreover, no matter how clear cut the experiment, a failure to find the results predicted by Galileo's law can always be explained away by a failure of its antecedent – that is, by the presence of some other, non-gravitational force.

So even if HP game theory makes testable empirical claims, like the testable claim Galileo's law makes, it can only be tested when conjoined with other propositions concerning the specific strategic interaction to which the theory is applied. This point – which is central to what is commonly called 'the Quine-Duhem problem' – should be sharply distinguished from the claim that theories must be interpreted to be testable or the claim that theorems cannot be refuted by observations. Each of the three arguments implies that 'by itself the theory cannot be tested', but the reasons are different. In the first case the theory cannot be tested, because it has no interpretation assigned to its terms and thus no meaning. In the second case, the theory cannot be tested, because it consists of logical or analytic truths. No matter what other sentences one takes to be true or false, there can be no falsifying evidence. In the third case, one can test the theory, but only if one takes other statements to be true. Since those other statements are contingent and often not testable by themselves either, it is always possible to deflect the blame for experimental failures away from the theory, but not because the theory has no empirical meaning or because the theory is logically true.

Another way of stating the same conclusions concerning the testing of game theory (when game theory is interpreted and not limited to theorems) is to maintain that what one tests are specific game theoretic *models*, rather than game *theory* itself. Game theoretic models embed the mathematical structure of game theory and its empirical claims – if there are any – in amalgams that include specific assumptions concerning features of the strategic situation to which the model will be applied. Tests of game theoretic models can bear on the empirical claims of game theory themselves, but this bearing is not direct or unproblematic. I prefer not to make the point in this language, because doing so encourages the instrumentalist view that one tests only models, never theories. As I have argued elsewhere, the appraisal of theories is crucial to science as we know it.[3]

3 DIFFICULTIES IN TESTING GAME THEORY

If one attempts to test game theory by constructing a strategic situation in the laboratory and comparing the way experimental subjects behave to the way that game theory predicts players will choose in some specific game, one needs be clear about what the empirical claims of game theory are, and one needs to know what game experimental subjects are playing. Until one knows what the game is, there is no way to test whether the predictions of some version of game theory are correct, because until one knows what the game is, there are no predictions to test. Without knowing what game one is playing, one cannot look to game theory for advice or explanation either. Until one specifies what the empirical claims of game theory are, there is no way to know whether they are implicated in the predictions one is testing.

Accordingly, for the purposes of this discussion I shall stipulate that game theory makes empirical assertions to the effect that people are, to a reasonable degree of approximation, rational and that they are intelligent enough to figure out what the game theorist can. Here I shall not attribute to the game theorist any further assertions about the character of preferences. One might, quite reasonably, attribute to game theorists stronger empirical generalizations concerning individual preference or belief; and in that case the following discussion would have to be recast.

Clever experimenters are able to control situations in the laboratory tightly enough that they can specify how many players there are and what strategies are open to each player. This is not as simple as it may appear. In principle, the experimenters might count as players along with the subjects. Experimental subjects always have more choices than the experimenter specifies. They might, for example, smash their computer terminals and set the laboratory on fire. A full specification of their possible strategies would have to include such possibilities. But it seems to me that in fact experimenters rarely go seriously wrong in their specification of the strategic possibilities. Similarly, though with greater difficulty, experimenters can control the beliefs the players have concerning the permissible strategies, the physical outcomes of strategy combinations, and the knowledge available to other players (including their beliefs about the beliefs of each other).

There are, however, very serious difficulties in the way of determining the payoffs or preferences of experimental subjects. These payoffs must be determined in order for game theory to make any substantial predictions concerning laboratory behavior. Until the preferences are specified, the experimenter only knows 'the game form', not the game. Determining the player's preferences might not seem all that difficult. If experimenters insure that subjects are completely anonymous – thereby eliminating all sorts of extraneous motives – it might seem a reasonable first approximation to regard the preferences of an experimental subject over the outcomes as tracking the monetary payoffs he or she would receive. But as I read the literature, this turns out to be unsatisfactory, even as a first approximation. It is in fact very difficult to know what motivates subjects in a laboratory for experimentation in economics.

To bring these points down to earth, consider a simple one-shot two-person prisoner's dilemma. In a prisoners' dilemma, a player's choice of strategy is extremely simple. In the normal form of figure one, the numbers are utilities (indices of preference), with larger numbers indicating more preferred. The first number records Row's preferences, while the second records Column's preferences. Everything in the normal form is common knowledge. The game theoretic argument for choosing the dominant strategy requires only ordinal utilities with no interpersonal comparability. A positive monotone transformation of either Row's or Column's payoffs changes nothing.

Each player has a dominant strategy: 'Down' for Row and 'Right' for Column. Nothing could be simpler, and barring irrationality, confusion, or some sort of blunder in execution, Row will play down and Column will play right. As is common in the literature, I shall call Down and Right 'defection,' and the strategy pair (Down, Right) 'mutual defection.' Similarly, I shall call Up and Left 'cooperation' or 'cooperative strategies' and the outcome 'the cooperative solution.' Finally, I shall call 0 'the sucker's payoff'.

Although the prediction that players will choose strongly dominant strategies seems scarcely to need testing, one might perform an experiment like the following make-believe example. This example is intended merely to illustrate the points. Actual experiments, especially in recent years, are much more subtle:

A Naive Experiment

Experimental subjects who do not meet and do not know each other are told:

> You are going to have a single interaction with another subject via a computer hookup. You will never meet this other subject. Each subject can choose one of two options, A or B. The following table explains how your earnings depend on both your choices and on the choices of the other subject. The other subject receives exactly the same instruction sheet, as the one you are now reading.

If the subjects understand their choices and if they care only about their own monetary payoffs, then it seems that they are playing a prisoner's dilemma. Since all that matters to the specification of the game are ordinal utilities, one need make no assumption about the utility of money – the relation between money and preferences – except that each player's utility is increasing in his or her own monetary payoffs and completely determined by them. Given this assumption, the players are playing exactly the game in figure 1, and game theory predicts that Row will play Down and Column will play Right.

Yet, as is well known, when faced with game forms such as Figure 2, many experimental subjects do not play their dominant strategies. One possible explanation is that the experimental subjects are inattentive and confused about the nature of their choices and the outcomes of their choices. James Andreoni (1995) has done some elegant experiments investigating how much of the anomalous behavior in related games can be attributed to confusion, and his work shows that confusion can explain only a part of the anomalous behavior. A great deal remains.

A second possibility is that people systematically misunderstand what game they are playing or violate axioms of rationality. They may engage in magical thinking, supposing that if they choose the cooperative strategy that will somehow lead other players to choose their cooperative strategy, or they may accept some fallacious argument for the rationality of cooperation.

		Column	
		Left	Right
Row	Up	2,2	0,3
	Down	3,0	1,1

Figure 1 A Prisoner's Dilemma Game

		Other subject's choice	
		A	B
Your choice	A	$2 for both	0 for you, $3 for other
	B	$3 for you; 0 for other	$1 for each

Figure 2 Payoffs in a naive test

Some of these explanations are cast in doubt by experimental work such as Andreoni's, but it is likely that errors in the axioms of game theory explain a good deal of the cooperation experimenters find in apparent prisoner's dilemmas.

Yet I (like many others) would emphasize a different explanation of the experimental results, which is that other things besides monetary payoffs strongly influence the choices of experimental subjects. My reasons for thinking that cooperation in an apparent on-shot prisoner's dilemma such as experiment one derives more often from factors influencing preferences besides own monetary payoffs than from failures of the axioms of game theory are broadly empirical: there is a great deal of evidence that people's preferences respond strongly to many factors. Furthermore, I believe that economists can often learn more by using game theoretic anomalies to study the factors influencing preferences rather than by treating them as disconfirming game theory. Since economists already have solid evidence showing that people do not conform perfectly to the basic axioms of game theory, and since they currently lack any serious alternatives to standard game theory, testing game theory may teach them comparatively little.

In addition to caring about their own monetary payoffs, subjects may be motivated by factors such as the following:

1. Subjects may care about the monetary payoffs that other players get. They may be altruistic or malevolent.
2. Subjects may care about 'winning.' They may take the interaction to be a competition, and rather than focusing exclusively on their own payoffs, they may care about how well they do, relative to the other subject.
3. Subjects may care about whether the outcome is in some sense fair.
4. Subjects may want to reciprocate – to repay a kindness with a kindness and a harm with a harm (Rabin 1993).

5. Subjects may be trustworthy and concerned to do what other subjects trust them to do.

This is only a partial list. There are many other possible motivations. Subjects might, for example, have a malicious desire to mess up the experiment, or they may seek to maximize the cost to the experimenter. On the other hand, not all of the listed motives will come into play in every kind of interaction. For example, in a one-move simultaneous-play game without any prior communication such as the prisoners' dilemma, it is impossible for subjects to signal any trust or any intention to be 'kind' or 'nasty.' (Subjects may nevertheless believe that their partners are trusting them or that they will behave in a kind or nasty way.)

How strong such other motives are remains to be seen. Simply to assume that they are all negligible compared to concern with one's own monetary gain is convenient, but hard to square with the outcomes of experiments. When these other motivations are present, experimental subjects faced with the payoff matrix depicted in Figure 2 need not be playing a prisoner's dilemma game. So the fact that they frequently play cooperatively is no refutation of game theory.

Notice that the existence of multiple motivations need be no problem for game theory itself. Most game theorists understand the utility payoffs in Figure 1 as already taking into account all factors influencing preferences. The extent to which Row cares about how an outcome affects Column is factored into the numbers representing Row's preferences. On this interpretation, game theory does not address the problems of modeling strategic interactions as games. Instead, it supposes that they have already been solved and that the game to be analyzed is given. In some cases, all the hard work in theorizing about strategic behavior lies in modeling it as a game. What's left for the game theorist, once is has been determined what the game is, may be very simple.

Since it is difficult to know what experimental subjects prefer and hence what game they are playing, it is difficult to test game theory. One fact that complicates learning the preferences is that preferences over outcomes of the interaction (which Sen calls 'comprehensive outcomes' 1997: 745) need not coincide with preferences over the monetary payoff pairs the outcomes involve (which Sen calls 'culmination outcomes'). Comprehensive outcomes are not identical to monetary payoff pairs. So unless people care only about the monetary payoffs (regardless of the path through the game that leads to them), their preferences over comprehensive outcomes need not coincide with their preferences over pairs of monetary payoffs. For example, suppose that an experimental subject is offered a choice between keeping \$3 or giving up \$1, which the experimenter will match and give to some other anonymous subject – that is, the choice is between the payoff pairs (\$3, \$0) and (\$2, \$2). Suppose also that the subject chooses to keep the \$3. This same subject, without inconsistency, may prefer the cooperative outcome of (A, A) to (B, A), even though the cooperative solution results in both subjects getting \$2, while (B, A) pays off \$3 for self and nothing for the other. Preferences among culmination outcomes are no more than fallible evidence concerning preferences over comprehensive outcomes.

There are two main ways to respond to the difficulties. The first uses the opportunities that a laboratory provides to manipulate people's preferences and essentially to force subjects to play the game one wants them to play.[4] So, for example, one might have the players play for 'points' rather than dollars and tell the players that each player's points will be converted to dollars according to a separate schedule that will not be revealed until the end of the game. Although more points means more money, zero points for one of the players might lead to a larger monetary reward than 3 points for the other player. Not knowing how points translate into dollars would greatly diminish concerns about fairness, reciprocation, trust, and winning. There would still be room for altruism and malevolence, though they would be weakened. Although there is no guarantee that experimenters can induce subjects to have the right preferences, there is a great deal to be done; and for the purposes of testing the claims of game theory, this seems the best path to follow.

However, this path is of little use if one is concerned with applications of game theory to explain and predict strategic behavior or to advise individuals facing strategic situations. For these purposes, one needs to be able to apply game theory to strategic situations that are not so tightly controlled. For practical purposes, one needs to know what people's preferences are like, not merely what they do when one forces them to have certain preferences. So the second response is to attempt to learn about people's preferences.

This is not an easy task, and it is one that economists may resist, preferring a division of labor whereby psychologists and sociologists study what determine the preferences individuals have and economists then take over to investigate the consequences of those preferences. But this division of labor is not workable, in part because game theory has so much to contribute to the task of modeling strategic interactions as games. I suspect – although I cannot claim to have established – that experimentation involving game theory may be of more value when it employs game theory to test claims about individual preferences and hence the right way to model strategic interactions than when it aims to test game theory itself. But there is, of course, no reason why different experimenters cannot pursue both goals. Even if the empirical difficulties with the axioms of game theory could all be resolved, empirical applications would still need accurate characterizations of people's preferences, and no matter how accurately experimenters characterize people's preferences, the predictions of game theoretic models will go astray if they do not correctly capture the principles governing individual choice, belief, preference and reasoning.

Let me say a bit more about how game theory – imperfect as it may be – can help test claims about individual preferences. Notice that precision about what the experimental subjects know or do not know can be exploited in variations on experiment one designed to investigate motivations. All five of the additional motivations mentioned above require that an experimental subject know something about the payoffs that the other subject will receive. If Row does not know Column's payoffs, Row cannot be moved by altruism or malevolence. A concern about 'winning' or avoiding getting a sucker's payoff cannot motivate subjects unless they have some way of comparing their own payoffs to the payoffs others receive. Concerns about fairness also require some way of comparing payoffs or differences in payoffs. Questions about trust and reciprocation are more complicated, but at least with respect to the interaction depicted in Figure 2, questions about whether Row is being trustworthy or is reciprocating cannot arise for Row if Row does not know Column's payoffs.

In standard game theory, the payoffs are common knowledge, and there is no way to 'shut off' these other motivations. But notice that the only reason why players need knowledge of the payoffs of others is to help make inferences about what others will do. Game theory stipulates that the payoffs of others have absolutely no motivational force. Note that this has *nothing* to do with whether agents are self-interested or altruistic. It follows instead from the requirement that a player's own payoffs reflect all the factors that influence the player's preferences, whether self-interested or not. In the case of the one-shot prisoner's dilemma game (but not necessarily the experimental implementation), the fact that the payoffs of others are irrelevant to an agent's preferences has the striking consequence that knowledge of the payoffs to the other player ought to be completely irrelevant. Since each player has a dominant strategy, it is irrelevant what the other player is going to do.

This suggests that one can make use of game theory in devising experiments to test what factors different motivations depend on and how strong different motives are. By altering features of the game forms and, in particular, by manipulating the precise beliefs each player has of features of the game and of the beliefs of others about features of the game form and of their own beliefs, experimenters may be able to make progress in understanding what governs choices in strategic situations and hence what games people are playing. For example, since all the motivations apart from an interest in larger monetary payoffs for oneself require that players know their partner's payoffs, one can 'shut off' all these factors and establish a baseline level of defection by depriving experimental subjects of this knowledge.

Since this trivial game is so similar strategically to a prisoner's dilemma, one can use it to test the predictions of game theory concerning what people will do in the two-person prisoner's dilemma by seeing how people play this trivial game. In this way the investigation of motivations can go hand-in-hand with testing the theory. The test is imperfect, because it does not permit subjects to make the mistake of treating the payoffs to others as relevant to the choice of strategy, but it does test the fundamental empirical hypotheses of game theory concerning rationality and intelligence.

4 CONCLUSIONS

This paper distinguishes three barriers to testing game theory: the need for interpretation, the question of whether the interpreted claims of game theory are all logical or analytical truths, and the problem that in testing game theory one is simultaneously testing the claims one is committed to in modeling a strategic situation as a game. Although game theory has, I maintain, some empirical content, it is not much; and what there is concerning, for example, the extent to which people are rational, might be tested in other contexts, too. While not abandoning efforts to test and improve game theory itself, I have emphasized the possibility of using game theory in experimentation designed to test claims about people's preferences.

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NOTES

1 I am only listing necessary conditions here. Deriving testable implications typically requires choices among solution concepts, and even then there are often multiple equilibria.
2 Compare Galileo's law with the mathematical truth the distance a body falling with a constant acceleration from a state of rest is proportional to the square of the time of fall. The latter would be analogous to a theorem of game theory.
3 See Hausman 1992: 81–2. Note that I am using the term 'model' here in an entirely different sense than I employed in chapter 5 of my *Inexact and Separate Science of Economics*. Since I shall from now on be talking only of interpreted game theory, I shall drop the 'HP' and for the rest of the paper speak simply of game theory.
4 Compare this to Vernon Smith's work on experimental markets (Smith 2000).

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