Contemporary Economic Games

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Introduction

The economic theory of games derives its name from the study of strategic interactions - games - between individuals known as players who are thought to be rational, self-interested and informed. The players use the information to form beliefs about each other's intentions. Their options for a decision are known as strategies. Their benefits or costs are known as payoffs and their decisions can be an equilibrium. The players may choose whether or not to cooperate with each other. If they do not cooperate, the theory is that of a non-cooperative game and the players are in a situation of conflict.

The prospect of a conflict imbued with rational calculations makes non-cooperative game theory relevant for predicting the outcomes of a wide range of public policy issues. For many such issues, the decisions are made by organizations and nation-states rather than by individuals. In order that game theory can continue to apply, the decision-makers must be just as motivated and informed as the rational individuals of a game. Also, the decisions must not instead be propelled by bureaucratic processes and pathologies, for these can clearly displace original intentions.

This article describes three examples of non-individualistic games. Global trade negotiations are shown as a conflict where countries inevitably inflict upon each other mutual harm. Union participation is seen as the consequence of sequential responses where a threat of reprisal is not credible. And finally, the invasion of Iraq by the United States (US) and coalition forces in 2003 is cast as a best response to an unknown Iraqi weapons-decision given a tolerable ranking of policy alternatives. For these and other examples, the underlying uniformity is that of a conflict between non-cooperative players that generates an outcome according to some equilibrium.

1 The author wishes to thank Richard Arnott, Karen Baehler, Jonathan Boston, Bob Gregory, Gary Hawke, Amanda Wolf and other colleagues for comments on earlier versions of this article. Any errors are the sole responsibility of the author.

The prisoners' dilemma and trade negotiations

The most-common concept of equilibrium in games is undoubtedly that from an example known as the Prisoners' Dilemma. Two selfish and unprincipled *prisoners*, confront a *dilemma* about whether or not to confess to a crime that they both committed. The game's defining characteristic is that both prisoners will want to confess even though their collective interest is maximized by neither of them doing so.

A Prisoner's-Dilemma type of game can serve to explain why international trade negotiations often fail to achieve the removal of import tariffs. Tariffs are inefficient because they entice trading countries to locally-produce goods that can be produced more cheaply abroad. Their removal is therefore potentially beneficial to all negotiating parties. For some facts, consider how in 1995, when the World Trade Organization (WTO) was created to foster trade, international import tariffs were particularly excessive in agriculture. During that time, countries classified as "high-income" were estimated to have been charging "low-income" countries an average tariff of 15.1 percent for agricultural imports, at the same time that the latter were estimated to have been charging 21.5 percent upon the former (Hertel et al, 2000). The WTO felt it necessary to moderate the balance through tariff-removal trade talks. But never once did the launching of such talks succeed. It failed in Seattle in November 1999 and again in Cancun in September 2004.

Consider the suggestion that a 40 percent reduction in tariffs could have increased the real income of all countries (both high and low-income ones) by an estimated $60 billion dollars per year (see Hertel et al, 2000). If the increase were apportioned according to import volume, the real-income gain for the high-income countries would have been $47 billion while that for the low-income countries would have been $13 billion. (In 1995, the agricultural imports of high-income countries from low-income ones were around $351 billion while those by low-income countries from high-income ones were around $95 billion.)

The payoffs in Figure 1 reflect the suggestion. Each of the players – a low-income country and a high-income one – can choose to *Do Nothing* about its high import tariffs. If both choose this strategy, there are no gains to be realized from a more efficient system of trade. If instead both choose *Repeal Tariffs*, the total gain of $60 billion is proportionately allocated as $47 and $13 billion. If one country chooses to repeal its tariffs while the other does not, there is a transitional (and equally applicable) cost of $C billion in terms of local job losses. These losses are emphasized because they are typically lobbied for more than any gains a country may make from cheaper imports. The country that does *not* repeal its tariffs can enjoy an interim benefit of $B billion, corresponding to an increase in its export earnings.

Figure 1. Global Trade Payoffs: Agricultural Imports, 1995

	Low-income Country	
	Do Nothing	Repeat Tariffs
High-Income Country		
Do Nothing	(0,0)	(47+B, -C)
Repeat Tariffs	(-C, 13+B)	(47, 13)

It is apparent that each country is *always better off choosing Do Nothing* even though the highest sum of players' payoffs can be that for both of them choosing *Repeal Tariffs*. Such a sum for joint payoffs (of $60 billion) is highest provided that the net transitional benefit (B-C) is less than $13 billion. Thus it can be said that the repeated failures of global trade negotiations are the consequence of a Prisoner's dilemma, there being a disparity between what players will want to choose for themselves and what *they ought to choose* for their collective interest. The proper role of government - or the WTO in this example - is to find the power to enforce a binding agreement that none of the players wants for itself (see Victorio 2004 for other examples).

The dominant-strategy equilibrium and the Nash equilibrium

In Prisoners'-Dilemma games, the strategy chosen by each player has a payoff that is superior to that of the other strategy in all possible cases. This can be generalized. A strategy is said to be dominant if it is a player's best strategy *regardless* of what the other player does. If each of the players has a dominant strategy (for example, *Do Nothing* in the preceding case), the corresponding strategies are known as a *Dominant-Strategy equilibrium*. A Dominant-Strategy equilibrium is also a *Nash equilibrium*, defined as *best-response strategies that neither player will want to deviate from given that the other does not*. However, the former requires that each of the two players has a dominant strategy while the latter does not. Because of this a Nash equilibrium can be made to apply to a wider range of games.

To illustrate the difference between the two equilibrium concepts, consider the removal of any export-earnings advantage to the country that decides to do nothing if the other repeals its tariffs. This is tantamount to assuming that B is zero. A consequence is that neither of the players now has a dominant strategy. While the high-income country will still want to do nothing if the low-income country repeals its tariffs (0 > -C), it *feels indifferent about what to do* if the low-income country decides to repeal its tariffs (it gets $47 billion either way). Its former choice *Do Nothing* is no longer dominant because it is advantageous only if the low-income country does nothing. The rest of the time, the strategy is *felt indifferent toward*. The same thing can be said about *Do Nothing* if instead the strategy were instead wielded by the low-income country.

The reduced advantageousness of *Do Nothing* qualifies it for a reduced rank, that of a *weakly-dominant strategy*, defined as clearly advantageous to use sometimes and felt indifferent-toward the rest of the time. Above, the "sometimes" is when the other country also does nothing while "the rest of the time" is when the other country repeals its tariffs. With both of the players now converted to having a weakly-dominant strategy rather than a dominant one, the strategies (*Do Nothing, Do Nothing*) are now still an equilibrium. But rather than this equilibrium being a dominant-strategy one, it is now "merely" a Nash equilibrium because it is composed of strategies that are best-responses to each other with neither player having a dominant strategy yet neither wanting to deviate from its choice.

Backward induction: union membership reprisal

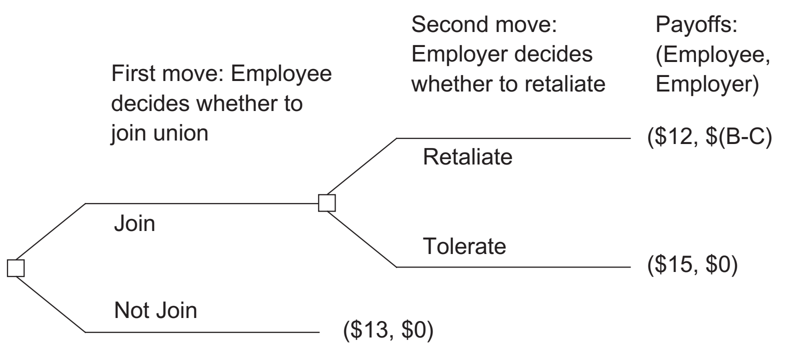
Weakly-dominant strategies can present the prospect of there being more than one Nash equilibrium. The prospect is uncomfortable because it introduces predictive imprecision: if the number of predictions to a game becomes anywhere close to the number of possible events, there might as well be none. In the preceding example of weakly-dominant strategies, a second possible Nash equilibrium is that of *(Repeal Tariffs, Repeal Tariffs)*. The reason is definitional: for this pair of strategies, neither will want deviate given that the other does not. (If the high-income country deviated while the low-income one did not, its payoff would remain at $47 billion, so why deviate? Analogously so for the low-income country.)

A single equilibrium can sometimes be narrowed if the game is instead a sequence of moves rather than a set of simultaneous decisions made by two players. The resulting description is known as a game tree or a dynamic game. The sequencing allows for an elimination of Nash equilibrium solutions that are not persuasive.

Thus consider a sequential game of two players, an employee and an employer, where decisions pertain to union membership. In the US, it is estimated that employees who join a union can earn a higher wage than those who do not, the wage premium being between 12 and 18 percent depending upon the extent to which other wage factors are controlled for (see, for instance, Budd and Na 2000). The reasons may stem from the greater power that a collective membership possesses when negotiating with an employer.

In the game, let the employee be the first to decide whether or not to join a union. Let the employer be the second to decide, who in spite of legal duties can choose to *Retaliate* against a union membership by way of punitive measures pertaining to tenure and promotion. The punitive measures yield for the employer a benefit of B dollars per employee-hour (in labour-cost savings) and entail a potential cost of C. The employer's alternative is to *Tolerate* the membership. Given this and if the employee were to join, the employee succeeds in obtaining a union wage of $15 per hour. If the employer were to retaliate, the wage is reduced to $12 per hour. Finally, if the employee decided not to join the union, the obtainable wage is $13 per hour. These payoffs are summarized in Figure 2.

Figure 2. A Game Tree



To uncover whether the game has any Nash equilibrium, one first investigates the optimal decision for the player at the end of the game tree. Then, given this decision, one *works backward* to investigate the optimal decision for the preceding player until the beginning of the game tree is reached. If $(B-C) were negative (as may be reasonable to assume of anti-discrimination laws), the employer's best response would be to tolerate the employee (zero dollars being better than a loss of $(B-C)). And given that the employer decides to tolerate, the employee's best response would be to join the union ($15 being better than $13). The joint decisions are thus *Join, Tolerate,* with payoffs ($15, $0), and these comprise a Nash equilibrium because neither of the players will want to deviate from its decision given that the other does not. This method of finding a Nash equilibrium by investigating decisions backward is known as *backward induction*. On this basis, the wage premium of union members is the result of a sequential game where membership has wage advantages to employees and punitive measures are more costly than beneficial to employers.

Non-credible threats

The option to retaliate against the employee is an example of a *non-credible threat,* defined as any threat that a threatener *does not want to* carry out (for instance, because it would imply for itself a loss) and *will not have to* carry out if believed. Non-credible threats are important because their presence can suggest the existence of a secondary Nash equilibrium that is itself not credible. This becomes apparent if one summarized the payoffs of a game tree according to a normal (matrix) form. In Figure 3, the employer's net benefit from retaliation, previously regarded as negative, is exemplified as -$1.

Figure 3. Union Membership in Normal Form

		Employer	
		Retaliate	Tolerate
Employee	Do Nothing	(0,0)	(47+B, -C)
	Repeat Tariffs	(-C, 13+B)	(47, 13)

In the normal form, there are two Nash equilibrium solutions, not one. The first is that previously predicted by the game tree which is *Join, Tolerate*. The second one is *Not Join, Retaliate*. This is also a Nash equilibrium because it qualifies the definition that if chosen by the players, neither will choose to deviate given that the other does not. It can arise simply because the employee may *believe* that the employer would retaliate.

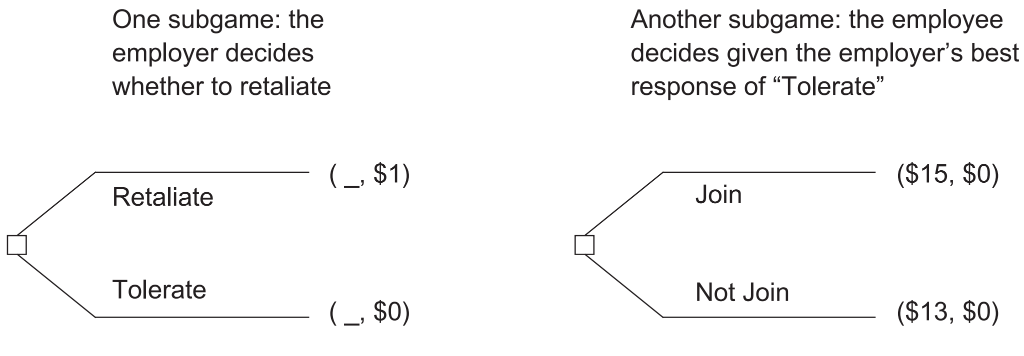
But in what sense is the second not as persuasive as the first and therefore itself *not credible*? Because the employer *no longer has to* carry out its threat of retaliation, which it knows is costly. (The equilibrium payoff to the employer is $0, not -$1, even though its equilibrium strategy is *Retaliate*.) Knowing this, the employee can gain by choosing to *Join*, which in turn elicits no other best response from the employer but *Tolerate*. As a result, what eventually re-emerges is the first equilibrium of the game tree – *Join, Tolerate.* In sum, the second equilibrium is *not credible* even though it is a Nash equilibrium, because it is based upon a *non-credible* threat that the employee must somehow *believe* and which the employer *does not want to carry out and does not have to* either.

Sub-games and sub-game perfection

Another way of repudiating the credibility of the second equilibrium is to say that it is not one that would emerge if all of the best responses were tabulated. The tabulation is conducted by first uncovering all of the sub-games of a game tree, each defined as any entire-remaining portion of the game to the right of an available decision node. When examined, each of the sub-games implies a best-response for the player making the decision. If all of these best responses (corresponding to all of the sub-games) are assembled together, the results are the strategies of a Nash equilibrium that corresponds to the credible one, e.g. the first equilibrium of the previous game, not the second one. The tabulation thus implies that if there were ever an equilibrium based upon a non-credible threat, it could be rigorously eliminated.

Applying the tabulation to the previous game tree, one uncovers two available decision nodes and therefore two

Figure 4. The Two Subgames. Payoffs: (Employee, Employer)



sub-games. In no particular order, the first is all that remains beginning from the employer deciding whether or not to tolerate the employee. The second is all that remains beginning from the employee deciding whether or not to join the union *after* the employer has decided upon its best response. This second sub-game is the entire game itself; in the right-hand-side in Figure 4 it is shown in a *reduced form,* that of the second-mover (the employer) having already decided upon its best response (*Tolerate*).

In the first sub-game, the best response is for the employer to *Tolerate*. In the second, the best response is for the employee to *Join* (given that the employer decides to *Tolerate*). These best responses form the strategies of the Nash equilibrium *(Join, Tolerate)*, a solution that eliminates the non-credible equilibrium that was previously discussed *(Not Join, Retaliate)*.

Clearly, an equilibrium that derives from the best responses of all possible sub-games must have a special rigour attached to it. For this reason, such equilibrium solutions are known as *sub-game Perfect.* Formally, a Nash equilibrium is also a sub-game-Perfect Nash equilibrium if the strategies contained in it are the best responses obtained from tabulating all the sub-games of a tree. A sub-game-Perfect Nash equilibrium is for a game-tree the way a dominant-strategy equilibrium is for a matrix of payoffs. Each is a more-focussed definition of an equilibrium than is merely required of a Nash.

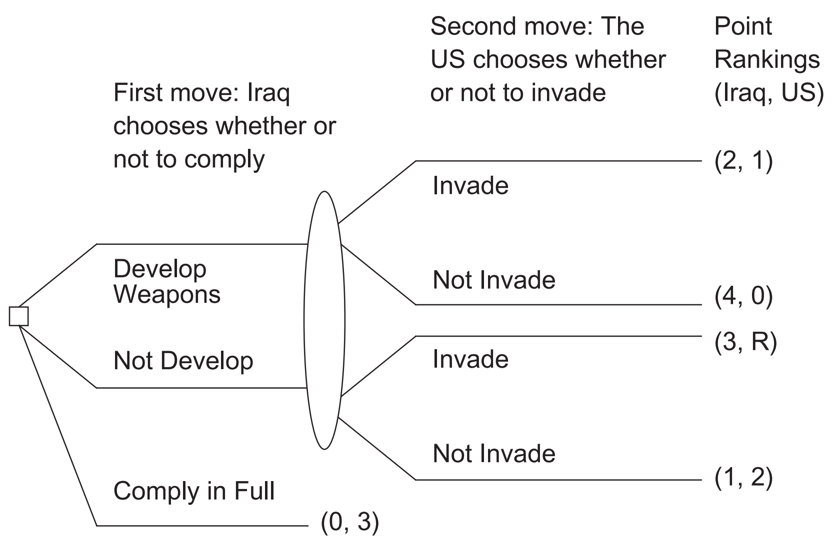
Game trees with imperfect information: Iraq versus the US

Quite often the one who makes the second move does not know which strategy was chosen by the one who made the first move. For instance, while the employer might know the employee's possible strategies, privacy laws might prohibit it from immediately finding out which of the two was chosen at the point of having to decide whether or not to *Tolerate*. In such a case, the game is said to be *dynamic with imperfect information.*

An example is the second invasion of Iraq by the US in 2003. The decision to invade was partly motivated by unsure expectations that Iraq's Saddam Hussein had developed unacceptable weapons of mass destruction. However, after the invasion inspectors could not find any strong evidence that such weapons were ever developed during the years that Iraq was under UN sanctions. In retrospect, the US made a decision to invade not knowing for certain whether or not the weapons had been developed.

The invasion can be regarded as the culmination of a dynamic game where Iraq moved first, followed by the US (see Figure 5). The game tree for it is such that Iraq can choose from among three strategies: *Develop* the weapons, *Not Develop* the weapons or *Comply in Full* with UN sanctions and resolutions. The third strategy – *Comply in Full* – includes not just avoiding the weapons development but also

Figure 5. Imperfect Information: Iraq vs. US



providing full disclosure of all military and economic activities in order to avoid reprisals. If this strategy is pursued, the US does not have to make a move and the game ends. For any of the others, the US can choose from either *Invade Iraq or Not Invade*. An oval is drawn around the options of the US in order to reflect its uncertainty about which strategy has been chosen by Iraq.

The payoffs are point rankings that might have reflected each country's national interests. Iraq is regarded as best off if it develops the weapons and the US does not invade (3 points). Its next-ranked outcome is not developing the weapons while invaded (2 points): for the destruction caused by the war is compensated by vindication in the international community. Next is developing the weapons despite a subsequent invasion (1 point). While this leads to destroyed weapons, the prospect of it is not nearly as severe as the loss of self-governance implied by complying in full (0 points). The payoffs suggest that Iraq will not develop the weapons if the US were to invade (3>2) and will develop if the US did not invade (4>1).

The US is regarded as obtaining a favourable outcome if Iraq complies with all UN sanctions and resolutions (3 points). Also favourable is the event pertaining to Iraq not developing the weapons and itself not having to invade (2 points). Both of these outcomes enhance its stature. Next preferred is the necessary evil of invading Iraq given that Iraq has developed the weapons (1 point). For this outcome, its war cost is regarded as justified by the added benefit of disarming what it perceives to be a malevolent dictator. Regarded as unsatisfactory is Iraq developing the weapons and itself not invading (0 points), an outcome it considers an admission of defeat. Listed as an unknown R, is the rank of the outcome that eventually materialized: that of Iraq not developing the weapons and the US deciding to invade.

Subjective probabilities as beliefs

Suppose that the game is at the point where Iraq has not complied in full with UN resolutions. However, the US does not know anything more. On what basis could the US eventually have decided upon an invasion? A useful way to begin is to conjecture that the US had in mind a subjective probability, p, associated with Iraq having secretly developed the weapons. This subjective probability, pertaining to what the initiating player (Iraq) may have chosen, is known as the responding player's belief. If this *belief* were to be combined with an acceptable rank, an invasion can be justified as having the highest expected payoff.

For example, suppose that the US ranked *Not Develop*, Invade as 1 point, (i.e. R=1), a value lower than the rank of 2 points for *Not Develop, Not Invade*. At the same time, suppose that the US also had a (probability) belief of 60 percent that Iraq had indeed developed the weapons (p=0.6). Then the *expected* payoffs for the US can be calculated using the beliefs as weights. For a decision to *Invade,* the expected payoff is 1 point (i.e. 0.6(1)+0.4(1) = 1). For *Not Invade*, the expected payoff is 0.8 points (i.e. 0.6(0)+0.4(2) = 0.8). The higher of the expected payoffs is thus for an invasion.

Accordingly, the values for the US's ranking of an invasion, R, are critically related to its belief, p. Given a fixed value for one of these variables, a high value for the other becomes a compelling reason for an invasion. A relationship between the two variables can be found by comparing the expected payoff of an invasion against the one for not invading, and then characterizing the values for R. If it were to invade, the US's expected payoff depends upon its belief and its ranking of an invasion, and this expected payoff is equal to the (points) expression: p(1)+(1-p)(R). (By definition of a probability, (1-p) is the US's belief that Iraq did not develop the weapons.) If it were *not* to invade, its expected payoff is equal to p(0)+(1-p)(2).

From comparing the two expected payoffs, the US would be expected to invade only if its expected payoff from doing so, p(1)+(1-p)(R), were greater than the one for *not* invading, [(1-p)(2)]. From this condition emerges a condition for the rank: R must be greater than the ratio given by (2-3p)/(1-p). For example, R must be at least 2 points (i.e. greater than the rank of *Not Develop, Not Invade)* if the US's belief were zero (i.e. if p=0). A rank greater than 1 point is sufficient if the belief were fifty-fifty (i.e. if p=0.5). A rank greater than 0 is sufficient if the US were *two-thirds sure* that Iraq had developed the weapons (i.e. if p=2/3).

The eventual outcome of the game *(Not Develop, Invade)* can thus be interpreted as the US's best response to an unknown Iraqi decision based upon its belief and ranking of an invasion. That Iraq might have anticipated such an invasion would then have been a compelling-enough reason for it to refrain from developing the weapons. The outcome is analyzed differently from that of a conventional Nash equilibrium because the payoffs of the responding player (the US) are accompanied by a belief about an uncertain precedent. The belief is just as important as the payoffs in terms of projecting an equilibrium that was consistent with what happened.

Perfect Bayesian equilibrium

The equilibrium outcome *(Not Develop, Invade)* is an example of a Perfect Bayesian equilibrium which can be defined as strategies chosen for a dynamic game of imperfect information where players form beliefs about unknown previous decisions. The inclusion of beliefs makes the equilibrium distinctive from that of either a Nash or a sub-game-Perfect Nash equilibrium. The term Bayesian derives from Bayes's theorem, which in statistics describes the solution for a conditional probability given some knowledge of the likelihood of preceding events. Cast in terms of this theorem, the US's belief about Iraq's unknown decision is a conditional probability derived from knowing Iraq's non-compliance with UN resolutions and its apparent history of having used such weapons in the past.

Conclusion

The preceding examples have all been founded on the assumptions that players are rational, self-interested and informed. Also, they ignore other important player considerations such as ethical commitments. The reality of policy making of course is much more complex, for one (or more) of these assumptions may not apply. Other social sciences are more acknowledging of this reality than is the science of economics upon which game theory is based.

But there are helpful developments from within the theory itself. In contravening *evolutionary* games, there is no presumption that the players are rational (Kahneman 2003). Strategies are instead compelled by genetic tendency. Those that result in superior rewards have a greater chance of being passed on to future offspring. The recipients in turn become so dominant in number that mutant strategies are unable to invade successful ones. The outcomes that eventually persist are instead defined as evolutionary-stable equilibrium solutions, rather than as Nash solutions, precisely because they are thought of as being driven by Darwinian self-selection rather than by rational intentions.

The predictive implications of such evolutionary games remain unexplored. But if genetic tendency were instead organizational predisposition, and if predisposition were acquired from strategies that were previously successful, then the decisions of organizations and nation-states can still be game-theoretic even without the theory's usual assumptions.

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