Provisions for Noncompliance and Treaty Value: A Game Theoretic Perspective

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We present a game theoretic analysis of the prevention of noncompliance that deals with treaty violations whether they are intentional or not. Game theorists have developed probabilistic trigger schemes to handle such situations. We analyze dispute resolution procedures in subgame perfect trigger terms and suggest alternative designs for the handling of signatory breach. This paper shows that designs can be compared directly by evaluating their ability to keep signatories close to the cooperative goal in the long run. This criterion enables us to highlight the merits of generosity and redress for dispute resolution. Generosity avoids retaliation with certainty so that parties can settle before any retaliatory action is implemented. But if retaliation does come to pass, it is the cost to the victim of punishing the perpetrator that determines a design’s value. Using a simple repeated prisoner’s dilemma framework we find that, in most circumstances, a subgame perfect design that adds concern for the injured party’s redress to the generosity built into a probabilistic trigger scheme yields better treaty value.

There is little consensus on the need for a game theoretic perspective on the design of treaty dispute resolution procedures. Proponents of the managerial school such as Chayes and Chayes (1993, 1995) argue vigorously against the relevance of game theory to treaty enforcement, while authors like Downs, Rocke and Barsoom (1996) disagree with equal passion. Chayes and Chayes rarely interpret observed signatory noncompliance as “willful disobedience” (Chayes and Chayes, 1995:22) while Downs et al. uphold the “dreary expectations” of the realist school; if a treaty requires deep cooperation, noncompliance will arise from the self-interested exploitation of its terms. Following the efforts of Koremenos, Lipson, Snidal and others1 we seek to understand the design of international agreements from a

* The authors, considering their contribution to be equal, have listed their names alphabetically.

1 A full issue of International Organization (Vol. 55, No. 4 autumn 2001) is dedicated to the rational design of institutions. While a number of authors explore rational design verbally, Kydd (2001) and Rosendorff and Milner (2001) adopt more formal approaches. Kydd presents a game theoretic analysis of the trust issues involved in NATO enlargement while Rosendorff and Milner show that, in the presence of political uncertainty over the domestic
rationalist perspective, and we focus on agreements to engage in cooperative activities such as trade, pollution abatement, conservation or disarmament. However, a discussion of the design of dispute resolution procedures requires an assessment of the nature of observed noncompliance, an area that is usefully informed by the managerial school.

From a game theoretic viewpoint the importance of the rules to be applied in case of observed noncompliance lies in their deterrent effect. If the dispute resolution provisions of a treaty are well designed, intentional noncompliance with the terms of the agreement, understood as self-interested and opportunistic exploitation of a treaty’s terms, should never come to pass. Observed noncompliance should then be unintentional. The managerial school recognizes that signatories will occasionally violate the rules unintentionally while realists argue that observed noncompliance is, in some instances at least, the result of an overt and intentional attempt at unilateral exploitation. ² The two interpretations of noncompliance have implications for the design of dispute resolution provisions. If observed noncompliance is intentional the punishment threats in place must be too weak to deter. But if noncompliance can be unintentional, new game theoretic solutions must be developed: the managerial school’s viewpoint has implications for the realist model.

Our objective in this paper is to measure the game theoretic principles that govern the prevention of intentional noncompliance and the handling of unintentional breaches of compliance. Game theory offers a variety of schemes to deter self-interested and opportunistic exploitation, and this raises the issue of design choice. One of the contributions of this paper is to develop a criterion for such choice: In an environment where unintentional noncompliance can occur, the punishment scheme chosen also determines how close to full cooperation signatories are likely to be, on average, at any point in time. This, in turn, determines a value for the treaty. The closer signatories can get to full cooperation, the higher the treaty’s value to them. Our second contribution lies in the use of this criterion to evaluate possible game theoretic designs. We find, in particular, that dispute resolution provisions that propose to build redress for harm done by the deviating signatory into the retaliation scheme, enhance treaty value for a wide range of game parameter values.

The paper is organized as follows: we first revisit the debate between the managerial and realist schools on the relevance of game theory to the handling of noncompliance. We then move on to the game theoretic analysis of current legal prescriptions and the development of alternative schemes. Treaty value, in a context where unintentional noncompliance is possible, is measured against the long run proximity to full cooperation that the dispute resolution mechanisms can ensure. We find current arrangements wanting from the viewpoint of signatory value, and propose that retaliatory schemes that reward the victim as they punish the defector provide signatories with better treaty value.

² We use the term “intentional” in the ordinary English sense of the word. We do not discuss “intentionality” as understood by philosophers of the mind. Philosophers have developed theories of intentionality “as long as philosophy has been with us” (Lyons, 1995:5). However, as Lyons points out “intentionality has little or nothing to do with intentions in the sense of someone having an intention to do something,” (Lyons, 1995:1). For philosophers of the mind, intentionality “refers to that aspect of mental states by which they are directed at, or about, or of states of affairs in the world beyond themselves,” (Searle, 2001:34). The concept goes well beyond that of intent (in ordinary English). The interested reader is referred to authors such as Searle (1995, 2001) or Lyons (1995).
I. Noncompliance: Legal versus Game Theoretic Implications

a. Unintentional Noncompliance: The Game Theoretic Issues

The nature of noncompliance with international agreements is the subject of heated debate. International lawyers such as Chayes and Chayes (1993, 1995) claim that most nation states enter international agreements fully intending to comply. Episodes of noncompliance can occur if treaty texts are unclear, if signatories face unexpected changes in circumstance, or if signatories lack the resources necessary to ensure full compliance. But noncompliance as intentional deviation by self-interested treaty signatories is rarely the case. Chayes, Chayes and Mitchell in a recent volume on environmental treaties refer to “the error of conceptualizing most compliance problems as being due to intentional violations” (Chayes et al., 1998:39). And while these authors would agree that sanctions are entirely appropriate in the face of willful breach, such instances are too rare to justify insistent attention to the design of deterrent punishments.

Downs, Rocke, and Barsoom (1996) strongly disagree with the proponents of what they refer to as the “managerial” school. For Downs et al. there is no problem with compliance when signatories are essentially doing what they would have done in the absence of a formal agreement. There will be little resistance to comply with treaties that do not require much depth of cooperation. Perhaps the fine compliance record cited by Chayes and Chayes (1995) is one that suffers from selection bias Downs et al. suggest: treaties may acquire official status precisely because they are sufficiently shallow to rally agreement among the signatories. While Downs et al. cite a number of arms control and environmental treaties to illustrate lack of depth, they also recognize that some international agreements do require deep cooperation of their signatories. The WTO agreements stand out among those that are “deep” and they come with provisions for the punishment of trade violations. Thus, Downs et al. conclude, where depth is achieved, it becomes important to assess the degree of punishment necessary to achieve deterrence.

Downs et al. argue for strategic deterrence because deep treaties widen the advantage of unilateral defection as is evidenced by “EU payments of subsidies to oilseed producers or US quantitative restrictions on sugar” (Downs et al., 1996:394). By interpreting certain episodes of noncompliance as instances of self-interested and opportunistic deviation, Downs et al. question the ability of treaty enforcement mechanisms to deter. If signatories fail to comply intentionally, enforcement mechanisms must be too weak. The pragmatic solution is in a strengthening of sanctions. But if observed noncompliance is unintentional, no such weakness is necessarily implied. Does the European ban on hormone treated beef reflect an overriding health concern or is it an overt protectionist measure? If intent remains veiled, observed noncompliance cannot be assumed to represent self-interested breach. The very possibility that deviation could be unintentional, and that signatories may not be able to untangle observation from intent, is what raises the more interesting deterrence issue. What should be done when most of the alleged violations of bilateral arms control agreements are “contestable, both as to factual predicate and as to the meaning of applicable treaty norm” (Chayes and Chayes, 1995:99)? For the managerial school, retaliation is not appropriate precisely because the observed noncompliance cannot be clearly identified as an intentional breach. As a result “efforts to negotiate sanction clauses into treaties…are largely a waste of time,” (Chayes et al., 1998:41). Yet, from a realist perspective, the fact that noncompliance could be unintentional has strong implications for the design of “sanction clauses.” And the design of these deterrent punishments affects treaty value for the signatories.

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3 Noncompliance that is the result of changing circumstances is accommodated in a game theoretic framework by Downs and Rocke (1995).
In a perfect world where signatories face a stable environment and intentions are communicated and executed with clarity, the game theorist's provisions for noncompliance are never tested. Just the credible threat of implementation ensures the compliance of all interested parties. Under such circumstances, the design of dispute resolution mechanisms is of little importance as long as the prevention of non-compliant behavior is assured. It is just as good from a deterrence viewpoint to threaten perpetual defection as it is to threaten just enough defection to rob the non-compliant party of any benefit. But if noncompliance can crop up unintentionally, the game theoretic picture changes radically. It is no longer enough to simply deter intentional noncompliance, game theoretic solutions must deal with unintentional deviations in a context where intent is not transparent. As a result, any punishment scheme in place will inevitably be tested and this raises the issue of excessive punishment. Clearly, if punishment came in the form of a grim trigger, one instance of breach, however unintentional, would compromise cooperation forever. Now dispute resolution procedures matter to the game theorist, as they do to the signatories of real world treaties and agreements.

b. Treaty Dispute Resolution Procedures: Some Characteristics

A game theoretic approach to compliance requires that parties be given the power to erase any unilateral advantage from a signatory’s failure to comply. We are therefore interested in international agreements that have provisions for dispute resolution, and allow for retaliation in case of noncompliance. These include several environmental accords as well as trade agreements. The Convention on International Trade in Endangered Species (CITES) and the Montreal Protocol on Substances that Deplete the Ozone Layer include provisions for dispute settlement and allow for retaliatory trade restrictions (Jacobson and Brown Weiss, 1998:527). Trade sanctions can be invoked for noncompliance with Conventions governing the conservation of highly migratory fish stocks. The North American Free Trade Agreement and the World Trade Organization (WTO) agreements specify conditions for retaliation and contain detailed dispute settlement understandings. This list is in no way exhaustive, and the agreements that specify dispute settlement rules and possible sanctions are many. But the combined scope of these agreements points to the relative importance of lawmaker attention to the question of retaliatory sanctions. However, the fact that sanctions are among a treaty’s provisions is less important than the use that signatories make of them. Ultimately, the design features of a dispute resolution procedure show up in the implementation of its terms.

While many treaties specify possible punishments in case of violation, the same agreements explicitly encourage treaty signatories to negotiate bargained solutions to their conflicts, avoiding the resort to sanctions altogether. Article 11 of the Vienna Convention for the Protection of the Ozone Layer states that “in the event of a dispute between Parties concerning the interpretation or application of this Convention, the parties concerned shall seek solution by negotiation.” The United Nations Convention on the Law of the Sea describes dispute resolution procedures that entail binding decisions but uphold “the right of the parties to the dispute to agree to some other procedure for the settlement of such dispute or to reach an amicable settlement.” Trade disputes that concern the World Trade Organization (WTO) can be resolved within a well-developed set of Dispute Settlement Understanding (DSU) provisions. As Cameron and Campbell (1998:20) point out, the DSU offers “clear procedural steps,.... and the availability of meaningful

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4 The Montreal Protocol on Substances that Deplete the Ozone Layer was negotiated under the framework of this treaty in 1987 (Brown Weiss, 1998).

and significant sanctions.” But states seek WTO panel rulings only if negotiated settlement fails.

Busch and Reinhardt (2001:158) estimate that “fully three fifths of all (WTO) disputes end prior to a panel ruling, and most of these without a request for a panel ever being made.” To date, of the 204 complaints that have been filed with the WTO since 1995, punishing trade restrictions have been imposed on the defendant in only two cases. Retaliatory measures were imposed on the EU in the Bananas case in which several Latin American countries and the United States complained about the EU banana regime that places very strict quotas on bananas from countries other than certain African, Caribbean and Pacific states. The United States retaliated against the European Union’s ban on the importation of hormone treated beef, unilaterally in 1989, and again in 1999, after an appeal panel judgment of EU infringement of WTO rules. While sanctions have been threatened for noncompliance with environmental accords, none have been implemented within strict treaty provisions. Nevertheless, the United States did unilaterally impose sanctions on Taiwan in relation to trade in endangered Rhino horns. Overall, then, the implementation of dispute resolution provisions reveals the strong reluctance to impose sanctions highlighted by Chayes and Chayes (1995).

The prevalence of settlement as an outcome of treaty compliance disputes is typically viewed with optimism. Hudec (1999:26), comparing WTO dispute data before and after the implementation of the DSU, notes that the rate of panel formation is lower after 1995 and offers as one possible explanation that the binding nature of rulings under the new DSU has “persuaded more governments to remove illegal practices voluntarily.” The effectiveness of the regime is here measured against the willingness of signatories to settle disputes out of court, a viewpoint that is shared by scholars and officials alike. But shouldn’t success be measured by governments’ increasing willingness to avoid illegal practices in the first place? Settlement provides the perpetrator with the opportunity to simply reverse the illegal act or, temporarily, offer compensating trade concessions to the plaintiff so that the overall level of trade openness required by the WTO agreements is restored on average. A settled outcome need not impose any costs on the perpetrator for having deviated from the agreement in the first place. If settlement is most likely, then the slim possibility of retaliatory punishment must involve dire consequences indeed for dispute resolution procedures to ensure deterrence. What is deemed a success from the legal viewpoint may in fact mask a failure of deterrence. A game theoretic analysis would want the threat of retaliation to prevent noncompliance. In a legal approach, the threat of retaliation serves to encourage negotiated settlement.

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6 European Communities-Regime for the Importation Sale and Distribution of Bananas WT/DS27.
8 The U.S. threatened China with trade sanctions for continued traffic in rhino horns and tiger bone in 1993, and imposed trade sanctions on Taiwan in April 1994. The sanctions on Taiwan were lifted in June 1995 (www.glo.gov.tw). The US also threatened to impose trade sanctions on Japan for its trade in endangered hawksbill sea turtles in 1991. While these threats and sanctions were CITES related, they were undertaken under the Pelley Agreement that allows the USTR to restrict trade in wildlife products originating from a country suspected of noncompliance with an international regime such as CITES (Glennon and Stuart, 1998).
9 WTO Director Michael Moore (Moore, 2000) points out that “settlement...is the key principle” without which “disputes would drag on much longer (and) have a destabilizing effect on international trade.”
10 Rosendorff (2001) points out the negotiated settlement of compensation in case of noncompliance with WTO rules is actually preferred by the signatories as long as compensation does not erase the net benefit from unilateral defection, or prove more costly than the consequences of retaliation. This, of course, explains why signatories would settle disputes using the compensation principle but it remains that this option does not deter the signatories from deviating in the first place.
The fact that retaliation harms both parties is a clear and widely recognized impediment to its implementation. Chayes and Chayes (1995:2) cite the cost of sanctions for treaty violations as one of the many strikes against them. And these authors point to the costs incurred by the sanctioning as well as the sanctioned states. Indeed, redress, or the compensation of the injured party for the cost incurred in implementing the retaliation, is not built in. For some, the cost of retaliation for the injured party will actually prevent recourse to it, a viewpoint that speaks to the very credibility of the threat of punishment. In the United States-Tax Treatment for Foreign Sales Corporations case the European Union is complaining that the tax advantages for US firms exporting through so called foreign sales corporations could amount to a $4 billion trade advantage. But in 2000, when the case first came to a fore, the United States was hopeful that a settlement would emerge: “one of the things that could drive the EU to settle the case instead of letting it escalate to trade retaliation is the magnitude of the case. There is no way the EU could institute a retaliation of that size without hurting the economic interests of its own industries” (Inside US Trade, March 24, 2000). Can redress be built into the strategic design of an international agreement without compromising its value to the signatories? This is what a game theoretic analysis will reveal. In summary, the differences between the legal and game theoretic approaches to noncompliance are shown in Table 1.

Settlement is the primary remedy in trade disputes from the legal viewpoint and its frequency is touted as a measure of the success of dispute resolution procedures. How then should game theory measure success? With costly punishment as the primary remedy it is not the frequency of punishment but rather its infrequency that will contribute to the success of dispute resolution rules from a game theoretic viewpoint. One of the contributions of this paper is to measure the value to signatories of adopting various possible game theoretic principles in the resolution of disputes. We will argue that punishment schemes that deter intentional transgression in an environment where intent is not transparent have a value that can be measured by the long run proximity to cooperation that signatories enjoy. Indeed, punishment of observed deviation will pull treaty members away from the desired level of mutual cooperation and reduce the value of the agreement to the signatories. But the extent to which deterrent punishment draws players away from full cooperation varies widely from scheme to scheme. Our goal in what follows is to highlight the best game theoretic approaches to deterrence from the viewpoint of long run signatory value.

TABLE 1. Comparing Legal and Game Theoretic Dispute Resolution: Highlights

<table>
<thead>
<tr>
<th>Game Theory</th>
<th>Legal Dispute Settlement</th>
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</thead>
<tbody>
<tr>
<td>The prevention of noncompliance depends on:</td>
<td>Negotiation and voluntary commitment</td>
</tr>
<tr>
<td>The primary remedy in case of noncompliance is:</td>
<td>Withdrawal of offensive measure or compensation by defendant</td>
</tr>
<tr>
<td>Punishment of the defendant by the plaintiff</td>
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11 United States-Treatment for Foreign Sales Corporations WT/DS108.
12 Article 3.7 of the WTO’s DSU, which is in many ways the most developed treaty dispute settlement understanding, provides the following hierarchy of remedies beginning with the preferred outcome: 1. bilateral settlement, 2. withdrawal of offending acts, 3. compensation, 4. retaliation.
II. A Game Theoretic Framework for Dispute Resolution

The game theoretic analysis that follows seeks to identify design principles. The objective is not to model the enforcement rules of a particular treaty by applying a mathematical mirror to the processes that are legally in place. This has been done successfully by Reinhardt (2001) for the WTO Dispute Settlement Understanding or authors such as Rosendorff and Milner (2001) for escape clauses in trade agreements. Instead our goal is to extract the game theoretic principles that underlie treaty enforcement as they are revealed by signatory experience with disputes and their resolution, and to compare them to alternative institutional principles as they emerge from a game theoretic analysis. We concentrate on situations that are adequately modeled by a Prisoner’s Dilemma since this structure highlights the enforcement issues that arise in cooperative agreements. With this commentary in mind we turn to our game theoretic framework.

a. The Stage Game, Player Objectives and Long Run Treaty Value

We explore game theoretic options in the context of a simple two-player game where players choose either to cooperate or to defect. We picture pairs of signatories as playing a repeated Prisoner’s Dilemma type game for each product with a payoff structure in the stage game as shown below:

$$\begin{array}{c|cc}
\text{Player 2} & \text{Cooperate } C & \text{Defect } D \\
\hline
\text{Cooperate } C & 0, 0 & -b_1, 1 \\
\text{Defect } D & 1, -b_2 & -c_1, -c_2 \\
\end{array}$$

The utility of cooperation is arbitrarily set to 0, the benefit of unilateral defection is normalized to 1, and the payoffs $-c_i$, and $-b_i$ ($i = 1, 2$) satisfy the dilemma conditions: $b_i > c_i > 0$ and $b_i > 1$. Players engaged in the repetition of this stage game will base their decisions on the expected discounted payoffs (for player $i$ at integer time $t \geq 0$):

$$U_t^i = \sum_{s=0}^{\infty} \omega^s u_t^{i+s}$$

where $u_t^{i+s}$ is the utility that player $i$ will derive at time $(t + s)$ from observed choices and payoff conditions, and $\omega$ is the discount factor.$^{13}$ Utilities $u_t^{i+s}$ in the noisy environment we describe are expectations that result from player intentions, the utility parameters in Table 2 and the probability that noise distorts them. Table 5 works out the specific form of these utilities given the noise model that we describe below.

Our discussion of compliance with international agreements highlights the possibility of a signatory’s unintentional defection. Intent and observation may not coincide but it is difficult to establish a signatory’s true intent. As Chayes and Chayes (1995:99) point out “the question whether the Soviets were or were not improperly encrypting telemetry on missile tests turned on debatable technical assessments and analysis.” We formalize this situation as follows: the observation of player $i$’s move $x_i \in \{C, D\}$ reflects this player’s intent with likelihood $(1 - \omega)$. But with some

$^{13}$ We assume that signatory utility parameter remain constant over time and concentrate on the design features of punishment schemes. Relaxes this assumption requires consideration of future renegotiation and leads to the choice of a finite duration for the agreement. This aspect is examined by Koremenos, 2001.
probability $e$, observation and intent do not coincide. Thus player $i$, with likelihood $e$, will be observed to defect while he intended to cooperate. The source of this observed noncompliance could be player $j$'s misperception or player $i$'s attempt at managing the complex network of domestic and international regulation. It could be the result of a changing environment that leads player $i$ to inadvertent defection, or it could be the accidental result of a faulty communication within the institutions that intervene in the regulation of international transactions.

It is important to note that parameter $e$ is not, in and of itself, a model of player intent. Instead it reflects the frequency with which a signatory will be observed to defect when he intended to cooperate. The origin of $e$ is statistical: of all the transactions that are undertaken under the umbrella of a treaty's terms, a proportion $e$ may not fall within the strict letter of the law. This is because signatories may not always be successful in translating an intention to abide by the treaty's terms into full compliance. For example, competing health and safety considerations in Europe can lead to the observed deviation from WTO rules in the beef hormone case while European intent, certainly in its public expression, is to abide by WTO rules. At the same time, European attention to health and safety considerations does not consistently lead to noncompliance. Rather our modeling assumption is that the causal relationship between intent and observed compliance has some degree of statistical regularity. The causal link between intent and observed compliance is that of a good marksman: the intention to hit the bull's-eye results in success "much of the time."

Conceptually, if unintentional noncompliance is thought of as a statistical irregularity it simply transpires with likelihood $e$. We could also attempt to mathematically accommodate the detail of the various cases of unintentional noncompliance mentioned but this would not change the substantive analysis that we are about to present. We have therefore chosen to adopt the simplest rendering of unintentional noncompliance. We assume that realization is public and impacts both sides' utilities. The parameter $e$, common to both players, is constant in magnitude through time and independent of prior events and across players. How should players respond to each other's observed moves under such circumstances? At issue is their choice of strategy.

The basic tenet of game theoretic rationality is that players behave in order to achieve their best objective and assume similar behavior on the part of others. But there are subtle issues beneath this proposition. When engaged in a mixed motive game, the best that a player can achieve is the payoff to mutual cooperation as long as neither party exploits the other by defecting unilaterally. One of the purposes of strategy is therefore to prevent such illegal defection by threatening appropriate punishment. But the noisy environment in which our players operate adds a significant wrinkle to this issue. Each player will inevitably be faced with the other's apparent noncompliance and will therefore need to be poised and ready to implement punishment. Otherwise, the threat of punishment would lack credibility and deterrence would not be achieved. Game theorists have dealt with the credibility issue by requiring that strategy pairs (in a two player game) form a subgame perfect equilibrium (SPE). This means that the strategic plan adopted by each party must be the best possible, given player objectives, and regardless of the circumstances. The strategies that we examine in what follows all, therefore, participate in an SPE. We will also limit our discussion to strategies for which players distinguish a finite set of possible states of the game. Such behavior is often called a Markov strategy because it results in a pattern of movement akin to that of a Markov chain. Well-known strategies such as triggers are Markov strategies. Indeed, classic trigger schemes distinguish between finitely many states of cooperation or punishment, and the rules that govern play when in one of the specified states may depend on the number of turns that the players have spent in punishment mode, but any history prior to the triggering is irrelevant. Our
exclusive consideration of Markov strategies rules out strategies that build on the whole of past history but admits consideration of a history of any length as long as it is finite. The simplification should not be too onerous.\footnote{Although we focus on Markov strategies, and therefore identify Markov Perfect equilibria (MPE), the equilibrium result is not limited to Markov strategies. A signatory cannot do better by deviating from its Markov strategy in an MPE by using a non-Markov strategy. In other words, a MPE is also a SPE within the set of all possible strategies. The reader is referred to Fudenberg and Tirole (1991:513–15) for a more technical discussion of these issues.}

In a noisy environment, any deterrent punishment scheme will eventually be tested. But this very feature is also what distinguishes one strategy from another since strategic choices will have observable consequences. Indeed, if there were no noise any credible strategy that promotes cooperation would lead to perpetual observed mutual cooperation. Once noise is introduced, choosing a credible trigger strategy with say ten punishment periods rather than five, will show up in the very observation of the length of punishment once one party has been observed to defect. In fact, the choice of strategic design for dispute resolution purposes determines an expected long run frequency for each of the possible states visited. Each state yields a payoff to the signatories. In expected terms, the value of a design can be equated to a weighted average of these payoffs with long run frequencies used as weights. What we will refer to as the long run value is just the ergodic value of standard Markov chain theory:

\[ V_i = \sum_{k=1}^{n} \mu_k U^k_i \]  

where \( \mu_k \) is the frequency of state \( k \) and \( U^k_i \) is player \( i \)'s value at each of the \( n \) states defined by the particular design for dispute resolution. It is also the criterion we will use to compare alternative designs. The best designs will keep both signatories cooperating with the highest long run likelihood. Our criterion therefore captures signatory expected proximity to the cooperative goal of an agreement. With our game theoretic framework in mind we can describe the strategic options for dispute resolution procedures. But first some technical details must be spelled out.

\[ b. \ \text{A Technical Preamble} \]

An important characteristic of all the designs we will examine here is their behavior as noise is introduced. In all cases the formulation of strategy remains constant while its exact parameters may vary with the introduction of noise. Definition 1 in appendix calls such strategies “stable under noise.” Stability under noise refers to the structural stability of the design, to the smoothness of adjustment of its strategic parameters, and to the changing long run frequency with which the states distinguished by the design are visited, as noise is introduced. In particular, structure, parameters, and long run frequencies approach those of the standard noiseless version of the design as noise approaches zero. Our perspective is that of a “designer” of strategic equilibria. Noise does not drive any adaptive change in strategy as it does in evolutionary game theory. Instead, noise is an inevitable nuisance that must be taken into account at treaty design time knowing that the signatories will be largely unable to change the design without substantial renegotiation. Our concept of stability under noise ensures that the design is structurally stable both as noise is introduced, and for different noise magnitudes. The fact that the strategies we examine are “stable under noise” means that they can be examined for behavioral structure in the noiseless case since noise will not affect the nature of the strategy although its parameters will change with the introduction of noise. Formal strategy characteristics will therefore be given first for the noiseless case. Propositions 1 and 2 in appendix give the conditions on the
strategic parameters for each of the two schemes studied in this paper, triggers and contrite tit-for-tat, to form a SPE. This simplifies the presentation without jeopardizing the conceptual content of the strategies described. However in all numerical examples (Tables 3 and 4 below) we provide numerical values for the noisy parameters of strategy.

Our technical developments also assume that noise magnitude $\varepsilon$ is “small.” This assumption has a number of technical advantages but it also reflects a point of view on the behavior of treaty signatories. If the managerial school is to be believed, treaty negotiators strive to make texts as transparent as possible, and signatories want and intend to abide by the agreement signed. The signatory as “good marksman” minimizes noise and, as a technical matter, this detail is helpful for the following reasons: First, the long run values of the various schemes can be compared with reference to the rates at which value declines with noise. In the absence of noise, the value of any credible cooperative scheme, given our stage game payoffs, would be 0, the value of mutual cooperation. But $V_i$ decreases when noise is introduced and becomes negative because signatories will necessarily find themselves in the configurations that punish observed unilateral defection with some long run frequency. The rate $v_i$ at which $V_i$ decreases, as noise magnitude $\varepsilon$ increases from 0, is therefore what distinguishes one such scheme from another in the long run. It turns out that $v_i$ can be calculated easily near $\varepsilon = 0$ for the schemes we discuss. Secondly, the analytical difficulties involved in finding explicit formulae under noise drives a need to approximate treaty value $V_i$. If $\varepsilon$ is small, rate $v_i$ can be used in a standard “first order approximation” of $V_i$. The technical conditions for the first order approximation to exist are spelled out in Proposition 3 and Theorem 1 in appendix. If $\varepsilon$ is “small” the first order approximation is reliable. Larger noise magnitudes can be accommodated but they would require that we sharpen our approximation of $V_i$ by extending the calculation to involve second order terms, or any number of (nonlinear) higher order terms.

Propositions 4 and 5 in appendix gives the reader proof that the designs we are interested in are stable under noise and Proposition 6 derives explicit formulae for the rates $v_i$ at which long run values decline with noise. With these technical pointers in mind we now turn to our dispute resolution schemes. We first describe trigger designs, arguing that dispute resolution procedures implemented in WTO, CITES or other treaty compliance disputes can be interpreted as trigger schemes. We then examine an alternative scheme that calls for compensation of the compliant signatory at the retaliation stage, and provides both signatories with better treaty value.

### III. Treaty Dispute Resolution Procedures as Trigger Mechanisms

#### a. Interpreting Dispute Resolution Procedures

Negotiated settlement is the preferred solution to disputes over compliance with a treaty’s terms. If settlement fails, then elaborate provisions typically involving third parties come into play. Thus disputes over the Law of the Sea are brought to special arbitral tribunals, the International Tribunal for the Law of the Sea, or the International Court of Justice while trade disputes can be brought to a WTO panel. While the decisions of these bodies are binding, their implementation is left in the hands of the states involved. As Koremenos, Lipson and Snidal (2001:772) put it “most international organizations have relatively decentralized enforcement arrangements. They specify possible punishments for rule violations but leave it up to the members to apply them.” When states engage in formal dispute settlement, they obtain the terms of legitimate remedy and the allowed timing of their imposition, while enforcement remains the decision of the parties in the dispute. Thus, a WTO panel ruling against the perpetrator of a trade restriction
opens the official door to retaliatory action, but does not preclude further attempts at negotiated settlements. Victims have, of course, also been known to impose or threaten, punishing sanctions unilaterally. As early as 1989, the US unilaterally imposed $100 million in retaliatory sanctions to protest Europe’s refusal to import hormone treated beef, and invoked the Pelley Amendment to impose trade sanctions on Taiwan for trading in endangered Rhino horn.\(^{15}\)

From a game theoretic perspective, two features of treaty dispute resolution processes are noteworthy: observed defection may not lead to retaliation at all, but if it does, punishment is imposed for an uncertain but possibly long period of time. The few instances of retaliation under WTO rules are instructive:\(^{16}\) In April of 1999, the United States imposed $191.4 million in retaliatory sanctions against European agricultural products to protest Europe’s refusal to modify its’ banana importation regime to the United State’s satisfaction.\(^{17}\) A satisfactory resolution of the conflict was reached in April of 2001 (New York Times April 12, 2001) with the United States pledging to remove retaliatory tariffs on July 1, 2001. The banana dispute had been ongoing since 1993, and retaliatory measures will have been in place for just over two years. In another case against the European Union, the US imposed $100 million in retaliatory sanctions as early as 1989 to protest Europe’s refusal to import hormone treated beef. This particular set of retaliatory measures was rescinded by the United States in July of 1996 (Inside US Trade, July 19, 1996), under European threat to call for an official WTO investigation of U.S. unilateral sanctions under Section 301. The measures had been in place for seven years. A new set of US retaliatory sanctions worth $116.8 million was imposed in July of 1999 and is in force at the time of writing (Inside US Trade, July 23, 1999). The dispute on Europe’s ban of hormone treated beef has now lasted for thirteen years, and retaliatory measures have been in place for ten of these years. Many disputes do not lead to retaliation. In those that do, retaliatory measures are in place for uncertain periods of time. These features of dispute resolution are characteristic of probabilistic trigger schemes.\(^{18}\)

Probabilistic trigger schemes operate as follows: observed unilateral defection by one party is followed, with some probability \(q\), by reversion to “punishment mode” where defection is expected from both sides. Once in punishment mode, a return to cooperation by both parties occurs only after a punishment period of probabilistic or deterministic length \(T\). In the probabilistic case, the expected length can be specified by a return probability \(r\) (the expected length is then \(T = 1/r\)). The lower the trigger probability \(q\) the longer it will take (in an expected sense) before a continuing unilateral defection will be punished. In the meantime mutual cooperation can be reestablished through negotiated settlement, in which case the defection goes unpunished. Probability \(q\) for a deviating treaty signatory therefore represents the likelihood, a priori, that a defection will result in a shift of expectation from cooperation to punishment mode. For example, the data on trade disputes suggests that probability \(q\) is small for WTO members, so that the reversion to non-cooperative behavior is often delayed long enough to allow the defector to reestablish compliance. And if the first spate of US retaliation against the EU beef ban is any indication of the duration of retaliatory episodes, the probability \(r\) of return to cooperation from punishment mode may also be small for WTO agreements signatories, since the expected length of punishment \(1/r\) appears to be

\(^{15}\) This sanctioning episode and the Pelley Amendment is briefly described in footnote 8.

\(^{16}\) While European Union retaliation for the US imposition of tariffs on steel products as a “safeguard” measure have been clearly threatened, at the time of writing, they have been postponed until after the WTO has ruled in the dispute (Inside US Trade, September 27, 2002).

\(^{17}\) European Communities-Regime for the Importation Sale and Distribution of Bananas WT/DS27.

\(^{18}\) It is worth noting here that probabilistic trigger schemes were actually developed to handle situations in which intent and observation could differ. Porter (1983), Green and Porter (1984) and Abreu, Pearce and Stacchetti (1986) are standard references.
large. Nevertheless, WTO members would certainly prefer that costly retaliation be short-lived. But the choice of probabilities $q$ and $r$ requires calibration for the initial temptation to defect to be overwhelmed by the fear of punishment. Speedy return to cooperation when in punishment mode may be the objective of a treaty, but returning to cooperation too early has the unfortunate consequence of lowering the magnitude, and therefore the credibility, of the deterrent threat. A higher likelihood of return to cooperation from punishment mode $r$ requires a higher trigger probability at the outset and therefore more frequent reversions to punishment mode. A delicate balance is necessary and it requires precise analysis. But the tradeoff is clear: if retaliation is unlikely, punishment must be severe.\footnote{Proposition 1 in the appendix provides the mathematical analysis of this tradeoff.}

The technical conditions of credibility on $r$ and $q$ emerge from a comparison of player discounted payoff from cooperation to the payoff he can expect from unilateral defection given the likelihood that such behavior will be punished. A probabilistic trigger scheme with probabilistic return distinguishes only two states of the game: cooperation $CO$ in which mutual cooperation is expected and punishment mode $PN$ in which defection is expected of both sides. If $U_{i}^{CO}$ is player $i$'s discounted payoff in mutual cooperation and $U_{i}^{PN}$ his discounted payoff in punishment, probabilities $r$ and $q$ must be set so that unilateral defection for $i$ at $CO$ yields a discounted payoff that is no better than that of perpetual cooperation. But if noise is present, punishment could be triggered by an accident since a player’s intention to cooperate can turn into unintentional defection with likelihood $\epsilon$. How then should the probabilistic trigger scheme be designed?

In a noisy environment it is still the case that the credibility of threatened punishment is assured by choosing probabilities $q$ and $r$ to make intentional cooperation yield the best expected discounted payoff for each player. But the calculations are complicated by the possible mismatch between intention and observation. For example, if the players are currently in state $CO$ and both intend to cooperate, each player will be observed to unilaterally defect with probability $\epsilon(1 - \epsilon)$ which is the likelihood that one player’s intended cooperation turns into observed defection while the other player’s intent to cooperate is observed as such. So, despite their best intentions, players whose intent is to cooperate will find themselves in punishment mode $PN$ with probability $2\epsilon(1 - \epsilon)$.\footnote{Bilateral defection need not lead to punishment since the purpose is to deter unilateral noncompliance.} So how does discounted value $U_{i}^{CO}$ at state $CO$ look to player $i$? First of all, intended cooperation will turn into observed cooperation at the next turn with likelihood $(1 - \epsilon)^2$. But with likelihood $\epsilon(1 - \epsilon)$ player $i$ could be the observed sucker, receiving payoff $-b_{i}$, or the observed unilateral offender receiving a payoff of 1. Then again both parties could be observed to defect with likelihood $\epsilon^2$. All in all, when noise is present, the discounted value $U_{i}^{CO}$ to player $i$ will account for the payoff to accidental defection next turn and the subsequent possible lapse into defection mode.\footnote{More precisely expected $U_{i}^{CO}$ and $U_{i}^{PN}$ to player $i$ take on the following values:}

\[
U_{i}^{CO} = T_{i} + \omega(1 - 2\epsilon(1 - \epsilon))U_{i}^{CO} + 2\epsilon(1 - \epsilon)U_{i}^{PN}
\]

\[
U_{i}^{PN} = P_{i} + \omega(rU_{i}^{CO} + (1 - r)U_{i}^{PN})
\]
scheme that provided enough deterrence to ensure perpetual cooperation was worth \( U_{CO}^{C} = 0 \) in a noiseless environment, when noise is present, a scheme’s value must account for the likelihood of being in any one of the two possible states \( CO \) and \( PN \). The intuition that a low likelihood of retaliation will require low likelihood of return from punishment mode while a higher value for return probability \( r \) will necessitate a higher likelihood of punishment \( q \) will still hold true in a noisy environment. But we will now be able to pick the best possible combination of \( q \) and \( r \) from the viewpoint of the scheme’s overall value to the signatories.

b. Choosing the Best Trigger Mechanism in a Noisy Environment

A trigger mechanism characterized by probabilities \( q \) and \( r \) and noise magnitude \( e \) will be associated to probabilities of transition from one state to the other. The situation can be pictured as follows:

The nodes in Figure 1 represent states \( CO \) and \( PN \), while the arrows indicate possible transition from one state to another (or from one state to itself) and are labeled according to the likelihood of that transition. For instance, the probability that one side is observed to unilaterally defect although cooperation is called for at \( CO \) is \( e(1 - e) \). Since this can happen for either side, and only results in punishment with trigger probability \( q \), the likelihood of moving from \( CO \) to \( PN \) is \( 2qe(1 - e) \). \( r \) is instead the likelihood of moving from \( PN \) to \( CO \) and is independent of what either side was observed to do at \( PN \).22 As the stage game is repeated and transition probabilities are applied to the various states that the players will visit, a long run likelihood of being in one state or another will emerge in much the same way as the 50% likelihood of landing “heads” when flipping a coin will emerge with repeated throws of the coin. Thus players will be observed to be in state \( CO \) with some long run frequency \( m_{CO} \) and in state \( PN \) with long run frequency \( m_{PN} \).23 In the end, player \( i \) can expect a trigger type mechanism for dispute resolution to yield the value \( V_{i} = \mu^{CO}U_{i}^{CO} + \mu^{PN}U_{i}^{PN} \). Since \( U_{i}^{CO} > U_{i}^{PN} \) the best possible trigger design must maximize long run frequency \( \mu^{CO} \) while ensuring credible deterrence.

The requirement of credible deterrence imposes a relationship between \( q \) and \( r \), and each possible pair of likelihoods associates a long run value to the design. Treaty signatories are clearly interested in avoiding costly retaliation. This suggests choosing a low value for probability \( q \). If the data is bench-marked to represent yearly utilities, then the choice of \( q \) can be interpreted as providing treaty signatories with an expected \( 1/q \) years to resolve their differences if one is observed to defect unilaterally. Table 3 provides the treaty values and return probabilities \( r \)

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22 Because \( D \) is expected while \( C \) does not exculpate either side from punishment mode.

23 Technically the long run likelihood \( \mu = (\mu^{CO}, \mu^{PN}) \) solves \( \mu M = \mu \) where \( M \) is the transition matrix corresponding to Figure 1:

\[
M = \begin{pmatrix} 1 - 2qe(1 - e) & 2qe(1 - e) \\ r & 1 - r \end{pmatrix}
\]
that ensure credibility given selected values for $q$. Noise magnitude is set at $\varepsilon = 0.01$ and the discount factor is $\omega = 0.95$. We compute the value of alternative trigger designs for various payoff parameter values assuming a symmetric stage game.24

The calculations of Table 3 illustrate the tradeoff between a low trigger likelihood $q$ and a longer expected punishment period. Thus, with $b_i = b = 2$ and $c_i = c = 1$, if signatories can hope that a dispute will not escalate to retaliation for an expected 6.7 years, then retaliatory periods if they do come to pass must be expected to last at least 12 years. If we can assume that these parameter values have empirical validity for some of the WTO trade relationships, these calculations suggest that the provisions of the DSU might be weak. Indeed, the data reveal that trading partners are typically engaged in ongoing negotiations about a particular trade restriction for many years. It took six years of bargaining before the first retaliatory measures were taken by the United States in the bananas dispute,25 and many disputes are ongoing behind the scenes and fester for years before emerging in the public eye. A representative trigger probability for the DSU might then lie in the 0.15 range with the corresponding expected delay before retaliation in the 6.5 year range. The corresponding value for $r$ in Table 3 leaves the two and ten year empirical duration of the punishment phase for bananas and beef hormones on the short side for deterrence.26 But perhaps most importantly, Table 3 illustrates the fact that even if deterrence is effectively achieved, signatories do better when retaliation is swifter, and $q$ is larger.

If retaliation is swift, then the expected time spent in punishment mode can be shorter while still imposing enough punishment to deter. Given $q$ and $\varepsilon$, there is a value for $r$ that ensures just enough punishment to deter: a lower value for $r$ would still ensure deterrence but would punish more than is necessary, a higher value for $r$ would make deviation attractive. Thus to each noise level $\varepsilon$ we can associate a relationship between $q$ and $r$ that ensures deterrence while imposing the least punishment. As noise magnitude $\varepsilon$ increases it takes a higher expected time spent in punishment mode (lower $r$) for all possible values of $q$ to ensure

<table>
<thead>
<tr>
<th>$b = 2$, $c = 1$</th>
<th>$b = 4$, $c = 2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>$E$(time to settle)</td>
</tr>
<tr>
<td>0.15</td>
<td>6.7 years</td>
</tr>
<tr>
<td>0.2</td>
<td>5.0 years</td>
</tr>
<tr>
<td>0.3</td>
<td>3.3 years</td>
</tr>
<tr>
<td>0.15</td>
<td>6.7 years</td>
</tr>
<tr>
<td>0.2</td>
<td>5.0 years</td>
</tr>
<tr>
<td>0.3</td>
<td>3.3 years</td>
</tr>
</tbody>
</table>

Proof is available from the authors upon request.

24 Subgame perfection requires that player $i$ cannot do better than $C$ at $CO$, and $D$ at $PN$. The latter condition is trivial while the former requires:

$$U_i^{CO} \geq T_i + \omega(1 - q(1 - 2\varepsilon + 2\varepsilon^2))U_i^{CO} + q(1 - 2\varepsilon + 2\varepsilon^2)U_i^{PN}$$

Parameters $q$ and $r$ must thus satisfy:

$$q \geq \frac{(1-\omega+\omega)(T_i-R_i)}{R_i(1-2\varepsilon)^2-2\omega(1-\varepsilon)(R_i+T_i)}$$

25 European Communities-regime for the Importation and Distribution of Bananas WT/DS27.

26 The full duration of retaliation in the beef hormones case is still uncertain. However, the average length of the few retaliatory periods on record is below 12 years. As for the stakes, if $b = 2$, the cost of a trading partner’s unilateral defection is assumed to represent twice the value to the perpetrator of that defection.
deterrence. Figure 2 illustrates the impact on $q$ and $r$ of a change in noise magnitude $\varepsilon$ from 0.05 to 0.1. The discount rate is $\omega = 0.95$, and we set parameters $b = 4$, and $c = 2$.

As $\varepsilon$ increases, the boundary for credible pairs $(q, r)$ shifts down and to the right. The pair represented by point $Q_1$ is not acceptable for either $\varepsilon = 0.05$ or 0.1. Point $Q_2$ as well as any within the light gray area is valid for $\varepsilon = 0.05$ but not for $\varepsilon = 0.1$. Point $Q_3$ as well as any within the dark gray area is valid for both values of $\varepsilon$.

Which combination of trigger and return probabilities is best given payoff parameters? $V_i$ decreases when noise is introduced because signatories will necessarily find themselves in state $PN$ with some frequency and the value of being in punishment mode is lower than the value attributed to state $CO$. As a consequence the rate at which $V_i$ changes with noise, denoted $v_i$, will be a negative number in need of maximization if the best trigger design is to be chosen. First derivative for trigger designs $v_i^{\text{Trigger}}$, calculated at $\varepsilon = 0$, is derived in appendix (Proposition 4) and takes on the following form:

$$v_i^{\text{Trigger}} = 1 - b_i - 2qc_i/r$$

Clearly, $v_i^{\text{Trigger}}$ decreases as $q$ increases and as $r$ decreases. But $q$ and $r$ must also satisfy credibility requirements. The optimization of $v_i^{\text{Trigger}}$ is shown in appendix (Proposition 4, corollary).

With reference to the parameters of Table 3, when $c_i = 2$ for both players, the best treaty value if $\varepsilon = 0.01$ would obtain for $q = 0.55$ corresponding to an expected time for settlement of about 1.8 years, and an expected time in punishment mode of 1 year. The value of this design is $-1.02$, which is higher than the value of the alternatives explored in Table 3. Swifter retaliation boosts the design’s value by limiting the expected time spent in retaliation mode if it comes to pass. When $c_i = 1$ for both players, the best trigger design would again require swifter possible retaliation with an expected delay before possible punishment of a deviation.
declining to 1 year. But then the expected punishment length needed to ensure deterrence also shrinks. When $\varepsilon = 0.01$, $r = 0.90$ and expected time spent in punishment mode drops to 1.1 years. Treaty value then increases to $-0.623$.

The metric of treaty values might give the reader the impression that possible value gains are of trivial magnitude. But a comparison across schemes is eloquent: the best trigger design when $b_i = b = 2$, $c_i = c = 1$ and $\varepsilon = 0.01$ represents a 38% increase in value to the signatories when compared to a trigger design allowing for an expected 6.7 years for settlement ($q = 0.15$). And a value gain of 11% is possible if signatories are willing to cut expected time for settlement to 1 year from 4.3 years. In conclusion, the delays in implementing punishment that are implicit in a lower DSU choice for trigger probability $q$ are detrimental to both parties in the long-run even if credibility requirements are met. Yet increasing the likelihood of retaliation would more often impose the costly retaliatory measures on victim and perpetrator alike. And it is the costs associated to retaliation that limit signatory recourse to punishment in the first place.

But there are alternative designs for dispute resolution that offer costless opportunity for retaliation to the victim. They are Tit-for-Tat like schemes that avoid institutionalized stays in mutual defection for credibility. Indeed retaliation in trigger type designs force both victim and perpetrator to endure the payoffs of mutual defection for some time before mutual cooperation can be reestablished. Both parties behave identically in the aftermath of a unilateral defection. In this symmetric case, they will therefore expect the same discounted payoff. The perpetrator gained the temptation payoff of 1 from his unilateral defection in the noiseless case. Discounted payoff to the perpetrator once punished must therefore decline by at least $1/q\omega$ for credible deterrence since the likelihood of triggering is $q$. With noise, the intent to defect unilaterally may not materialize so that the expected gain from it falls short of 1. But the trigger principle is the same: both parties behave identically in intent in the aftermath of an observed unilateral defection. It follows that the victim who retaliates loses in the same amount as the perpetrator. Retaliation in trigger designs is a self-punishing proposition.

Probabilistic trigger schemes also come with more subtle conceptual problems. First, it is an absolute technical requirement of trigger schemes that the state of the game be public knowledge. In the absence of noise, triggering is unambiguous since it automatically results from unilateral defection. But in a noisy environment triggering happens only with probability $q$, which should be independent of the players’ decisions and publicly observable. So, what is the mechanism that realizes $q$ in actual treaties? In practice, signatories publicly communicate their observation of another’s deviation and the resulting shift to a situation where punishment is a possible outcome. Although independent panels rulings are involved in several treaties, the actual shift to punishment mode seems to be largely left to the discretion of the injured party. The state of the game is indeed public knowledge as required, but the mechanism that realizes the public and supposedly objective randomization $q$ is largely left to the subjective judgment of the injured party and is therefore wanting from a strict game theoretic viewpoint.

Realizing probability $r$ of return to cooperation is perhaps even more of a conceptual challenge for real world signatories. Technically, a probabilistic trigger scheme does not need to specify a probabilistic return to cooperation- probabilistic punishment is enough to deal with noise. The probabilistic trigger scheme could stipulate a specific and deterministic punishment period of integer length

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27 Game theorists call it a “public randomization.” Game equilibria must always be seen as “common conjectures” entertained by the players. This means that they implicitly understand and agree on common features such as the number of punishment periods in deterministic triggers, the threshold in continuous triggers, or a public random device in probabilistic triggers. A trigger is quite demanding of common devices compared to a simpler tit-for-tat scheme. But the latter usually fails to form an SPE.
approaching $1/r$ instead of a likelihood $r$ of return to cooperation once in punishment mode.$^{28}$ But explicit guidance for punishment length is absent in the treaty texts, which usually call for a return to cooperation as soon as possible. Restoring full cooperation is therefore left to the subjective discretion of the signatories and return probability $r$ is not engineered or controlled by any specific clause or device. So while treaties are quite specific about the conditions under which retaliation is possible, they fail to specify the critical mechanism for return to cooperation (or the corresponding expected time $1/r$ in punishment mode) that makes triggers reliable. But telling signatories that they cannot return to cooperation before enough time has passed in punishment runs against the spirit of most cooperative agreements. There is an inherent tension between the theoretical need for the severity, and therefore credibility, of punishment and the practical need to foster as much cooperation as possible. Even if dispute resolution provisions could mirror optimized trigger mechanisms, the nature of these mechanisms could ultimately pose implementation problems.

The alternative design that we describe next builds in redress to the victim of a deviation if the dispute escalates to the retaliation stage. It also comes with clearer prescriptions in case of retaliation. And it improves treaty value for both signatories by increasing the long run frequency of full cooperation.

IV. An Alternative Design for Dispute Resolution

a. Generosity and Redress

A dispute resolution scheme that improves treaty value must avoid long spells of punishing defections. This is first achieved by delaying retaliation itself, ensuring that the signatories have some time to settle the dispute before escalating to punishing measures. This is the generosity that is built in to a probabilistic trigger scheme by setting a trigger probability $q$ below 1. Generosity in the response to noncompliance addresses one of the problems associated with retaliation by avoiding it, but the organization of the retaliatory phase, if it comes to pass, is also critical to treaty value. The alternative scheme we will discuss also builds in the opportunity to settle, but in contrast to trigger designs, the retaliation phase actually brings redress to the victim of the unilateral defection. The issue of redress comes up in discussions of “unfair” trade. In his discussion of dumping Jackson (1999:274) notes that “some parties advocate that domestic-competing producers in the importing country should be given a “private right of action” under which they could sue the foreign exporting producers who are dumping and recover damages that would go directly to the harmed interests.” Jackson also points out that such a right would surely be in violation of GATT rules if similar provisions did not apply to domestic companies whose pricing policies were found akin to dumping. Nevertheless, provisions for remedy in case of dumping found their way into the US House version of the 1987 trade bill although they were not taken up in the Trade Act of 1988.

The idea of rewarding the victim of a unilateral defection is not new to game theorists and has been associated with trigger schemes in various guises. Fudenberg and Maskin (1991) and Morrow (1994) describe strategies that call for two phases. In the punishment phase victim and perpetrator defect long enough to ensure that the perpetrator looses any short term gain from unilateral defection. This phase is then followed by a “reward” phase during which the perpetrator cooperates while the victim is allowed to defect enough to reap his reward for carrying out

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$^{28}$ From a technical viewpoint, the use of a return probability to characterize probabilistic triggers is also a device that allows for non-integer punishment lengths making an expected punishment length of, say, 2.6 periods attainable while a trigger with fixed length of punishment would impose 3 punishment periods. This effect could also be achieved by increasing the frequency of decision-making.
punishment in the first place. Such a scheme would reduce treaty values since it would involve more defection on the part of the victim without avoiding the spate of joint defection by which trigger designs punish the perpetrator. Interestingly, a variation on a simple Tit-for-Tat like design suggested by Sugden (1986), “Contrite” Tit-for-Tat, builds in redress while actually increasing treaty value to the signatories. We expand upon Sugden’s scheme by adding generosity in order to delay retaliation, while maintaining redress in the retaliatory phase.

Signatories adopting a Contrite Tit-for-Tat like scheme (CTFT) punish a unilateral defection only if it is unjustified. If it is justified by the opponent’s unjustified prior defection then it should not be punished. This introduces an element of judgment in the strategic calculations of the protagonists. CTFT requires that each player be judged as innocent (I) or guilty (G) and prescribes a course of action based on the status of the players. There are four possible states: both players are innocent, one or the other is guilty or both are guilty (II, IG, GI, GG). At the outset, signatories are presumed innocent and the rules of play are as follows: a signatory should always cooperate with an innocent opponent. A signatory then becomes guilty if he defects while his partner is innocent. A guilty player is always expected to cooperate, reestablishing innocence if he does, but remaining guilty if he doesn’t. An innocent player can righteously defect against a guilty opponent without compromising his innocence, although he remains innocent if he doesn’t. Adding institutional generosity to Sugden’s original scheme, guilt no longer results automatically from defection against an innocent party, but is established with some probability \( q \).

Boyd (1989) was first to point out that Sugden’s scheme forms an SPE under noise. Our study extends his result to the case where guilt is established with some probability \( q \) (see Proposition 2 in appendix). This is an important refinement for our purposes since \( q \) is interpreted as the likelihood that noncompliance will actually be acted upon whether unofficially or in full light of a panel or tribunal ruling. It is also the likelihood that a defector is found guilty while still being observed to defect, a state that justifies retaliation by the injured party and should encourage the guilty party to reestablish innocence through cooperation. How likely should it be that guilty judgment is passed? The corollary of Proposition 5 in the appendix shows that the best credible CTFT design occurs when the probability that an unjustified defector be found guilty reaches its minimum at:

\[
q = \frac{1}{\delta} \max \left\{ \frac{1}{\epsilon} \right\}
\] (4)

The likelihood \( q \) with which a CTFT signatory is found guilty when his unilateral defection is observed, changes slowly with \( \varepsilon \) in a complex way that depends on payoff parameter values. In contrast to the probabilistic trigger designs whose long run values increase with the likelihood of retaliation \( q \), that of CTFT always decreases. In the conceptual framework of guilt and innocence, giving respite to the possibly accidental defector is beneficial to both sides in the long run: the likelihood of retaliation should be brought down to the lowest level that is compatible with credibility. Put in different terms, the adoption of a subgame perfect CTFT scheme requires that the non-compliant signatory be given the longest possible time to reestablish innocence before a judgment of guilt triggers retaliation. It turns out that as long as it is credible, CTFT provides treaty signatories with better long run value than the best subgame perfect trigger scheme. Table 4 provides some data. In all cases discount factor \( \omega \) is set at 0.95 and noise magnitude is \( \varepsilon = 0.01 \).

Time allowed for settlement in the shadow of the law is higher for CTFT than it is for the best trigger designs. CTFT offers substantial improvement in long run value

\[ \frac{df}{dx} = -q((2 + \omega - b)\omega^2 + 1 - b + \varepsilon). \] Calculations are available from the authors upon request.

29 It is possible to merge the \( II \) and \( GG \) states since no redress is expected there.

30 \( \frac{df}{dx} \).
to the signatories: For $b = 2$ and $c = 1$ the improvement over the best trigger reaches 104%. The performance of CTFT is clearly quite impressive for low values of $b$ with a tenfold improvement in treaty value to the signatories for $b = 1.1$ when compared to the best trigger scheme. It would therefore seem worthwhile to examine possible treaty signatory reactions to the dispute resolution principles that are embedded in CTFT.

While the scheme is quite generous in its allowance for settlement, it requires that signatories accept the principles of judgment and redress for the injured party, but this acceptance ensures that the realization of likelihood $q$ is an objective one. Redress can take the simple form of a compensating but short unilateral defection in response to a partner’s past noncompliance while that partner returns to full cooperation. Or it could take equivalent forms such as the payment of damages and penalties by the guilty party. In fact, treaty texts could encourage that such equivalent forms be implemented in lieu of suffering through a retaliatory unilateral defection by the injured party. The point is that, because redress in either form is part of an SPE design, it is self-enforcing since it is in the perpetrator’s best interest to participate in his own punishment. In addition, treaty texts can specify clearly the extent of the necessary compensation by the guilty signatory, thus avoiding the ambiguities on expected length of punishment that are inherent to trigger schemes. It is to be noted that guilt does not imply self-interested and opportunistic deviation, it simply implies that a signatory is recognized to have failed to comply with an agreement made with a compliant signatory. It is the unilateral nature of observed defection in the absence of retaliation that leads to guilt. The rulings of the International Court of Justice, a WTO panel or an ad hoc arbitral tribunal can be interpreted as rulings of guilt in the CTFT sense. But these rulings, while binding, do not force the guilty party to return to cooperation (or offer concessions). They merely allow official retaliation.

Would a CTFT type design be feasible? In practice, if $b = 2$ and $c = 1$ were the correct payoff parameters, CTFT would suggest that the EU get an expected 2 years to either remove it’s ban on hormone treated US beef or to make a compensating concession. During this time the US could be trying to negotiate a settlement with the EU and could eventually call for a panel to investigate the

### Table 4. Treaty Value and Alternative Designs for Dispute Resolution

<table>
<thead>
<tr>
<th>$q$</th>
<th>CTFT E(Time to settle)</th>
<th>Value</th>
<th>Best Trigger E(Time to settle)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b = 2, c = 1$</td>
<td>0.53</td>
<td>1.9 years</td>
<td>$-0.305$</td>
<td>$-0.623$</td>
</tr>
<tr>
<td>$b = 4, c = 2$</td>
<td>0.27</td>
<td>3.8 years</td>
<td>$-0.758$</td>
<td>$-1.023$</td>
</tr>
<tr>
<td>$b = 1.1, c = 1$</td>
<td>0.96</td>
<td>1.0 years</td>
<td>$-0.039$</td>
<td>$-0.443$</td>
</tr>
</tbody>
</table>

### Table 5. Noisy Payoffs $W_i^k$

<table>
<thead>
<tr>
<th>Intention</th>
<th>Observation Probabilities for Pair</th>
<th>Noisy Payoff to $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>By $i$</td>
<td>By $j$</td>
<td>$R_i = \varepsilon(1 - \varepsilon)(1 - b_i) - \varepsilon^2 c_i$</td>
</tr>
<tr>
<td>$C$</td>
<td>$C$</td>
<td>$(1 - \varepsilon)^2 \varepsilon(1 - \varepsilon) \varepsilon(1 - \varepsilon) \varepsilon^2$</td>
</tr>
<tr>
<td>$D$</td>
<td>$C$</td>
<td>$\varepsilon(1 - \varepsilon) (1 - \varepsilon)^2 \varepsilon^2 \varepsilon(1 - \varepsilon)$</td>
</tr>
<tr>
<td>$C$</td>
<td>$D$</td>
<td>$\varepsilon(1 - \varepsilon) \varepsilon^2 (1 - \varepsilon)^2 \varepsilon(1 - \varepsilon)$</td>
</tr>
<tr>
<td>$D$</td>
<td>$D$</td>
<td>$\varepsilon^2 \varepsilon(1 - \varepsilon) (1 - \varepsilon)^2 \varepsilon(1 - \varepsilon)^2$</td>
</tr>
</tbody>
</table>

Catherine C. Langlois and Jean-Pierre P. Langlois
deviation. Such a process only differs from current practice in its pace and is suggestive of a possible acceleration of signatory responsiveness to observed deviations by others. Once a non-compliant signatory is found guilty, however, the rules of CTFT dispute resolution would require the EU to compensate the US while the US, at the same time, gains redress for the past uncompensated EU ban by imposing punitive tariffs for one year. Or the EU would need to compensate the US beyond the compensation needed to make up for the beef ban, that extra compensation covering one year’s worth of the harm imposed by the ban. With such a monetary assessment in place, the US would not need to defect in order to get redress.

Interestingly in an effort to finalize the U.S.-Jordan trade agreement, the Bush administration proposed that monetary fines be the preferred enforcement mechanism for bilateral trade agreements (Inside US trade, April 2001). But proposed fines according to the Draft USTR Paper on Monetary Fines were to fall far short of any redress. Yet CTFT type designs provide superior treaty value over a wide range of parameter values as we illustrate graphically below.

b. A Graphical Comparison of CTFT, and Trigger Designs

The long run performance of the two designs that we have examined can be compared across the full range of payoff parameter values. We compare the subgame perfect trigger design that maximizes treaty value to the credible CTFT design that can be implemented given parameter values. The stability of these schemes under noise allows for a ranking of the designs according to the rates at which their long run values decline with noise. We will compare them in the symmetric case where both parties enjoy the same payoff parameters $b$ and $c$ and discount factor $\omega$. These rates, formally derived in the appendix, are as follows (see Propositions 4 and 5):

\[
\begin{align*}
\nu_{\text{Trigger}} &= 1 - b - \frac{2c}{r} \\
\nu_{\text{CTFT}} &= \left(1 + \frac{1}{\omega b}\right)(1 - b)
\end{align*}
\]

The formal comparison of these rates is worked out in the appendix (Proposition 6) and illustrated in Figure 3 below.

Figure 2 bounds parameter values $b$ and $c$, highlighting the region within which our designs become relevant. The 45° line boundary ensures the dilemma condition $c < b$. The horizontal boundary $c = (1 - \omega)/\omega$ and the vertical boundary $b = 1$ are relevant to trigger designs. Indeed, trigger designs can be credible as long as $b > 1$ and a grim trigger would impose a punishment of $\omega c/(1 - \omega)$. Given our choice of payoffs for the stage game, the very existence of a credible trigger design therefore also requires that $c > (1 - \omega)/\omega$. Vertical boundary $b = 1/\omega$ and $c = (1 - \omega)b$ limits the region within which CTFT is credible.\(^{31}\) Whenever CTFT is credible it is also the best design from a long run value perspective. This is our key finding. It is also the case that the area of dominance for trigger designs is small.

Conclusion

While rationalist authors such as Downs et al. point to the self-interested noncompliance of the signatories of deep treaties, international lawyers such as Chayes and Chayes argue that treaty violations are, in most cases, unintentional.\(^{31}\) $\omega b > 1$ ensures that the likelihood of retaliation $q = 1/\omega b$ for CTFT is a true probability. In addition, CTFT requires that $\omega c > \max(1, b - c)$. Given the dilemma condition, this translates into the additional boundary condition for CTFT, which reads $c > (1 - \omega)b$ (see Proposition 2 in appendix).
The rendered judgments of WTO panels lend credence to both of these views. 32 But in so doing, the empirical evidence requires of a rationalist approach to deal with violations whether they are intentional or not. Thus the managerial school’s emphasis on the unintentional nature of noncompliance has important design consequences for a rationalist analysis. Game theorists have developed probabilistic trigger schemes to handle situations in which noise rather than intent can determine observed noncompliance, and we find that the features characteristic of current treaty dispute resolution processes are also those of probabilistic trigger mechanisms. But we find that actual dispute resolution designs are lacking in clarity regarding essential technical features such as the expected lengths of negotiation and punishment in case of noncompliance. However, treaty signatories could adopt alternative designs to settle their disputes and our analysis suggests that signatories may benefit from considering such alternatives. One of the contributions of this paper is to show that designs can be compared directly by evaluating their ability to keep signatories close to the cooperative goal in the long run. It is the long run treaty value criterion that enables us to highlight the merits of generosity and redress for dispute resolution and this is the second contribution of this paper.

Generosity avoids retaliating with certainty and this feature allows for a delay between the observation of a deviation and the implementing of retaliatory action. Parties can settle during this time so that punishment is no longer necessary. But if retaliation does come to pass, it is the cost to the victim of punishing the perpetrator that determines a design’s value. Using a simple repeated prisoner’s dilemma framework we find that, except in very limited circumstances, trigger designs perform poorly in their ability to keep signatories close to the cooperative goal, and this is in large part due to the self-punishment endured by a signatory who implements trigger type punishments. By contrast Contrite Tit-for-Tat (CTFT),

\[ c = (1-\omega)b \]

\[ 1/\omega \]

\[ \omega \]

\[ c \]

Fig. 3. A Graphical Comparison of CTFT and Trigger

32 A ruling of intentional deviation was made against Korea when the WTO panel concluded that Korea applied higher taxes on imported alcoholic beverages than on shoyu “to afford protection to domestic production” (Korea-Taxes on Alcoholic Beverages DS75 and DS 84). By contrast, a WTO Appellate Body stated that there was insufficient evidence to show that EU objectives “were not really designed to protect its population from the risk of cancer but to keep out US and Canadian hormone treated beef and thereby to protect the domestic beef producers,” (EC Measures Affecting Meat and Meat Products Hormones-AB-1997-4-Report of the Appellate Body, WT/DS26/AB/R, WT/DS48/AB/R (January 16, 1998)).
when spiced with the right dose of generosity, yields by far the best treaty value to the signatories whenever it is self-enforcing.

CTFT would have signatories respond to a judgment of guilt. A non-compliant signatory will be found guilty of deviation with some likelihood (building in generosity), but if a party is found guilty the scheme prescribes that he return to full cooperation while the victim defects. The victim’s ability to punish a guilty defector for past deviation, while that defector returns to full cooperation, is the key to CTFT’s success. It is also this feature that ensures that the victim of non-compliant behavior gets at least partial redress for past losses at the retaliation stage. Redress under CTFT can be monetary with its magnitude specified in treaty texts. Then, the ambiguities that surround punishment length in probabilistic trigger-like schemes are avoided altogether. By identifying design characteristics that deter intentional noncompliance and enhance treaty value, our game theoretic analysis has normative implications for the design of dispute resolution mechanisms in international agreements.

Appendix

**Proposition 1.** A trigger pair is subgame perfect if:

\[ 1 - \omega(1 - r + q_c) \leq 0 \]  

*Proof:* i’s values (at CO and PN) are \( U_i^{CO} = 0 + \omega U_i^{CO} = 0 \) and \( U_i^{PN} = -c_i + \omega(r U_i^{CO} + (1 - r) U_i^{PN}) = -c_i/(1 - \omega(1 - r)) \). Unilateral defection for i at CO yields the value \( 1 + \omega q U_i^{PN} \leq 0 = U_i^{CO} \) (the value of cooperating) if \( 1 - \omega(1 - r + q_c) \leq 0 \) holds. Cooperating at PN yields \( 0 + \omega q U_i^{PN} < 1 + \omega q U_i^{PN} \) (the value of defecting). Q.E.D.

**Proposition 2.** A CTFT pair is subgame perfect if \( \omega b_i > \max_i \{1, b_i - c_i\} \) and \( q \geq 1/\omega b_i \).

*Proof:* By definition, i’s values are \( U_i^{H} = 0 + \omega U_i^{H} = 0 \), \( U_i^{GG} = 1 + \omega U_i^{H} = 1 \), \( U_i^{GI} = -b_1 + \omega U_i^{H} = -b_1 \), and \( U_i^{GG} = 0 + \omega U_i^{H} = 0 \). If Player 1 defects at II or GG (while 2 cooperates) he becomes guilty with probability \( q \). His value of doing so is \( 1 - \omega q b_1 \leq 0 \) provided \( q \geq 1/\omega b_1 \) (less than one) and cooperating is best. If he defects at GI he remains guilty with probability \( q \) and value: \( -c_1 + \omega q U_i^{GI} = -c_1 - \omega q b_1 < -b_1 \) (if \( \omega b_i > \max_i \{1, b_i - c_i\} \)). If he cooperates at IG he forsakes redress but remains innocent with value 0 < 1. The argument is symmetric for Player 2. Q.E.D.

**Proposition 3.** The long run value \( V_i \) of a Markov strategy pair \( \Psi \) reads \( V_i = \frac{1}{1 - \gamma_i} \sum_k \mu_k W_i^k \) where \( W_i^k \) is i’s noisy expected payoff in state \( k \) (see Table 5) according to \( \Psi \) and \( \mu_k \) is the long run frequency with which state \( k \) is visited.\(^{33}\)

*Proof:* Following standard Markov Chain theory, if player i receives discounted payoff \( U_i^k \) in state \( k \), the long run value to player i of the strategy characterized by the set of states \( \{1, 2, \ldots, k, \ldots, n\} \) and transition matrix \( M \) is \( V_i = \sum_{k=1}^n \mu_k U_i^k \).

\(^{33}\)The Markov strategy pairs we deal with define a probability transition matrix \( M \) over a finite number of states of the game (for example see footnote 25 for the trigger transition matrix between the two states \( CO \) and \( PN \)). It follows from standard Markov chain theory (see Norris, 1997) that there exists a single invariant probability distribution \( \mu \) satisfying \( \mu = \mu M \). This \( \mu \) gives the long run frequencies with which the various states of the game are visited.
discounted values under noise. But in dot product form:

\[ V_i = \mu \cdot U_i = \mu \cdot W_i + \omega \mu \cdot MU_i = \mu \cdot W_i + \omega \mu \cdot U_i = \mu \cdot W_i + \omega V_i = \frac{1}{1-\omega} \mu \cdot W_i \]

Q.E.D.

Definition 1. A family \( \Psi(\epsilon) \) of Markov strategy pairs is “stable under noise” (SUN) if: (i) \( \Psi(\epsilon) \) is differentiable for \( \epsilon > 0 \); (ii) all \( \Psi(\epsilon) \) share the same set of states; (iii) there exists a unique \( \Psi = \lim_{\epsilon \to 0} \Psi(\epsilon) \)-meaning that the probability of each move at each state in \( \Psi(\epsilon) \) approaches the probability of that move in \( \Psi \); (iv) there is a unique invariant distribution \( \mu \) of the transition matrix \( M \) of \( \Psi \); and (v) \( \mu(\epsilon) \) is differentiable in \( \epsilon \) and its derivative has a limit \( \mu' = \lim_{\epsilon \to 0} \mu'(\epsilon) \).  

Theorem 1. If \( \Psi(\epsilon) \) is SUN then: (i) \( \mu \) satisfies \( \mu' = \mu' M + \mu M' \); (ii) player \( i \)'s long run value \( V'(\epsilon) \) is differentiable in \( \epsilon \); (iii) \( \lim_{\epsilon \to 0} V'(\epsilon) \) exists and is given by \( V'(0) = \frac{1}{1-\omega} \mu \cdot W_i \) with \( v_i = \mu_0 \cdot W_i^0 + \mu_0 \cdot w_i^0 \) - where \( W_i^0 = W_i(0) \) is the noiseless utility vector and \( w_i^0 \) is the derivative \( \frac{dw}{d\epsilon} \) at \( \epsilon = 0 \); and (iv) there exists \( O(\epsilon) \) such that \( \lim_{\epsilon \to 0} O(\epsilon) = 0 \) and \( V_i(\epsilon) = \frac{1}{1-\omega} v_i + \epsilon O(\epsilon) \). 

Proof: Since \( \mu \) and \( M \) are differentiable the product rule yields the first formula. Moreover, since \( W_i \) is also differentiable, by Proposition 3: 

\[ V'(\epsilon) = \frac{1}{1-\omega} (\mu' \cdot W_i + \mu \cdot \frac{dW_i}{d\epsilon}) \]

and by stability of \( \Psi \) under noise \( V'(\epsilon) \) has the given limit. By the Mean Value Theorem of Calculus \( V_i(\epsilon) = V_i(0) + \epsilon V_i'(v_i) \) for \( 0 < v_i < v_i(\epsilon) < \epsilon \). But by the above limit there exists \( \alpha(v) \) such that \( V_i'(v) = V_i'(0) + \alpha(v) \) with \( \lim_{\epsilon \to 0} \alpha(v) = 0 \). Letting \( O(\epsilon) = \max \{ \alpha(v_i(\epsilon)) \} \) and observing that \( V_i(0) = 0 \) yield the result. Q.E.D.

Proposition 4. The family of triggers with fixed \( q \) and \( r \) is SUN. Moreover \( v_i^{\text{Trigger}} \) is given by \( v_i^{\text{Trigger}} = 1 - b_i - \frac{2q}{r} \).

Proof: Condition (i), (ii), and (iii) of Definition 1 are clearly satisfied since \( \Psi \) is constant in \( \epsilon \). The transition matrix follows from Figure 1 and is given in footnote 23. At \( \epsilon = 0 \) it has the unique invariant distribution \( \mu(0) = <1,0,0> \) which is also the limit as \( \epsilon \to 0 \) of \( \mu(\epsilon) \). Since the second row of \( [I-M] \) is the vector \( <-r, r, > \) the unique solution \( \mu'(\epsilon) \) to \( \mu'[I-M] = \mu M' \) satisfies \( \sum_i \mu'_i = 0 \) and is given by \( \mu'(\epsilon) = \frac{2q}{r} (1-2\epsilon) \mu_CO(\epsilon) <-1,1,1> \) which has limit \( \mu' = \frac{2q}{r} <-1,1,1> \) as \( \epsilon \to 0 \). Since at \( CO \), \( W^0_i = 0 \) and \( w_i^0 = \frac{dR_i}{d\epsilon} \epsilon = 0 = 1 - b_i \), Theorem 1 yields \( v_i^{\text{Trigger}} \). Q.E.D.

Corollary. As \( \epsilon \to 0 \), subgame perfect triggers with maximum long run values obtain for pairs \( (q, r) \) with limit \( (q, r) \) as \( \epsilon \to 0 \) satisfying \( r = 1 \) and \( q = \min \{ \frac{1}{\omega q} \} \) if \( c_i > \frac{1}{\omega} \) and \( r = \min \{ c_i - \frac{1}{\omega \epsilon} \} \) and \( q = 1 \) if \( c_i < \frac{1}{\omega} \) for at least one player \( i \). 

Proof: \( v_i^{\text{Trigger}} \) is maximum when \( \frac{q}{r} \) is minimum. Since all conditions are continuous in \( \epsilon \) we can examine the limit case. For \( \epsilon = 0 \) the minimum of \( \frac{q}{r} \) is found when a credibility constraint (6) is saturated - which means \( q = \frac{\omega q}{1-\omega q} \) (for \( i = 1 \) or 2) with \( q > \frac{1}{\omega \epsilon} \) (to ensure \( r > 0 \)). The minimum of \( \frac{q}{r} \) occurs for the maximum \( q \) that allows both \( q \) and \( r \) to be probabilities. Either this means \( q = 1 \) and the given \( r \) when it is a probability, or it means \( r = 1 \) and the given \( q \) which must then be a probability. Q.E.D.

\( ^{34} \) Condition (iii) can be ensured by assuming that the derivative \( \Psi'(\epsilon) \) is bounded. Tit-for-Tat and the grim trigger are typical of a failure of condition (iv). That \( \epsilon \) is differentiable can be inferred from the previous conditions. 

\( ^{35} \) As the derivative of a probability distribution \( \mu' \) has components that add up to zero.
Proposition 5. The family of CTFT with constant $q$ is SUN. Moreover

$$v_i^{CTFT} = (1 + q)(1 - b_i)$$  \hspace{1cm} (7)

Proof: Conditions (i), (ii), and (iii) of Definition 1 clearly hold since $\Psi(\varepsilon)$ is constant in $\varepsilon$. Condition (iv) is just as obvious with $\mu_i = 1$. To obtain $\mu'$ we need $M'$ for which we need $M = M(\varepsilon)$. When $CC$ is intended (at $II$ and $GG$) a unilateral defection by $i$ occurs with probability $\varepsilon(1 - \varepsilon)$ and a bilateral defection occurs with probability $\varepsilon^2$.

The probability that $i$ alone is guilty is therefore $q\varepsilon(1 - \varepsilon) + q(1 - q)\varepsilon^2 = q\varepsilon(1 - q\varepsilon)$ and they both are guilty with probability $q^2\varepsilon^2$. When $DC$ is intended (at $IG$), only Player 2 can be guilty and this occurs with probability $q\varepsilon$ (that $D$ is observed and results in guilt for 2). The transition matrix on states $\{II, IG, GI, GG\}$ thus reads

$$M = \begin{pmatrix}
1 - q\varepsilon(2 - q\varepsilon) & q\varepsilon(1 - q\varepsilon) & q\varepsilon(1 - q\varepsilon) & q^2\varepsilon^2 \\
1 - q\varepsilon & q\varepsilon & 0 & 0 \\
1 - q\varepsilon & 0 & q\varepsilon & 0 \\
1 - q\varepsilon(2 - q\varepsilon) & q\varepsilon(1 - q\varepsilon) & q\varepsilon(1 - q\varepsilon) & q^2\varepsilon^2
\end{pmatrix}$$

As $\varepsilon \to 0$, the right-hand side of the condition $\mu'[I - M] = \mu M'$ approaches $\rho = \langle -2q, q, q, 0 \rangle$ – the first row of $M'$ evaluated at $\varepsilon = 0$. So, the condition on $\mu'_{\text{II}}$ (the last three columns of $\mu'$) approaches

$$\mu'_{\text{II}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \rho_{\text{II}} :$$

It follows that $\mu' \to \rho$ and (7) results from Proposition 3. Q.E.D.

Corollary. As $\varepsilon \to 0$, Markov perfect CTFT with maximum long run values are obtained for $q(\varepsilon)$ that approaches $q = \max_i \{ \frac{1}{1+b_i} \}$. In the symmetric case $c_i = c$ this yields formula (5b).

Proof: Values $U_i$ are solutions of $[I - \omega M]U_i = W_i$ and approach continuously the noiseless values as $\varepsilon \to 0$. Similarly, the condition $C$ is best at $II$ approaches $1 - \omega q b_c \leq 0$ as $\varepsilon \to 0$. By (7), the long run value increases as $q$ decreases and is therefore obtained at its minimum compatible with credibility $q = \max_i \{ \frac{1}{1+b_i} \}$. The other perfection requirements are similar and evolve continuously with $\varepsilon$. Q.E.D.

Proposition 6. In the symmetric case $b_i = b$, $c_i = c$, the long run values for the best Trigger and CTFT decline with noise at rates given by (5a) and (5b).

Proof: In the symmetric case, the derivatives depend on $b$ and $c$. Formulae (3), and (7) thus reduce to (5a,b). For the best trigger $v^{\text{Trigger}}(b,c) = (1 - b) - g(c)$ with $g(c) = \{ \frac{2q\varepsilon}{\omega(1 - \omega)} \}$ if $(1 - \omega) < \omega c \leq 1$, $\frac{2q\varepsilon}{\omega}$ if $\omega c \geq 1$. For the best CTFT the rate $v$ reads $v^{CTFT} = \frac{(\omega b + 1)(1-b)}{\omega b}$. One observes that $g(c) \geq \frac{2q\varepsilon}{\omega}$ for all $c > \frac{1-\omega}{\omega}$.

It follows that $v^{\text{Trigger}}(b,c) \leq (1 - b) - \frac{2q\varepsilon}{\omega} < \frac{(\omega b + 1)(1-b)}{\omega b} = v^{CTFT}(b)$. However, the condition $c \geq (1 - \omega)b$ is necessary for the credibility of CTFT. Q.E.D.

References


