

Simple Game Theoretic Considerations for Environmental Problems

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Abstract

This paper uses elementary arguments from game theory to consider the interaction between protagonists involved in environmental problems. It is argued that ‘generic’ global problems often result in a Prisoner’s dilemma, with the *status quo* as equilibrium. Also, a brief consideration of the Kyoto Protocol confirms that if developing countries were asked to join, their dominant strategy would be to refuse, and that the recent withdrawal of the United States leaves other signatories in a precarious position. Finally, the paper focuses on a specific recent project, the CO₂ Ocean Sequestration Field Experiment, to demonstrate that many of the difficulties hampering the resolution of global-scale environmental problems have to be dealt with at local levels as well.

Key Words: game theory, environmental problems, Kyoto Protocol, CO₂ Ocean Sequestration Field Experiment

1. Introduction

Game theory has been developed by mathematicians as a rational framework for a broad variety of interactions between *players*. Historically speaking, the development of the theory of probability by Blaise Pascal in the 17th Century may have been the earliest attempt to provide a mathematical foundation for games of chance. That a devout Jansenist like Pascal devoted some of his genius for what often carries negative social connotations is interesting in itself, but more importantly shows how a serious theoretical approach may be given to games perhaps frivolous *per se*. Today, game theory is a thriving and challenging field of knowledge widely applied in many areas of practical interest (economics, strategy etc). Since it ultimately deals with human behavior, it may appear as just another attempt to reduce human beings to objects. Clearly, all caveats applicable to science and technology when they are related to human reality hold for game theory.

It is well beyond the scope of this paper to dwell into even moderately advanced aspects of game the-

ory. Instead, some elementary but essential features will be used in a particular context to tentatively shed a different light on problems of great concern. Readers unfamiliar with game theory are encouraged to acquire some background with a basic text (e.g. Dixit and Skeath, 1999.) Those seeking advanced applications of game-theoretical knowledge in the analysis of environmental issues can consult several recent publications (e.g. Carraro and Filar, 1995; Hanley and Folmer, 1998.)

The next Section will present elementary aspects of game theory that are sufficient throughout the paper. In Section 3.0, a ‘generic’ environmental problem will be defined, and its solution will be discussed. Section 4.0 will pay closer attention to the Kyoto Protocol, while Section 5.0 will focus instead on the tribulations of a specific scientific project aimed at advancing the state-of-knowledge on the oceanic carbon sink.

2. Background

A game is defined as an interaction between rational players. Players can choose between strategies. To any possible outcome of the game, different payoffs are assigned to each player. It would be trivial to just postulate that *rational* players should seek to maximize their individual payoffs. One fundamental point of game theory is that players should seek to do so *according to their perception of other players’* moves. We will give two short examples below.

The first one illustrates a simultaneous-move game, and is none other than the famous *Prisoner’s dilemma*. Two criminals in their twenties are caught for a string of robberies, but the evidence against them for the most serious charges is rather weak. In fact, they would likely be handed a short jail term (e.g. 5 years) if none of them confesses to anything. Each is interrogated separately and offered a deal: to reveal the full extent of their criminal activities and receive a lenient treatment, or to keep silent with the risk that the other prisoner may confess. If both cooperate, the prosecutor would seek a 10 year prison term. If only one talks, he would receive a 2 year sentence (as a reward for his crucial testimony), but his resilient partner would serve 20 years behind bars.

The game typically is represented as a two-by-two table, shown below as **Table 1** (two is the number of available strategies to each player, and a table, i.e. a planar artifact is possible because only two players are involved.). The rows and columns in Table 1 are filled with pairs of outcomes for the players, their payoffs in game theory terminology; the *First Prisoner’s* payoffs are shown as left-hand-side entries.

The *Second Prisoner* first assumes that his partner cooperates (first row): it then is clear that *he himself* is better off cooperating (upper left corner). He next assumes that the *First Prisoner* remains silent (second row); in this case as well, he receives the lightest sentence by cooperating (lower left corner). Thus, the *Second Prisoner’s* rational attitude is always to cooperate.

Table 1. The payoff table for a typical version of the *Prisoner’s dilemma* (left-hand-side payoff is assigned to row player).

		<i>Second Prisoner</i>	
		Cooperate	Keep silent
<i>First Prisoner</i>	Cooperate	10 years, 10 years	2 years, 20 years
	Keep silent	20 years, 2 years	5 years, 5 years

Applying the same reasoning from the vantage point of the *First Prisoner*, we would easily conclude that he too should choose to cooperate. For this game, a convergence of strategic choices therefore exists and is [Cooperate, cooperate]; this is known as a Nash equilibrium for the game, thus named after the American mathematician John Nash. The outcome is a *dilemma* inasmuch as it does not represent the best possibility for the players, namely [Keep silent, keep silent].

The game illustrates well how players choose their moves given their expectations of other players' behavior. It should be noted that the ordering of different payoffs is important, while the precise values are not (e.g. the precise length of the jail sentences in the above game): one simply could have *ranked* outcomes as 1, 2, 3 and 4, for example; this is true as long as one deals with *pure strategies* (in repetitive games, players may choose to apply a probabilistic approach where they *mix* strategies; payoff values then become important). At any rate, the worth of game theory always is highly dependent on the careful evaluation of payoffs beforehand.

The next example illustrates a sequential-move game between *Player 1*, who alone starts the game, and *Player 2*, who alone ends the game. To show how flexible game theory is, we actually construct an example where *the same person* at two different stages of his/her life plays the game: *Player 1* is 20 years old, and *Player 2* 60 years old, while the person represented by both players is expected to pass away at 70. The game itself is a version of *Pascal's wager* formulated in a game theoretic context. *Pascal's wager* simply states that although the existence of an afterlife may be questionable, possible rewards for a righteous life in a hypothetical afterlife are too great to risk losing. Although *rational*, one can seriously challenge the effectiveness of this argument in matters of faith and moral conduct, which is a reminder of an earlier caveat about the complexity of human reality. Yet, we now proceed to formulate our game more precisely.

We surmise that the probability that an afterlife exists is 50%. If it does exist, rewards for those who led a righteous life are huge, say 1,000,000 on an arbitrary scale ("Heaven"); for those who were righteous most of their life, but abandoned the right path, as well as for those who spent many carefree years before amending their ways, the afterlife prize is assumed to be the same and substantial, e.g. 100,000 ("Purgatory"); those with an entirely carefree life would receive nothing ("Hell"). Meanwhile, there are "earthly" benefits associated with a carefree life, i.e. 1,000 per year. We are now in a position to construct a game tree, shown in **Figure 1**.

Payoffs at the end of the game ("Death") are shown on the right-hand side. Please note that with two *distinct Players*, payoffs would be represented by *pairs of values* as in the previous simultaneous-move game example. Values are the sum of earthly benefits that are certain, and of heavenly rewards that are 50% probable.

This type of game is analyzed backward, starting with the move contemplated by *Player 2* (at age 60). It is obvious that in all cases, *Player 2* is better off choosing a righteous path for his expected 10 years' life left, since 500,000 exceeds 60,000 and 90,000 is larger than 50,000. *Given that fact*, *Player 1* (at age 20) should rationally choose a lifestyle leading to the greater payoff, between 500,000 and 90,000, i.e. a righteous life as well. In this example, a completely righteous life represents the rollback equilibrium of the game.

It is important to note that the order of playing may be very important in a sequential-move game (with distinct players). Unlike the case of a genuine simultaneous-move game, information about initial moves is known to the players of subsequent moves. For example, if the *Second Prisoner* of the simultaneous-game example above knew about the *First Prisoner's* move (i.e. if the game were sequential),

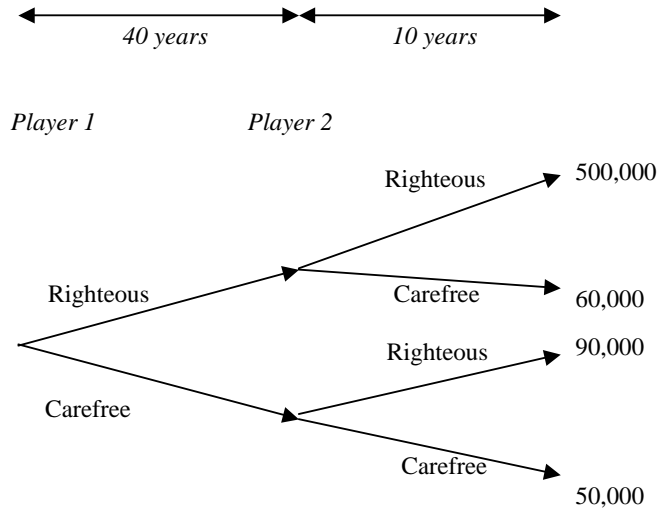


Figure 1. The game tree for a game-theoretic version of *Pascal's wager*.

there would be no *dilemma* as can easily be verified: the rollback equilibrium would be for both to keep silent, and the outcome would be optimal (5 years' sentence each).

3. An Ideological Conflict and a Challenge

Let us consider two very broad classes of players interacting in a game with simultaneous moves. Although members of such classes would generally act independently, this great complication is left for further analysis when the specifics of a given situation would be known. It is equally true that in reality, these classes of players would interact repeatedly. For the time being, however, only a one-move game is being considered.

The first class of players can be labeled as the *Developers*. It consists of public and private groups - companies, businesses, government agencies etc. - which for a number of reasons (profit, market share, strategic security, policy implementation...) seek to extract important resources, such as oil, coal, mineral ore, or to simply develop undisturbed environments for expanded human utilization. In all cases, these activities are potentially rewarding for the *Developers*, but also detrimental for the affected environments.

The second class of players will be designated as the *Environmentalists*. These can be grassroots activists, concerned individuals, government agencies etc. Their role is primarily to protect the environment and act as watchdogs. Historically, they have emerged as a class because of severe environmental damage caused by the activities of the *Developers*. Although a great deal of this environmental degradation may have occurred inadvertently over a long period of time, it has created a basic lack of trust between *Environmentalists* and *Developers*, and has resulted in a legal framework where disputes between the two classes may be arbitrated.

We now turn to a one-time conflict between the two classes. Even though the argument that will be made is thought to be rather general, and should be applicable to many situations insofar as a simplistic

approach can suffice, let us assume that the object at stake is the wish of the *Developers* to access greater resources of fossil fuels. After all, fossil fuels are not only at the root of modern development, but they also have been a source of widespread conflicts and epitomize a fundamental lack of sustainability in our societies. The *Developers* have two basic strategies:

A: use more fossil fuels but also do something good for the environment

B: use more fossil fuels without paying much attention to the environment

It can be argued that many more possibilities than A and B should be considered. In particular, there is no provision for the *Developers* to fail in their goal to access greater resources of fossil fuels. Whether this stance is too cynical or not, variations on the theme presented here are almost limitless, and can be investigated later. What the *Developers* could do for the environment under Strategy A, might include compensatory development of renewable energy, restoration of damaged ecosystems, expanded environmental research, inclusion of enhanced fossil fuel production safeguards etc. Aside from the very important issues of *future* interactions with the *Environmentalists*, and of public perception in general, the positive environmental mitigation measures contemplated by the *Developers* are costly in a basic and perhaps short-term sense. The extent of such costs is relatively greater in a competitive context *within* the class (e.g. with nations and companies competing with one another).

Faced with this hypothetical conflict, *Environmentalists* have two elementary strategies as well:

a: vigorously oppose the use of more fossil fuels

b: oppose the use of more fossil fuels, but allow for concessions

The latent inflexibility in these choices, whereby using more fossil fuels will be opposed in principle, is a natural match to the narrow spectrum of strategies contemplated by the *Developers*. Concessions under Strategy b could be a moderate stance on certain permitting issues, which would save time or diminish risks of litigation for the *Developers*. The intent of concessions by the *Environmentalists* would be to coax the *Developers* to ‘do something good for the environment’, while perhaps increasing their appeal to a broader membership. Making concessions may be costly for the *Environmentalists*’ credibility, however, especially in relative terms when members of the class compete with one another. Thus, while concessions naturally seem to make more sense in a context of successive-move games, especially if a negotiation process is allowed to take place, the simultaneous-move context captures well the fact that *internal competition* within each player class introduces a great deal of uncertainty and risk. In this sense, one can anticipate internal competition to radicalize the players’ positions, which in turn may prevent the establishment of trust. Such radicalization may not only proceed within each group of players as a result of some internal competition, but through a positive feedback mechanism, radicalization in one group will also reinforce the tendency in the other group: after all, it may only take *one* aggressive *Developer* to cause severe or irreversible damage to a given environment, while it may only take *one* hard-line *Environmentalist* to block an ongoing permitting process.

We may now build a 2×2 payoff table for the game. To simplify, numbers from 1 to 4 will be used to qualitatively rank possible outcomes for each class of players; higher values represent more favorable payoffs. The left-hand-side numbers will indicate the *Developers*’ expected ‘return’ and consequently, the right-hand-side values represent the *Environmentalists*’ expected ‘reward’.

For the *Developers*, the best outcome is to wrest concessions from the *Environmentalists* while doing nothing substantial for the environment. Of course, this combination of respective strategies [B, b] clearly is the worst for the *Environmentalists*. By the same token, it is obvious that the *Environmentalists* would prefer that something good were done for the environment without conceding

anything to the *Developers*, i.e. a situation corresponding to scenario [A, a]. Such positions allow the diagonal terms of the payoff table to be filled, and express a high degree of polarization between the two player classes since ‘what is best for one group is worst for the other’ and vice-versa. This state of affairs led us to use the obsolete-sounding Section heading ‘ideological conflict’, because bridging the gap between the players may truly be a daunting task. As a matter of fact, it can be shown that the outcome of the game is already determined with the two diagonal entries set at (1, 4) and (4, 1), respectively for the upper-left and lower-right cells of the table. For the sake of completeness, the table will, however, be completed.

To assign payoff values to the off-diagonal cells, we will take a non-cynical stance, perhaps for a change. In other words, we will not doubt that *Environmentalists* would rather see something good done for the environment even if it costs them making concessions. Therefore, scenario [A, b] is more valuable than scenario [B, a]. We will also assume that the *Developers* sufficiently value concessions from the *Environmentalists* to be ready to do something good for the environment in return for such concessions. In other words, the two classes of players have exactly the same ranking for the two scenarios [A, b] and [B, a]. This convergence of good will, however, will not suffice to bring out [A, b] when the game is played out.

The payoff table for the game is shown in **Table 2**. It is immediately apparent that each group of players has a dominant strategy. Whether the *Environmentalists* allow concessions or not, by selecting either Strategy available to them, the *Developers* should always pick Strategy B in response. Conversely, no matter what the *Developers* may choose to do, between Strategies A and B, the *Environmentalists* should always prefer Strategy a in response. The Nash equilibrium of the game is therefore the *status quo* [B, a] with the pair of mediocre payoffs (2, 2). The dominant strategy for the *Developers* is to do nothing for the environment, while that for the *Environmentalists* is to vigorously oppose the use of more fossil fuels without making any concession. As formulated, the game is a *Prisoner’s dilemma* since the outcome of the game clearly is not ‘the best outcome for everyone involved’, i.e. [A, b]. In other words, neither class of players obtains from the other what they value most: the *Environmentalists* are left with a damaged environment, while the *Developers* cannot expect any concession and must prepare themselves for litigation and perhaps adverse public opinion.

It cannot be overemphasized that the above approach is very simplistic. Before any ‘game’ is played, the implicit polarization of players in only two groups, their limited choices of ‘bleak’ strategies and the assumption of a purely simultaneous-move game all may be highly questionable. The disturbing result of such an exercise, however, may reveal a more dangerous fracture than we would like to imagine between those whose task is to exploit natural resources and those whose mission is to protect the environment. The fact that game theory at its simplest may show that a degraded environment and acrimonious litigation could constitute the elements of some *equilibrium* is rather disturbing. It presents at

Table 2. Payoff table for a ‘generic’ one-move environmental conflict (left-hand-side payoff is assigned to row player).

		<i>Environmentalists</i>	
		Strategy a	Strategy b
<i>Developers</i>	Strategy A	1, 4	3, 3
	Strategy B	2, 2	4, 1

least all *real* players in this ‘game’ with the challenge of avoiding this purported outcome. Game repetition in general and the assumption of leadership by one or several players in particular are typical mechanisms by which a *Prisoner’s dilemma* may be avoided, though such desired outcome is by no means guaranteed. The issue of leadership is brought up in the next Section..

4. The Kyoto Protocol

We start with the fictitious context of three *identical* parties contemplating the signature of an international treaty aimed at curbing the accumulation of greenhouse gases in the atmosphere. *Identical* means a symmetry in the attitudes of (groups of) *Countries A, B and C* with respect to the potential benefits as well as the costs associated with any commitment to such a treaty. By signing the treaty (and ratifying it if required), a player in this hypothetical game will partially contribute to a better environment, but will also incur significant expenditures.

The nature and magnitude of a *Greenhouse Effect* caused by anthropogenic emissions is such that the environment would not benefit very much if the treaty is signed by only one of the three players. Payoffs corresponding to a damaged environment will be described by three arbitrary levels 1, 2 and 3. The worst outcome of 1 is for a *Country* to be the sole bound signatory to the treaty: in this case, the environment will hardly be better overall while that *Country* would bear a great economic burden; on the other hand, the other two parties would enjoy a relative competitive edge while sharing any improvement of the environment, however small it might be; for them, therefore, a payoff of 3 can be assigned when the ‘other’ *Country* alone has signed the treaty. If no one agrees to the terms of the treaty, obviously no one would spend any resources, although the environment certainly would be the worse off; in this situation, a payoff of 2 can be given to each *Country*.

By symmetry in argumentation, a best possible outcome of 6 for a *Country* would be to be the only party refusing to join the international agreement. In this case, both economic and (substantial) environmental advantages would be reaped; for the other parties, a payoff of 4 would reflect the healthier state of the environment due to their joint commitments, but the slight economic disadvantage that they would suffer for having one party staying out of the treaty. Finally, if everyone participates in the treaty, there would be a level playing field in terms of economic burden and the best possible environment could be preserved; in this case, everyone would get a payoff of 5.

Tables 3 represent the payoff tables for this ‘symmetric’ three-player game, where ‘Yes’ indicates an agreement to the treaty and ‘No’ a refusal to participate. Payoffs are listed as triplets of values respectively assigned to *Countries A, B and C*.

A cell-by-cell inspection reveals that this hypothetical game has no fewer than four equilibria,

Table 3. Payoff tables for a ‘symmetric’ three-player Kyoto Protocol (payoffs are assigned to *A, B, C*, respectively, from left to right).

Country A: Yes

		Country B	
		Yes	No
Country C	Yes	5, 5, 5	4, 6, 4
	No	4, 4, 6	1, 3, 3

Country A: No

		Country B	
		Yes	No
Country C	Yes	6, 4, 4	3, 3, 1
	No	3, 1, 3	2, 2, 2

although three of them *globally* correspond to the same situation. In one case, no *Country* would spend anything for a dismal payoff of (2, 2, 2.) In the remaining three cases, any two *Countries* would commit themselves to the treaty while the third party would enjoy a ‘free ride’; in other words, the three more desirable equilibria all would result in a healthy environment, with a payoff of 4 for the signatories, while ‘allowing’ the non-participating party to enjoy relative economic advantages to boot (and a maximum payoff of 6).

The positive aspect of the *symmetrical* game is that a *commitment* to the treaty by any one of the three players would be sufficient to eliminate the undesirable equilibrium when no one would sign. Unfortunately, the *real* (groups of) players in the Kyoto Protocol analyzed as a game are not symmetrical at all.

Grouping nations in a judicious way may not be easy and certainly is likely to be open to criticism. We will, however, propose a choice based on weight (i.e. the scale of greenhouse gas emissions) and, in a loose sense, ‘philosophy’. Therefore in our choice, *Country A* represents large populous developing nations, *Country B* the United States and *Country C* the bulk of the other wealthiest nations notably including Western Europe and Japan. For an example of a much less simplistic analysis of the Kyoto Protocol and its most recent ‘satellite agreements’, the reader is referred to L schel and Zhang (2002.)

From the outset, the new asymmetric game has to be ‘larger’ than the mere signing of the Kyoto Protocol, since developing nations are exempted from any commitment to the treaty, at least temporarily. This aspect of the Kyoto protocol can in fact be backed up by game theory. For *Country A*, developing has to be the top priority for a long while; its ability to incur substantial and immediate expenses for environmental benefits is obviously very doubtful. With emissions per capita one order of magnitude less than those of the richest nations, *Country A* also holds a significant ‘moral high ground.’ If *Country A* were nevertheless asked to play the game, its payoffs for all possible scenarios would have to reflect such specific circumstances. The maximum reward of 6 would continue to correspond to everyone else signing the Kyoto Protocol, but because of the unbearable drain that compliance would require on its own resources, the next best scenarios would now be when only one other party signs the treaty (payoff of 5) or no one at all (payoff of 4). The ranking of all possibilities if *Country A* were coerced to participate in the Kyoto Protocol would straightforwardly decrease as indicated in the partially-filled payoff **Table 4**.

The reason why *Countries B* and *C* have been left out of the game so far is that, granted that *Country A*’s payoffs have been accurately represented, *Country A*’s dominant strategy is to stay out of the Kyoto Protocol no matter what everyone else decides to do. In other words, only the right-hand-side table is relevant, and the game can now be simplified as involving only two players. It should thus be no won-

Table 4. Partially filled payoff tables for an ‘asymmetric’ three-player Kyoto Protocol extended to developing countries grouped as *Country A* (payoffs are assigned to *A, B, C*, respectively, from left to right).

Country A: Yes

		<i>Country B</i>	
		Yes	No
<i>Country C</i>	Yes	3, ,	2, ,
	No	2, ,	1, ,

Country A: No

		<i>Country B</i>	
		Yes	No
<i>Country C</i>	Yes	6, ,	5, ,
	No	5, ,	4, ,

der why the architects of the Kyoto Protocol crafted a binding treaty that would not implicate developing nations, at least initially. It is very doubtful and it should not be expected that the developing countries' commitment to ... development would soon be allowed to accommodate strong environmental safeguards, as illustrated by the recent international conference on climate change in New Delhi (Honolulu Star Bulletin, 2002c).

We can now turn our attention to the reduced game, being cognizant that a smaller game offers fewer opportunities for commitment.

If *Countries B and C* had the same philosophy regarding the Kyoto Protocol (i.e. toward the need to reduce atmospheric emissions of greenhouse gases), the smaller two-player game would be symmetric. It is straightforward to show that two equilibria would then exist, namely the remnants of the four equilibria of the larger three-player symmetric game: these two possibilities correspond to both *Countries* signing the treaty or to both *Countries* abstaining from participation in the Protocol. For the sake of completeness, the symmetric payoff table is shown in **Table 5**, where the row-and-column order of *Countries B and C* has been switched, with the convention adopted in Section 3.0: the left-hand-side payoffs are assigned to the row player. This symmetric game would be quite nice inasmuch as the commitment by *any* player to sign the Kyoto Protocol would entice the other player to do likewise. Unfortunately, even the reduced game is not symmetric.

Cultural values prevailing in *Countries B and C* strongly affect the payoffs assigned to different scenarios, just as straightforward economic needs remain overwhelming for *Country A*. While member nations in both groups B and C are all comparably wealthy, as measured for instance by GDP per capita (with proper adjustments for currency matters), their attitude toward environmental issues is very divergent, as measured for instance by greenhouse gas emissions per capita. The fact that a North American emits on the average at least twice as much carbon dioxide (CO₂) than his (her) Western European or Japanese counterpart is troublesome from the outset.

Even though such arguments may seem like old clichés, it is undeniable that the United States has built its enormous might and success on a credo of social Darwinism played out over a short history. This can be traced back to the country's Calvinist roots. Thus, a belief in man's ability to adapt to - and to succeed despite - any social and environmental hardship lies at the core of the 'American Dream.' Such collective self-confidence and faith is often scorned as naïveté elsewhere, but the global results achieved by this 'young' nation are nonetheless impressive. Europe and Japan are not foreign to worldwide power and glory, but their optimism has been tested and certainly tempered over a much longer period of time, when some nations grabbed a leadership role while others' might waned; it has often been argued that such optimism was largely shattered by the horrendous conflicts of the 20th Century.

American attitudes certainly do not favor any restrictions placed on economic growth, the paramount measure of personal and overall success, especially if they are imposed through an international legal

Table 5. Payoff tables for a 'symmetric' two-player Kyoto Protocol (left-hand-side payoff is assigned to row player).

		Country C	
		Yes	No
Country B	Yes	4, 4	1, 3
	No	3, 1	2, 2

framework. Thus and for radically different reasons, the United States often aligns its position with that of developing nations, and less surprisingly with that of oil producing (OPEC) countries when global environmental issues are on the table. Such political maneuvering was quite clear during the so-called U.N. Johannesburg Earth Summit in 2002, with European Environment Commissioner Margot Wallstrom denouncing the ‘unholy alliance’ of the U.S. and developing countries in watering down a biodiversity pact (Honolulu Star Bulletin 2002a), or with the U.S. and OPEC nations opposing higher targets for renewable energy use (Honolulu Star Bulletin, 2002b.)

The payoffs attributed to *Country B* (the United States) in **Table 6** realistically reflect its adverse attitude toward the Kyoto Protocol. In other words, the country’s priorities warrant that not signing (or not ratifying) the treaty is a dominant strategy. That stance has considerably hardened since the election of George W. Bush in 2000, with the withdrawal of the U.S. from the previous administration’s signature, even though no one envisioned a ratification of the signed treaty by the U.S. Congress as even remotely possible. Interestingly, the principal argument given by the Bush administration for the formal U.S. withdrawal was the exemption granted large developing countries from emission targets, and thus the creation of an ‘uneven playing field.’

The payoffs given *Country C* were only modified to make the signature of the Kyoto Protocol *no less* attractive than not participating, *even in the face of Country B’s dominant strategy*: Japanese and Europeans probably see enough political benefits and perhaps a certain amount of face-saving in signing the treaty to offset the costs of ‘going at it alone.’ This approach gives *Country C* a leadership role if it participates in the Kyoto Protocol, though it is quite a risky situation. As far as the environment is concerned, it is likely that the benefits of the Kyoto Protocol may prove insufficient unless a more critical mass of signatories can be reached (and granted that present signatories are able to meet their binding targets under the Protocol!)

This simple look at the Kyoto Protocol using elementary notions of game theory could be seen as a vain exercise since the proposed payoff tables are qualitative and based on *fait accompli*: different countries’ positions today are *given*, and not the results of a *future* one-move game (in other words, the game has already been played.) The cursory analysis, however, confirms the extraordinary difficulties lying ahead if any real progress should be achieved in curbing atmospheric emissions of greenhouse gases. A very real challenge is to find ways to overcome the negative attitude of the U.S., since it is believed to be deeply rooted in that nation’s cultural values. One great hope rests with the design of reward mechanisms that would strongly appeal to American ideals, such as tradable carbon emission permits. Needless to say, such ideas have been aggressively pursued, but will be dauntingly difficult to implement.

After considering game theory on a very global scale, the next Section will examine how strategic moves that deeply affected a small environmental project could be cast in a game theoretic framework.

Table 6. Payoff tables for a ‘realistic’ two-player Kyoto Protocol (left-hand-side payoff is assigned to row player).

		<i>Country C</i>	
		Yes	No
<i>Country B</i>	Yes	2, 4	1, 3
	No	4, 2	3, 2

5. Strategic Moves in a Small Project

5.1. Background

This Section coincidentally deals with a project launched in Kyoto in December 1997 under the auspices of the Climate Technology Initiative (CTI.) This modest international scientific research *Field Experiment* (referred to as the *Field Experiment* below) was designed to investigate the behavior of CO₂ injected into the deep ocean. It would have addressed some of the many questions related to the concept of CO₂ Ocean Sequestration. Succinct information on the initial parameters of the *Field Experiment* and difficulties encountered in its early years can be found in Nihous (2003) and de Figueiredo et al. (2003.) In the spring of 1998, the project was first sited along the Kona Coast of the Big Island of Hawaii, in the Ocean Research Corridor of the Natural Energy Laboratory of Hawaii Authority (NELHA.) At that time, it was envisioned that the CO₂ storage facility would be land-based, with a small seafloor-mounted pipeline reaching the injection water depth of 800 m from the shoreline. Public concerns about the project first surfaced in the local press in March 1999.

5.2. A surprising proposal (May 2000)

After more than a year of sustained opposition to the project, two prominent activists based on the island of Maui made a surprising proposal to the project team. They offered to join the project's Technical Committee (TC) in order to offer more effective advice in the areas of environmental conservation and Hawaiian native rights, respectively. Their only request was to be provided with *ad hoc* help if and when TC membership entailed substantial expenses, as with international travel. Per se, the possibility of cooperation at a modest cost, rather than the pursuit of a bitter debate, was attractive to a few project participants, especially among those dealing with the problem 'head-on' in Hawaii. Already, the TC had recognized the need to expand its membership with the addition of expert benthic biologists.

Unfortunately, the element of surprise in the activists' proposal was the result of previous lengthy and frustrating argumentation between the two sides over more than a year. In particular, the team's technical and scientific expertise, used to great lengths in establishing that the *Field Experiment* would not be harmful to the local environment, essentially was flouted. This attitude particularly hurt researchers from the academic sector who are routinely held to rigorous standards, without being alien to sometimes bitter debate. In other words, earlier interaction could bring considerable doubt about the wisdom of accepting the two activists within the TC. The implicit hope that their inclusion suddenly would boost cooperation lacked credibility, while the risk that many *other* opponents could still hamper project execution was substantial.

The *Project* (participants) could accept or turn down the *Activists'* proposal, following one of two obvious strategies. At the same time, the *Activists* might or might not cooperate in either case, and pursue their adamant opposition. In a game-theoretic context, the *Project's* payoffs can be rated from 1 to 4 exactly as for the *Developers* in the generic case of Section 3.0. This choice results from an overall preference for the *Activists'* cooperation, but coupled with a fundamental lack of trust. The worst payoff of 1 corresponds to the fear of a *Trojan horse*, i.e. accepting the *Activists* within the TC only to witness their relentless opposition. Clearly, then, turning down the *Activists'* proposal is a dominant strategy for the *Project*, as shown in **Table 7**. Payoffs for the *Activists* actually need not be specified: as long as $z > t$, which is very likely, a *Prisoner's dilemma* is obtained: the *status quo* [Turn down, Oppose] represents the Nash equilibrium of the game.

Table 7. Partially filled payoff table for a one-move game between *Activists* opposing the *Field Experiment* and *Project* participants (left-hand-side payoff is assigned to row player).

		<i>Activists</i>	
		Oppose	Cooperate
<i>Project</i>	Accept	1, x	3, y
	Turn down	2, z	4, t

Not surprisingly but sadly, the project team rejected the two activists' proposal, and their opposition never abated henceforth.

5.3. A stunning reversal (February 2001)

In March 2000, after an extensive technical and economic evaluation, the project team had decided that project infrastructure would be entirely based offshore of NELHA, with the CO₂ storage facility located on a dynamically-positioned floating vessel. Thus, the small CO₂ delivery pipeline would go straight down to the seafloor without crossing the shallow, high-energy and environmentally sensitive shoreline and reef zones. Moreover, the issue of removing all underwater infrastructure upon completion of the short project was automatically resolved with a configuration based on the ability to pay out and retrieve the pipeline as many times as needed.

This decision was considered by the team to potentially simplify the overall permitting process, while there was some hope that many in the public would appreciate the improvements afforded by the revised design. Clearly enough, however, a move offshore was likely to be exploited by project opponents as a sign that the project could take place anywhere if it relied on a floating ship instead of shore-based infrastructure. For NELHA itself, in the narrowest sense, this could lead to decreased rental revenues, although the project team was ready to pay fees to use the Ocean Research Corridor alone, a practice apparently without precedent at NELHA. The NELHA administration was informed of the design change in a timely manner, but never indicated thereafter that such a change warranted a new submittal of the original application (for NELHA to host the project).

At that juncture, NELHA was standing behind its October 1999 approval to host the project in spite of some local public opposition, while the sponsors of the project in general, and the U.S. Department of Energy (DOE) in particular remained hopeful that such difficulties would be ironed out in time. In the following months, though, the permitting process under the National Environmental Policy Act (NEPA) greatly polarized public opposition, with the publication of a Draft Environmental Assessment (EA) report in August 2000 and the subsequent collection of public comments. This in turn started alarming local politicians. As a matter of fact, the permitting process substantially slowed down and its favorable conclusion became less obvious than ever. By early 2001, the DOE had not yet released a Final EA as well as their official opinion.

In the meantime, the possibility that the project should be relocated had been informally discussed within the project team, though its members remained quite divided on the issue. It is likely that such a discussion would have been known to NELHA. Also, NELHA got a new executive director by the end of 2000, and he was keen on evaluating ongoing issues from a 'fresh' perspective; in particular, it is doubtful that he felt any personal commitment toward the project. He actually never met with anyone directly working for the *Field Experiment*!

The situation culminated in a stunning reversal in February 2001. At the regular monthly Meeting of the NELHA Board of Directors, Board members voted to rescind the authorization for the project to take place in the Ocean Research Corridor. This vote violated the *sunshine law* in effect for public agencies inasmuch as the issue was not slated for a vote on the Meeting's published agenda. Remarkably, the local media was apprised of this decision before the project team itself, and promptly notified them!

It may be interesting to examine this apparent case of 'backstabbing' from the point of view of game theory. It will then be apparent that NELHA acted 'rationally', if not nicely, considering a payoff structure that was credible at the time of their decision. We will initially consider a sequential game where a first player is the *Project* (team) and a second player *NELHA*. The first player must decide whether the project should stay at NELHA or be relocated elsewhere, while the second player must *then* decide to maintain its support of the project or not. Clearly, the strategy of withdrawing support after the project leaves does not make much sense and will be indicated by a dotted line (a "lost" strategy).

In determining payoffs for this game, a maximum value of 3 is assigned to the *Project* team if it decides to leave the NELHA site; a lower value of 2 is given in the case when there is no planned relocation while support from *NELHA* continues. Clearly, the worst scenario for the *Project* members, with a payoff of 1, would correspond to a decision to stay followed by an eviction from the site (i.e. if *NELHA* then rescinds their prior agreement). It should be noted that the ordering of *Project* payoffs for the scenarios [Leaves, ...] and [Stays, Not] perhaps reflects the author's personal opinion in late 2000 and early 2001; in reality, there remained very strong reasons for key *Project* participants to avoid a relocation, from logistical readiness to setting an example in principle (or avoiding a precedent in yielding under public pressure.) The effect of this ordering will be further discussed below. More essential perhaps is the fact that the *NELHA* strategy [..., Rescinds] was essentially unknown, or at least overlooked by the *Project*, which limited their ability to avoid a very embarrassing situation.

From the point of view of *NELHA*, the crucial element is their perception that if the *Project* chose to stay, they would rather rescind their authorization (payoff of 3) than not (payoff of 2). In other words, a breach of loyalty toward *Project* sponsors and participants, even with an evaluation of future possible consequences (retaliation) did not seem so risky to *NELHA* when weighed against the wrath of local activists and politicians. If correct, the ranking of those two payoffs definitely evolved under public pressure; otherwise, it is believed that *NELHA* would not have granted an initial authorization at all in October 1999. Naturally, the worst scenarios for *NELHA* would occur if the *Project* left the site before *NELHA* could make any decision. In this respect, *NELHA* was aware of all strategies available to the *Project* and deemed them credible.

Thus, we can propose the extensive form of the sequential game in **Figure 2**, with a payoff structure that was highly credible in early 2001. Payoffs are shown as pairs with values for the *Project* in the left-hand-side. A rollback analysis shows that *NELHA* would select either [Stays, Rescinds] or (obviously) [Leaves, Not], and that the *Project* would then have picked [Leaves, Not]. This rollback equilibrium obviously is very detrimental to *NELHA*, with a payoff of 1.

It is interesting to verify that reversing the payoffs of 3 and 2 for the *Project alone* or for *NELHA alone* would not alter the outcome of the game (inasmuch as the *Project* recognized the existence of both *NELHA* strategies.) If *all* payoffs of 3 and 2 were switched, however, the rollback equilibrium would correspond to [Stays, Not] with payoffs of (3, 3.) This situation is believed to represent the players' positions in 1999 and early 2000, when neither leaving the site nor rescinding the *NELHA* agree-

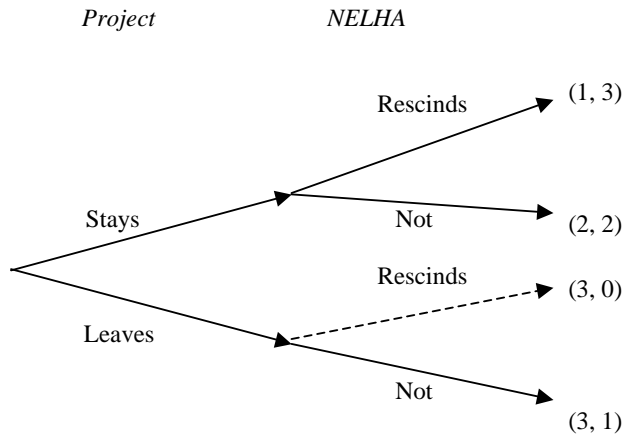


Figure 2. Extensive form (game tree) of the sequential-move game where *Project* participants would first decide whether to relocate the *Field Experiment* away from *NELHA*'s Ocean Research Corridor (*Project*'s payoffs are left-hand-side values).

ment were serious options.

We now consider how *NELHA* did avoid the negative outcome of the previous game by seizing a *first-mover advantage*. It suffices to recast the game with *NELHA* as the first player. It is easy to realize that if *NELHA* does not act on their agreement (i.e. adopt the strategy "Not"), *the playing order is in fact unimportant* (in other words, such a strategy on their part really is equivalent to not playing); therefore, payoffs are the same for the scenarios [Not, Stays] and [Not, Leaves] when *NELHA* plays first as for the scenarios [Stays, Not] and [Leaves, Not], respectively, when the *Project* was the initial player. The case when they would rescind their October 1999 authorization must now be considered.

When *NELHA* was the second player in the previous two-move game and would opt for the strategy "Rescinds" (after the *Project* had initially played "Stays"), it was implicitly assumed that the *Project* then automatically had to "Leave". If not, i.e. if the *Project* had had in fact any choice left, a three-move game would have been needed. This complication was not avoided just to simplify the analysis, but because in early 2001, *NELHA* had no credible reason (or had not received any signal to the contrary) to believe that the *Project* had sufficient time, will power and resources to vigorously contest a 'surprise' decision (to rescind) if they made it. *NELHA* must have been aware of possible future 'retaliations', but did not judge them potentially harmful enough. A 'vigorous contest' could have consisted of immediate and decisive legal action initiated by the *Project*, but events showed that *NELHA* had been correct in their risk assessment. In a sense, their action proved to be 'a successful version of Pearl Harbor.'

Thus, payoffs for the scenario [Rescinds, Leaves] when *NELHA* plays first are the same as for the scenario [Stays, Rescinds] proposed when the *Project* was the first player. The previously 'hidden' case [Rescinds, Stays] is now resurgent, but remains so unlikely that it is shown by dotted lines with very poor payoffs for both players since litigation would be bitter and uncertain.

The corresponding game tree is shown in **Figure 3**, with payoff values for the *Project* in the left-hand-side as before. A rollback analysis shows that the *Project* would select either [Rescinds, Leaves]

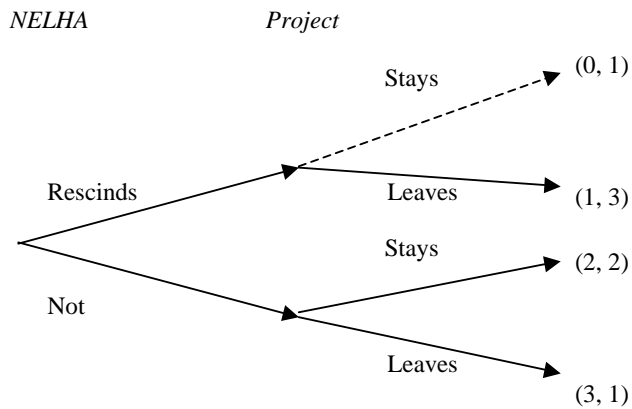


Figure 3. Extensive form (game tree) of the sequential-move game where *NELHA* would first decide whether to rescind its agreement to host the *Field Experiment* in the Ocean Research Corridor (*Project*'s payoffs are left-hand-side values).

or [Not, Leaves], and that *NELHA* would then have picked [Rescinds, Leaves]. This rollback equilibrium obviously is very favorable to *NELHA*, with a payoff of 3. Thus, seizing the initiative as just outlined allowed *NELHA* to reverse payoffs associated with the equilibria of the two versions of essentially the same two-move sequential game.

5.4. Another stunning reversal (August 2002)

As 2001 wore on in the aftermath of *NELHA*'s decision, efforts to hold a field experiment on CO₂ ocean sequestration in Hawaiian waters had to be abandoned. With less time left and a fast decreasing budget, the project team opted to substantially reduce the scope of any possible attempt to release CO₂ in deep waters. Perhaps more importantly, it was decided to move the project to Norway. This country's exceptional marine infrastructure, large output of offshore oil and gas and its expert representation in the TC all favored such an action. One logistical difficulty with this choice, however, stemmed from the roughness of the Norwegian Sea and the relative remoteness of sites with deep enough waters: any field experiment would have to be conducted in the summertime.

By January 2002, an expedited permitting process was completed with Norwegian environmental authorities for the smaller field experiments. More precisely, a permit exemption was granted because of the project's small size, short duration, research goals and benign predicted impact. This was an exceptionally favorable outcome when measured against several frustrating earlier years, though possibly a 'poisoned gift' in retrospect. During the following months, the team frantically prepared the necessary infrastructure to complete the project by the end of September 2002.

Incensed by the permitting exemption granted by the Norwegian government, several high-profile environmental groups launched an appeal process shortly before the summer of 2002. These groups quickly became aware of the project's history and of its failure to be executed in Hawaii. The appeal process proceeded in July and early August 2002, and the Norwegian permitting agency stood firm on its original ruling. Only a final decision by the Minister of Environment himself was necessary to close

the case.

Late in August 2002, the Minister's decision was handed down as another stunning reversal for the project. He revoked the permit to proceed until certain international legal matters could be clarified. Overruling the findings of his own agency, he basically obliterated any realistic possibility for the project to take place in offshore Norwegian waters in 2002, as favorable summer conditions were waning.

The fact that the Minister was about to participate in the U.N. World Environmental Summit in Johannesburg, and that he probably wished to have a 'clean slate' with environmentalists is believed to have weighed heavily in his decision. It is left as an exercise to frame the project's misfortunes in Norway as a game, but similarities with the February 2001 NELHA reversal should be apparent. In particular, the two middle branches of the game tree where NELHA was the first player could easily be representative of the situation, the other branches being merely hypothetical (e.g. dotted lines.) In his brief review of the events in Norway, Haugan (2003) notes that "*a decision [by the Minister] which is illogical, unfair, and counter to all professional advice, turns out to be politically correct.*" This clear-sighted statement lends credibility to a game-theoretic approach where protagonists are *rational players*: political correctness should be in a politician's best interest.

In the last analysis, it is likely that both incarnations of the CO₂ Ocean Sequestration Field Experiment, in Hawaii and in Norway, failed from strategic moves executed by entities with permitting authority for short-term gains and little fear of reprisals. In both instances, project participants suffered from insufficient access to critical information (e.g. a knowledge of the mere *possibility* that a 'game' was being played.)

6. Conclusions

This paper has attempted to show in the simplest way how elementary game theory can frame environmental problems in a revealing light. For example, 'generic' global problems often lead to hard-line positions, with the *status quo* as equilibrium. This is detrimental to the environment, and does not even represent the protagonists' best interests. Avoiding such outcomes poses enormous challenges. These are more specifically apparent when considering the Kyoto Protocol; a game theoretic approach confirms that if developing countries were asked to join, their dominant strategy would be to refuse, and that the recent withdrawal of the United States leaves other signatories in a precarious position. When focusing next on a recent project, the CO₂ Ocean Sequestration Field Experiment, it became clear that many of the difficulties hampering the resolution of global-scale environmental problems have to be dealt with at local levels as well. This linkage is rather explicit in the minutes of a recent panel discussion entitled "Public Outreach and CO₂ Sequestration", reported in Freund (2003.) The similarity of hurdles encountered in a wide spectrum of environmental issues may simply reflect the globalization of modern societies at the beginning of the 21st Century, with the unprecedented development of electronic communications. Perhaps more fundamental to such commonality, however, is the fact that decision makers at all levels tend to act as rational players in interlocking games.

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