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Insiders Versus Outsiders: A Game-Theoretic Analysis of the Puerto Rican Status Debate and Other "Legislative Wars of Attrition"

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INSIDERS VERSUS OUTSIDERS: A GAME-THEORETIC ANALYSIS OF THE PUERTO RICAN STATUS DEBATE AND OTHER "LEGISLATIVE WARS OF ATTRITION"

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I. INTRODUCTION

This paper focuses on two-party conflicts that result in protracted and costly stalemates, a negative-sum situation often referred to in the game-

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theoretic literature as a "war of attrition."[1] Since such conflicts are counter-productive and collectively irrational, they pose a difficult puzzle. What is the underlying logic of these conflicts, why do such conflicts occur with such regularity in the real world, and what role can law play in these situations?

This paper is divided into five parts. Following this introduction, Part II provides some background and presents some real-world examples of costly and protracted wars of attrition.[2] Part III examines one particular war of attrition—what I refer to as a "legislative war of attrition"—the current impasse over Puerto Rico's constitutional status.[3] Next, Part IV presents an idealized two-player war of attrition model as well as a more realistic *n*-player evolutionary model.[4] Lastly, Part V concludes by identifying some areas for further research.[5]

II. BACKGROUND AND SUMMARY OF PREVIOUS LITERATURE

Competitive interactions often involve conflicting claims over scarce resources. Examples range from the division of revenues among players and owners in sports leagues to disputes over land and water rights in the West Bank. Competitive interactions also revolve around opposing preferences regarding public policy—such as Puerto Rico's territorial status. How are these conflicting claims or preferences to be decided or resolved?

One solution method is "spontaneous order," or the decentralized creation and evolution of self-enforcing norms and conventions.[6] However, the resulting norms and conventions may not be wealth-maximizing or mutually-beneficial. Furthermore, the conditions necessary for the creation and evolution of self-enforcing order may not be stable or present.[7] Another solution method is centralized coercion.[8] A coercive

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1. *See* JOHN MAYNARD SMITH, EVOLUTION AND THE THEORY OF GAMES 28-39 (1982).

2. *See infra* Part II (introducing solution methods such as spontaneous order, coercion, and bargaining).

3. *See infra* Part III (reviewing the history of and logic behind the conflict over Puerto Rico's status).

4. *See infra* Part IV (presenting mathematical models and hypothetical situations to exemplify the author's war of attrition theory).

5. *See infra* Part V (summarizing and suggesting that slight alterations of the variables of the author's war of attrition theory could lead to further productive research).

6. *See* Robert Sugden, *Spontaneous Order*, 3 J. ECON. PERSP. 85 (1989). *See generally* DAVID K. LEWIS, CONVENTIONS: A PHILOSOPHICAL STUDY 36-42 (1969) (considering incidents of self-enforcing norms and conventions such as meeting in the same location every day).

7. *See* F.E. Guerra-Pujol, On the Origins of Property Rights 3-4 (Dec. 31, 2008) (unpublished manuscript, on file with author) (explaining why spontaneous-order

solution, however, presupposes the existence of an external Leviathan, a body strong enough to impose its will. Regardless of whether a Leviathan truly exists, coercive solutions are often perceived as illegitimate or unfair by the losing side, leading to further conflict and unrest.[9] Lastly, a more desirable method of resolving competing claims is through bargaining.[10] In theory, negotiated solutions produce gains beneficial for both sides.[11] In practice, however, bargaining might be unfeasible or unproductive for a wide variety of reasons, such as self-serving biases,[12] high transaction costs,[13] and the existence of "infeasible" or mutually-incompatible claims.[14]

Consider, for example, the disastrous Major League Baseball strike/lock-out of 1994-1995[15] and the long-standing Israeli-Palestinian conflict over West Bank settlements.[16] These types of negative-sum conflicts are not amenable to the classic solutions set forth above. As a result, when conventions, external coercion, and bargaining are not practicable solutions or are unavailable, competitive interactions often lead to a costly and protracted stalemate among the competing sides.[17] Other real-world

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solutions are often unstable).

8. *See generally* THOMAS HOBBES, LEVIATHAN 115-19 (A.R. Waller, ed., Cambridge Univ. Press 1904) (1651) (considering the rationale behind relinquishing power to a central authority).

9. *See, e.g.*, EDWARD E. ZAJAC, POLITICAL ECONOMY OF FAIRNESS 129-30 (1995) (considering principles of fairness and how "fairness" factors into institutional change).

10. *See, e.g.*, R. H. Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1, 2-8 (1960)

11. *See id.* (providing an example in which both parties were made better off from negotiation).

12. *See* Linda Babcock & George Loewenstein, *Explaining Bargaining Impasse: The Role of Self-Serving Biases*, 11 J. ECON. PERSP. 109, 110 (1997) (arguing that negotiating parties tend to arrive at judgments that reflect their self-serving bias, significantly impeding settlement).

13. *See* Duncan Simester & Marc Knez, *Direct and Indirect Bargaining Costs and the Scope of the Firm*, 75 J. BUS. 283, 284, 303 (2002) (explaining the bargaining costs of negotiation, including documenting and enforcing an agreement, and that an option with a lower cost is often more desirable).

14. *See* Simon Gächter & Arno Riedl, *Moral Property Rights in Bargaining with Infeasible Claims*, 51 MGMT. SCI. 249 (2005) (recognizing that inconsistent feelings of entitlement among parties historically result in unsuccessful negotiations).

15. *See, e.g.*, Paul D. Staudohar, *The Baseball Strike of 1994-95*, MONTHLY LAB. REV., Mar. 1997, at 21. (examining four areas that caused negotiations between baseball players and owners to fail and result in work stoppages: the allocation of revenues, cooperating for mutual gain, behavioral atmosphere during bargaining, and the accommodation of varying interests).

16. *See, e.g.*, Ethan Bronner, *Painful Mideast Truth: Force Trumps Diplomacy*, N.Y. TIMES, Oct. 20, 2009, at A4; Mark Landler & Ethan Bronner, *Clinton Fails to Win Palestinian Assent to Israeli Plan for Slowing Settlement Building*, N.Y. TIMES, Nov. 1, 2009, at A6 (suggesting that Middle East peace talks are proving unsuccessful due to various issues and barriers).

17. Another possible method of resolving competing claims is the use of a random device for assigning such claims. *See, e.g.*, Charles V. Bagli, *Flipping a Coin,*

examples of this phenomenon include civil actions and civil litigation. Although a large portion of civil actions are settled out of court,[18] some civil actions resemble costly and protracted wars of attrition. In those cases, litigants and their attorneys find themselves locked in a no-win situation where neither side is willing to compromise or back down. Therefore, both plaintiff and defendant end up investing significant resources in the contest, but their efforts cancel each other out, leading to a Pyrrhic victory or no victory at all.[19]

The "war of attrition" concept, often referred to as the "Hawk-Dove Game," has been extensively treated in the evolutionary biology literature.[20] This paper presents a modified war of attrition model designed to capture the essential features of the myriad conflict situations described above. Before presenting this model, I present a detailed discussion of one specific war of attrition for illustration.

III. THE PUERTO RICAN STATUS DEBATE AS A "LEGISLATIVE WAR OF ATTRITION"

The century-old debate over Puerto Rico's constitutional status, the focus of this paper, provides another good illustration of a costly and protracted war of attrition.[21] At present, Puerto Rico is a "commonwealth," or territory of the United States.[22] Most Puerto Ricans, however, are dissatisfied with their Island's current political status and thus favor some form of change. This begs the question: what type of change? Indeed, this question is so important to Puerto Ricans that political parties and politics on the Island are not divided along the more familiar Democratic-

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Dividing an Empire, N.Y. TIMES, Nov. 1, 2009, at BU1 (describing an alternative method of conflict resolution that essentially employs a random device—exemplifying what can occur when the traditional methods of resolution fail or are unavailable).

18. *See* Marc Galanter, *The Vanishing Trial: An Examination of Trials and Related Matters in Federal and State Courts*, 1 J. EMPIRICAL LEGAL STUD. 459, 459 (2004) (noting that only 1.8% of federal civil cases are resolved in a trial).

19. *See, e.g.*, JONATHAN HARR, A CIVIL ACTION 449-93 (1996) (detailing the problems presented by civil litigation in which both parties to the described toxic tort lawsuit were unsatisfied after their drawn-out and expensive trial).

20. *See* MAYNARD SMITH, *supra* note 1, at 10-20; D.T. Bishop & C. Cannings, *A Generalized War of Attrition*, 70 J. THEORETICAL BIOLOGY 85, 88 (1978); J. Maynard Smith & G.R. Price, *The Logic of Animal Conflict*, 246 NATURE 15, 17 (1973) (providing examples and interpretations of the "war of attrition," including mathematical models and hypothetical situations).

21. The author expresses no opinion as to whether the Commonwealth of Puerto Rico is an "incorporated" or "unincorporated" territory of the United States, since the precise territorial status of Puerto Rico is immaterial to the results of our model.

22. *Compare* Balzac v. Porto Rico, 258 U.S. 298, 313 (1922) (holding that Puerto Rico is an unincorporated territory), *with* Consejo de Salud Playa de Ponce v. Rullan, 586 F. Supp. 2d 22, 52 (D. P.R. 2008) (stating that Puerto Rico has since become an incorporated territory).

Republican lines, as in the mainland United States, but rather over each party's preferred status solution.[23]

Puerto Rico has two major political parties and one minor third party. One of the major political parties, the Popular Democratic Party (PDP), supports an improved or "enhanced" version of Puerto Rico's current Commonwealth status, in which Puerto Rico would enjoy greater autonomy in certain policy areas, such as customs, shipping, and immigration policy.[24] In the enhanced commonwealth proposal, Puerto Ricans would still enjoy American citizenship and the right to travel to the mainland United States. The other major Puerto Rican political party, the New Progressive Party (NPP), supports "statehood" or annexation, with the goal of Puerto Rico becoming the fifty-first state of the Union.[25] The Puerto Rican Independence Party (PIP), a minor but influential party, supports independence or total separation from the United States.[26]

At this time, Puerto Rico's two main political parties, the PDP and NPP, have taken opposing sides on a bill that is pending before Congress, "The Puerto Rico Democracy Act of 2009" (H.R. 2499).[27] In summary, this bill would authorize "a federally-sanctioned self-determination process for the people of Puerto Rico."[28] Specifically, the bill calls for a two-stage referendum process, with an initial referendum at time T_1 and a subsequent referendum at time T_2. The initial referendum at time T_1 would propose the following two options: Option 1: "Puerto Rico should continue to have its present form of political status" (the status quo option), and Option 2: "Puerto Rico should have a different political status" (the change option).[29]

In the event that a majority of the voters chose Option 1—the status quo option—an identical, repeat referendum would be held after eight years

23. *See generally* ARTURO MORALES CARRIÓN, PUERTO RICO: A POLITICAL AND CULTURAL HISTORY (1983) (describing the centrality of the status issue in Puerto Rican politics).

24. *See, e.g.*, *Congressional Panel: Enhanced Commonwealth Not an Option*, P.R. HERALD, Oct. 5, 2000, ¶¶ 4-5, http://www.puertorico-herald.org/issues/vol4n40/ NoEnhancedCommon-en.html [hereinafter *Congressional Panel*] (describing the PDP's enhanced commonwealth proposal as including local ability to decide which U.S. federal laws to apply in Puerto Rico, among other components).

25. *See* F.E. Guerra-Pujol, *Puerto Rico as a Critical Locality: Is a Post-Colonial Puerto Rico Possible? A Game-Theoretic Analysis of the Impasse over Puerto Rico's Status*, 20 ST. THOMAS L. REV. 561, 563 (2008) (presenting NPP's support for Puerto Rican statehood).

26. *See id.* at 562-66 (describing PIP's support for independence and using the positions of the three major political parties to present a three-player or "true" game model of the Puerto Rican status debate).

27. *See* H.R. 2499, 111th Cong. § 2(a) (2009) (presenting the bill as a Puerto Rican referendum in which voters would choose to either continue Puerto Rico's current status or to change that status in an undefined way).

28. *Id.*

29. *See id.*

with the same two options. This process would continue ad infinitum every eight years until a majority of the voters eventually selected Option 2—the change option. But once a simple majority of the voters agree to the change option, the bill then calls for a final referendum at time T_2 in which the voters would choose among the following three non-territorial options: (1) independence, (2) statehood, or (3) "sovereignty in association with the United States."[30] One possible source of the PDP's opposition to H.R. 2499 is the language used to describe this third option, since it is unclear whether "sovereignty in association with the United States" is the same as the improved or enhanced commonwealth status supported by the PDP.[31]

H.R. 2499, however, is simply the latest installment in a longstanding struggle between the PDP and NPP over Puerto Rico's constitutional status. In summary, Puerto Rico's main political parties have been engaged in a costly and protracted war of attrition over the Island's future status, which I shall refer to as a "legislative war of attrition." Thus far, these myriad competing efforts appear to have cancelled each other out and produced the current impasse over Puerto Rico's status. Will the current effort to change Puerto Rico's status, H.R. 2499, suffer a similar fate of impasse, deadlock, or stalemate?

Next, I present a symmetrical war of attrition model. My goal is not only to explain the ultimate source of the impasse over Puerto Rico's constitutional status but also to understand the perverse underlying logic of costly and protracted wars of attrition generally.

IV. A GAME-THEORETIC APPROACH TO LEGISLATIVE WARS OF ATTRITION

In this section, I discuss the utility of mathematical models in law and present a two-player war of attrition model along with an *n*-player evolutionary model.

A. A Few Words about the Utility of Models in Law

Before proceeding, I wish to make a few points about the utility of game-theoretic models in law. Most legal literature is based on purely verbal arguments. However, the problem with purely verbal arguments is that they tend to be imprecise, fuzzy, and vague.[32] The "looseness" of most

30. *See id*. § 2(a)-(b).

31. *Compare id*. § 2(c)(2) (defining "sovereignty in association with the United States" as a "political association" between the same nations), *with Congressional Panel*, *supra* note 24, ¶¶ 4-5 (describing the enhanced commonwealth proposal, which includes a permanent connection to the United States, citizenship for Puerto Ricans, U.S. government benefits without taxes, and the Puerto Rican government's ability to choose which U.S. laws it wants to apply).

32. *Cf.* LAURENCE H. TRIBE & MICHAEL C. DORF, ON READING THE CONSTITUTION 73-80 (1991) (discussing the "level of generality" problem—the way

verbal arguments leads to confusion and unproductive squabbling among scholars, who end up arguing back-and-forth for years about the meaning and implications of their verbal models.

Of course, I recognize at the outset that game-theoretic models and mathematical models are generally much simpler than the real-world scenarios they are designed to depict. For example, the models in this paper are highly stylized and based on a finite set of simplifying assumptions, such as symmetrical payoffs and a well-defined strategy set consisting of only two choices. In addition, I ignore the psychology of sunk costs, the problem of stochastic effects (such as random shocks), and the possibility of altruism or "other-regarding" behavior. Nevertheless, what models sacrifice in specificity and detail, they gain in tractability and clarity. In the words of two contemporary game theorists, "models are simple maps for understanding the consequences of a small number of key assumptions."[33] In addition, formal models may help to uncover the underlying logic or unifying structure of seemingly unrelated situations. Then, and only then, after stating the operating assumptions of these models up front, do I attempt to explain the results of these models in words.

B. A Two-Player War of Attrition Model

This two-player war of attrition model consists of a one-shot, simultaneous-move game in which the players, designated as Player A and Player B, support opposing positions on a given issue or public policy debate. I begin with this simple scenario first for ease of exposition. Later in this subsection, I consider an infinite version of the game.

In addition, I make the following set of assumptions: each player prefers that his policy position prevails and obtains the positive payoff (v) if his position indeed prevails. For simplicity, I assume that the intensity of each player's preferences are equal. That is, I assume that the value of v is fixed. Also, the players must simultaneously choose between one of two possible strategies at the outset of the game: hawk or dove. The hawk strategy is the equivalent of fighting, and there is no bluffing in this game; the player who fights always pays a cost (c) to obtain his or her desired policy goal. The dove strategy, in contrast, consists of backing down or retreating. By choosing to back down, the player does not pay the cost of fighting. Unlike some hawk-dove models in the previous literature, in this

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the Supreme Court determines how generally constitutional rights are meant to be interpreted).

33. RICHARD MCELREATH & ROBERT BOYD, MATHEMATICAL MODELS OF SOCIAL EVOLUTION 4-6 (2007).

model there are no display costs.[34] Lastly, I assume that the benefit or value of prevailing (*v*) is always larger than the cost of fighting (*c*), so *v* is greater than *c*. The intuition behind this assumption is that the players are unlikely to fight when the cost of fighting outweighs the utility of prevailing or the value of the contested resource, as the case may be.

Notice that I specify the respective benefits and costs corresponding with each strategy in abstract terms (the parameters *v* and *c*) rather than expressing them in terms of numerical values (such as 1, 2, and 3) in order to illustrate the underlying logic and structure of seemingly unrelated problems. In addition, another advantage of expressing these values as abstract parameters is flexibility and generality; that is, this abstract model permits me to derive results for any value that these parameters might actually take.[35]

Since this is a game-theoretic or interactive model, the payoffs depend on the strategies simultaneously chosen by the players at the start of play. The structure of the game and the payoffs can be expressed in "extended form" (see Figure 1a) as follows:

34. In some models, doves pay a display cost when they pretend to adopt the hawk strategy for some time period *t* before deciding to back down. *See generally* MAYNARD SMITH, *supra* note 1, at 149 (evaluating the success and long-term indicator of displays).

35. *See* MCELREATH & BOYD, *supra* note 33, at 4-6 (explaining that game theory models are deliberately general in order to eliminate variables that are irrelevant to a given study and allow researchers to understand complex phenomena at a micro level, one detail at a time).

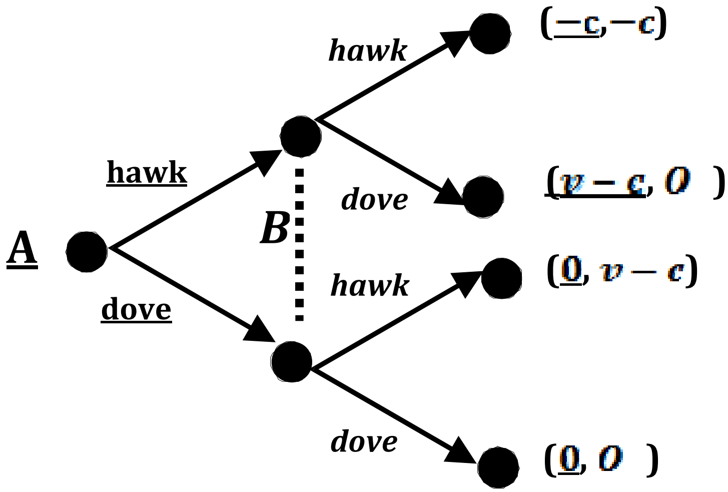

Figure 1a

Extended form (game tree) symmetrical war of attrition game with two players and two strategies

The payoffs can also be expressed in "normal form" (see Figure 1b) as follows:

	Player B chooses hawk	Player B chooses dove
<u>Player A chooses hawk</u>	$-c, -c$	$\underline{v-c}$, 0
<u>Player A chooses dove</u>	$\underline{0}$, $v-c$	$\underline{0}$, 0

Figure 1b

Normal form payoff table of symmetrical war of attrition game with two players and two strategies

Accordingly, there are four possible interactions in the one-shot game: (1) hawk-dove, (2) dove-hawk, (3) dove-dove, and (4) hawk-hawk, resulting in four possible payoff combinations. For instance, if Player A chooses hawk and Player B chooses dove, then Player A receives a positive payoff minus the cost of fighting ($v - c$), while Player B obtains no payoff.[36] This result occurs because Player A is more likely to obtain his desired policy change if the other player does not fight back, though Player A still ends up paying the cost of fighting. Likewise, if Player A chooses dove while Player B chooses hawk, the payoffs are reversed: Player A gets nothing while Player B gets $v - c$.

In the event of a dove-dove interaction in which both players choose to back down instead of fighting, neither prevails or obtains his preferred

36. The payoff to the dove player in this scenario might, in fact, be negative. My student, Nadine Sfeir, has pointed out to me that although such a player avoids the cost of fighting, his choice of the dove strategy might generate a reputation for backing down and weaken his ability to fight in future rounds. Nevertheless, since this model consists of a single, one-round game, I ignore reputation costs and the like for simplicity.

policy outcome and both players receive a zero payoff. The reason for a zero payoff (instead of $v/2$ as in the classic hawk-dove game) is that in this model, both players prefer change to retaining the status quo, but when both players back down, the status quo is preserved by default.[37] Lastly, if both players choose to fight, resulting in a hawk-hawk interaction, then both players end up paying the cost of fighting (c) and neither prevails because, by fighting, their efforts cancel each other out, leading to a preservation of the status quo, a state of affairs that neither player prefers.

At this point, it is worth noting that one aspect of this war of attrition model shares some similarities with a model often referred to as the "Game of Chicken."[38] In the Game of Chicken, there are two players driving race cars towards each other at high speeds on a one lane road. Like the binary strategy set forth in this model, the strategy set of the drivers in the Game of Chicken consists of two choices: swerve or drive straight. If both players drive straight, there will be a serious collision and thus a cost will be imposed on both drivers. Similarly, if the players in the war of attrition model both fight, they both pay the cost of fighting.

Nevertheless, this model differs from the Game of Chicken in two important dimensions. One difference is the treatment of cooperative interactions, the "swerve-swerve" and "dove-dove" interactions. In the war of attrition model, dove-dove interactions produce a zero payoff for both players since both avoid the cost of fighting and since neither is able to impose his desired outcome on the other player. In the Game of Chicken, however, swerve-swerve interactions produce a small positive payoff for both players because both drivers avoid being the sole "chicken."

Another difference between this model and the Game of Chicken is the treatment of mixed-type interactions, such as "swerve-drive straight" and "dove-hawk" interactions. In this model, when a dove interacts with a hawk, the dove's payoff is zero. He avoids the cost of fighting, and the other player's win does not impose a cost on the dove. In contrast, the worst possible outcome in the Game of Chicken is to swerve if the player is going to drive straight. The player that swerves not only obtains a negative payoff (since he has lost the contest), but also this negative payoff is greater than the negative payoff generated when both players drive straight. The logic of this result is that the driver that swerves is the sole "chicken." That is, although a head-on collision produces a negative payoff, neither player can be called a "chicken," an epithet deemed worse than the cost of

37. As my colleague Carlos del Valle has pointed out to me, a dove-dove interaction might produce a positive payoff, a "peace dividend." However, analysis of this type of payoff is outside the scope of our current inquiry.

38. *See, e.g.*, WILLIAM POUNDSTONE, PRISONER'S DILEMMA 197-201 (1993).

a head-on collision.[39]

Before proceeding, it is also worth taking a moment to describe the salient differences between the hawk-dove model presented in this paper and the traditional or classical hawk-dove model that appears in the game theory literature.[40] For reference, I shall refer to the traditional hawk-dove model as the "Maynard Smith model" to contrast it with the model presented in this paper, which I shall refer to as the modified war of attrition model, which differs from the Maynard Smith model in the following dimensions:

1. Biological versus social science approach

The focus of the classical Maynard Smith model is animal conflict.[41] Specifically, the Maynard Smith model is designed to explain the prevalence of "display" behavior in nature in which many species of animals settle contests without resort to actual fighting. The focus of my model, in contrast, is on actual human conflict, such as conflicts over public policy or scarce resources, and not on mere display behavior.[42]

2. Dove-dove interactions

Dove-dove interactions in the Maynard Smith model produce a payoff of $v/2$ for both players because the players are assumed to share the resource or, in the alternative, because the winner of the contest is selected at random, so that each player wins half of the time.[43] In my model, by contrast, I assume more realistically that when both players choose to back

39. The Game of Chicken thus raises an intriguing possibility: under what conditions might the dove strategy in our model generate a negative payoff? For example, there might be a cost to backing down (choosing dove) when the other player chooses hawk, such as a reputation cost. In addition, backing down at time T_1 might affect the outcome of a future contest at time T_2. That is, one's choice of strategy may have a "path-dependent effect." In the standard war of attritions model in the existing literature, the outcome of hawk-hawk and dove-dove interactions are completely random. *See, e.g.*, MAYNARD SMITH, *supra* note 1, at 12-13. However, one could imagine a more complex or dynamic model in which the choice of strategy during one round of play increases or decreases the distribution of payoffs in future rounds of the game. The intuition behind this idea is as follows: if A plays hawk and B plays dove during the first round of play, A not only wins the first round, A is also in a better position to win future rounds of play even if B later switches to hawk. Nevertheless, we ignore this possibility in our model for the sake of simplicity.

40. *See generally* MAYNARD SMITH, *supra* note 1, at 11-20 (detailing the numerous variables that are considered in the traditional model).

41. *See id.* at 10-12 (noting that the use of the word "strategy" in describing game theory is derived from animal behavior, specifically when animals compete over resources).

42. *See infra* Part IV.C (developing an evolutionary or biological model).

43. *See* MAYNARD SMITH, *supra* note 1, at 13 (rationalizing that if the resource cannot be shared, the cost is minimal since in the dove-dove interaction, the contestants are more prone to "display" and thus not injure each other).

down, neither player wins the contest, leading to a zero payoff (instead of $v/2$) for both players.

3. Hawk-hawk interactions

Lastly, in the Maynard Smith model the outcome of a hawk-hawk interaction is determined at random, leading to a payoff of $(v - c)/2$, because the players are assumed to be equally-matched.[44] My model likewise assumes that the players are equally matched, but I reach a fundamentally different conclusion from this baseline assumption. I conclude that neither player wins the contest, leading to a negative payoff of $-c$ instead of $(v - c)/2$ for both players, since their efforts are likely to cancel each other out, producing a costly war of attrition and preserving the status quo.

This approach to hawk-hawk interactions provides the key to understanding the inherently negative-sum nature of costly and protracted wars of attrition: when both sides choose to fight, neither side wins because a hawk-hawk interaction increases the likelihood of stalemate. Why? When both sides expend resources fighting for their respective policy outcomes, their efforts cancel each other out, leading to a costly war of attrition with no change in the status quo. Consider once again the Puerto Rican status debate and other examples set forth in Part II of this paper: the Major League Baseball strike of 1994-1995[45] and the Israeli-Palestinian conflict over West Bank settlements.[46] Both sides in these myriad conflicts prefer to see their respective positions prevail, but by refusing to negotiate or surrender to the demands of other side, the warring factions end up perpetuating a negative-sum conflict in which all sides are worse off.

Nevertheless, despite these differences, my modified model shares the same underlying logic and structure of the Maynard Smith model: in both models, the individual players are competing against each other, they are acting as proxies for strategies (either hawk or dove), and their strategies are set at the start of the game. Also, in both models the hawk strategy (fighting) can be compared to defection, while dove (backing down) is more akin to cooperation. That is, if both players choose to back down, then neither gets its preferred outcome, but neither pays the cost of fighting either, perhaps allowing time for a mutually-beneficial compromise

44. *See id*. at 12-13 (reasoning that each hawk contestant has a 50% chance of injuring the other contestant and winning the resource, and also a 50% chance of being injured by the other contestant and losing the resource).

45. *See* Staudohar, *supra* note 15, at 26 (documenting the losses that both Major League Baseball players and owners suffered during the strike).

46. *See* Bronner, *supra* note 16 (discussing the costs borne by both Israelis and Palestinians as a result of barriers, checkpoints, and other security procedures in place to prevent military escalation).

solution or a negotiated settlement. If both choose to fight, however, neither obtains its preferred outcome, yet both end up paying the cost of fighting.

Having compared and contrasted the classical Maynard Smith hawk-dove model with my modified war of attrition model, I now proceed to find the existence of Nash Equilibria[47] in the modified model. That is, what is the likely outcome of this revised hawk-dove game?

In summary, there are two pure-strategy equilibria in the modified one-shot game. This conclusion becomes apparent once one evaluates each player's best response to the other. Given the payoff structure of this modified hawk-dove model (as set forth in Figures 1a and 1b above), hawk is the best response to dove because $v - c$ is greater than 0, while dove is the best response to hawk because 0 is greater than c. That is, Player A prefers to fight if Player B is going to back down, and vice-versa, Player B prefers to back down if Player A is going to fight. Nevertheless, this is not the outcome one observes in the war of attrition scenarios described in Parts II and III above.[48] In the absence of conventions, external coercion, or bargaining, one observes that a conflict often escalates into a costly and protracted war of attrition. How can one explain the persistence of such wars of attrition (hawk-hawk interactions), in so many myriad types of conflict scenarios?

One source of this incongruity is the simultaneous-move nature of the modified hawk-dove game. Being a simultaneous-move game, neither player can observe the other player's move ahead of time, so the players could end up choosing the same strategies (hawk-hawk or dove-dove), leading to sub-optimal payoffs for both players. For example, both players might be committed *ex ante* to fighting—hoping in vain that the other player has chosen to back down—leading to a costly and pointless war of attrition in which both players end up fighting.

Another source of negative-sum hawk-hawk interactions is the possibility of mixed strategies. In place of a single, pure strategy (hawk or dove), the players might select a probabilistic mix of hawk-dove combinations, playing the hawk strategy, for example, with probability p and choosing dove with probability $1 - p$. Once I introduce the possibility of mixed strategies, one can easily determine the probability of a hawk-hawk interaction, that is, the probability that the game will turn into a war

47. *See* Guilherme Carmona, *Intermediate Preferences and Behavioral Conformity in Large Games*, 11 J. PUB. ECON. THEORY 10, 12 (2009) (defining a Nash Equilibrium as one in which all players choose the optimal strategy for themselves, while taking into account the actions of the other players, and each player cannot be better off by changing his strategy if the other players do not change theirs); *see also* John Nash, *The Bargaining Problem*, 18 ECONOMETRICA 155 (1950).

48. *Supra* Parts II & III.

of attrition.

Consider an infinite version of this two-player hawk-dove war of attrition game. That is, instead of a one-shot or single-round game, I now imagine a potentially never-ending game consisting of an infinite or endless number of rounds. For example, returning to some of the conflict scenarios set forth in Part II, one could model the long-standing debates over Puerto Rican status or the Middle East conflict as an endless hawk-dove game. Indeed, this idea is explicit in H.R. 2499, which proposes a potentially never-ending series of referenda if a majority of the voters fail to approve Option 2, the option to change Puerto Rico's status.[49] In summary, the payoff structure of the infinite game is identical to that of the one-shot game, since each individual round of the infinite game provides the same payoffs to the players as the one-shot game does. Furthermore, I assume the players avoid the "sunk cost fallacy" and ignore their previous payoffs (i.e., accumulated losses and wins during the previous rounds of play) because such previous payoffs are, in essence, sunk costs and thus have no bearing on the current round being played. The sunk cost fallacy assumes that a player considers their past decisions, and that their prior investment in fighting commits them to future investment. In ignoring sunk costs, I assume that the players act rationally and consider instead their expected or future payoffs in deciding his optimal strategy and thus in deciding whether to continue playing at all.[50] Later, in Part IV.C below, I relax this rationality assumption.Before proceeding, it is worth noting that the infinite version of the game will end only when one or both of the players decide to stop playing the game, either because one of the players has accumulated too many losses during the course of the game, leading to his voluntary surrender, or because both players are able to opt-out of the game altogether through a negotiated settlement or compromise solution. In this model, however, I assume that the players have an unlimited amount of resources to fight and that negotiations are not feasible.

What is the optimal strategy in the infinite game? Since neither player knows with certainty the strategy of the other player, the optimal approach might consist of a mixed strategy in which a player is indifferent to playing either hawk or dove. Consider Player A, although my analysis applies equally to both Players A and Player B since the payoffs in this model are

49. *See supra* notes 27-31; *see also* H.R. Res. 2499 111th Cong. § 2 (2009) (as reported by H. Comm. on Natural Res., Oct. 8, 2009) (declaring that if Option 1 is selected, Puerto Rico will only be able to reassess their status every eight years, whereas Option 2 lists three choices which would allow Puerto Rico to reach a final resolution on this ongoing debate).

50. *See, e.g.*, RICHARD DAWKINS, THE SELFISH GENE 150 (Oxford Univ. Press 1989) (1976) (analogizing situations where investors opt to cut their losses and abandon currently unproductive projects regardless of how much they have already invested to courtship rituals between males and coy females).

symmetrical for both players. Here, I introduce the related ideas of expected payoff and probability. That is, Player A's expected payoff from playing a given strategy (say, hawk) depends on the probability (p) that Player B might also play hawk as well as the probability ($1 - p$) that Player B might choose dove.

Thus, if Player A chooses hawk, Player A will pay a cost $-c$ with probability p and will obtain the payoff $v - c$ with probability $1 - p$. Recall that p is the probability that Player B also plays hawk, while $1 - p$ is the probability that Player B plays dove. Accordingly, the expected payoff (V) to Player A of playing hawk [$V(H)$] can thus be expressed mathematically as follows:[51]

$$V(H) = (-c)(p) + (v - c)(1 - p) \quad (1.1)$$

Likewise, Player A's expected payoff from choosing the dove strategy [$V(D)$] can be expressed in the following form:

$$V(D) = (0)(p) + (0)(1 - p)$$
$$V(D) = 0 \quad (1.2)$$

That is, if Player A chooses dove, then Player A receives a zero payoff because, regardless of the other player's strategy, the dove strategy always produces a zero payoff against both hawk and dove, given my initial assumptions.

Lastly, I determine Player A's optimal mixed strategy [$V'(A)$] by setting equations 1.1 and 1.2 equal to each other, substituting p' for p, and solving for p' as follows:

$$(-c)(p') + (v - c)(1 - p') = 0$$
$$-cp' + v - c - vp' + cp' = 0$$
$$v - c - vp' = 0$$
$$vp' = v - c$$
$$p' = (v - c)/v = V'(A) = V'(B) \quad (1.3)$$

In other words, Player A's optimal mixed strategy is to play hawk with a probability equal to $(v - c)/v$ and dove with probability $1 - (v - c)/v$. Notice that the optimal mixed strategy is actually the same for both players since the payoffs in this modified model are symmetrical.

Assuming v is greater than c, each player's optimal strategy in the

51. I present the complete details of our algebraic analysis so that the careful reader can follow each step of our analysis.

infinite game is to play hawk (fight) with a probability equal to the ratio that appears on the right-hand side of the above equation. This ratio is a function of the stakes of the contest (*v*) and the cost of fighting (*c*) and increases as the numerical value of *v* increases and decreases as the value of *c* increases. Thus, when $v > c$, there is a proportional relationship between the variables p' and *v* but an inverse relationship between p' and *c*.

Having determined the probability that either player will play hawk (equation 1.3 above), I will now find the probability that any given round of play will result in a hawk-hawk interaction, that is, the probability that both players will simultaneously play hawk in round *n* of play, where *n* is any individual round of play. In summary, since both players will choose the hawk strategy with probability p' due to the symmetrical payoff structure of the game, the probability that both players play hawk on any given round of play is simply $p' \times p'$, or p'^2. Similarly, the probability that hawk-hawk interactions occur on two consecutive rounds of play is $p'^2 \times p'^2$, or p'^4.Since the value of p' (and thus the value of p'^2) is a function of the stakes of the contest (*v*) and the cost of fighting (*c*), my modified hawk-dove model conveys a valuable insight about real-world symmetrical wars of attrition. In essence, the lesson is this: the larger the stakes of the conflict (the higher *v* is), the larger the probability of fighting. By the same token, the larger the cost of fighting (the higher *c* is), the smaller the probability of fighting. Thus far, I have presented a two-player war of attrition model. In the next subsection, I consider a more realistic *n*-player evolutionary model.

C. An n-Player Evolutionary War of Attrition Model

In place of the two-player model above, I now consider an *n*- or multi-player modified hawk-dove model. The *n*-player model operates on the following assumptions: the population consists of a large number of individuals; during each round of play, two individuals selected at random from the population meet and engage in a micro-conflict; and as before, there are only two possible strategies or types of individuals: hawk and dove. Lastly, I further assume that these strategies are transmitted through an asexual inheritance mechanism: the victor of each two-pair, micro-conflict not only survives but also produces a descendant-clone who asexually inherits the victor's strategy; the loser, in contrast, is eliminated from the population. If the conflict ends in a draw or tie, both contestants survive but neither produces a descendant.

Given these assumptions, which strategy will be favored by natural selection? To answer this question, I proceed in two stages. First, I restate the payoff (*V*) corresponding to each possible interaction. Since the payoffs are the same as before,[52] and since there are four possible micro-interactions in all (hawk-hawk, hawk-dove, dove-hawk, and dove-dove), the payoffs corresponding to each interaction can be written as follows:

$V(H \mid H) = -c$ (the payoff to a hawk, given that it interacts with another hawk)
$V(H \mid D) = v - c$ (the payoff to a hawk, given that it interacts with a dove)
$V(D \mid H) = 0$ (the payoff to a dove, given that it interacts with a hawk)
$V(D \mid D) = 0$ (the payoff to a dove, given that it interacts with another dove)

On the left-hand side, I have written the payoffs corresponding to each interaction in mathematical form, and on the right-hand side, I have "translated" the mathematical notation into plain English for the non-mathematical reader. Notice too that, because of the symmetrical nature of this model, for simplicity I state the payoffs of the row player only (Player A). In a population model, the fitness of a given strategy is said to be "frequency dependent" because the success or fitness of a strategy depends not only on the frequency of the other strategy but also on that strategy's own frequency.[53] When fitness (rate of survival) is frequency dependent, evolutionary game theory helps one to determine which strategies are "evolutionarily stable strategies" and thus to find the long-run evolutionary equilibrium of the population—that is, the frequency of hawks and doves over many generations. Specifically, I wish to answer the following two questions:

(1) Is either the hawk or dove strategy able to resist invasion by the other strategy?

(2) If no strategy is evolutionarily stable (i.e. able to resist invasion by the other strategy), is there an evolutionarily stable mix of strategies?

Let p be the frequency of hawks in the population and $1 - p$ the frequency of doves in the population. First, consider a population in which the frequency of hawks is very high ($p \approx 1$). Under this scenario, hawks rarely interact with doves because the frequency of doves is very low ($1 - p \approx 0$), and thus the expected or average payoff (W) when the player acts as a hawk (H) is determined by her interactions with other hawks as follows:

$$W(H) = w' + (1)[V(H \mid H)] + (1 - 1)[V(H \mid D)]$$

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52. *Cf.* Figure 1b, *supra* Part IV:B.

53. *See* MCELREATH & BOYD, *supra* note 33, at 38 (citing the significance of evolutionary game theory in determining when it best pays an individual to fight or flee based on the actions of the individual's opponent).

$W(H) = w' + V(H \mid H)$
$W(H) = w' - c$

Note that the parameter *w'* in this equation refers to the "baseline fitness" of all the individuals in the population—that is, the probability of survival from generation to generation—and thus reflects the strength of selection on a given population.[54] For convenience, I assume that *w'* is larger than *c*, the cost of fighting.

Now, consider the possibility of a rare dove-like mutant. What would happen if a hawk were to interact with this rare dove mutant? Will the dove strategy begin to spread across the population, gradually displacing the hawks, or will the hawk strategy be able to resist invasion? To answer this question, I determine the average fitness of the rare dove mutants among the population of hawks. Since doves are rare ($1 - p \approx 0$), the chance one dove will meet another dove is likewise small. As a result, the average fitness of a rare dove [$W(D)$] is determined by his interaction with hawks as follows:

$\mathrm{W(D) = w' + V(D \mid H)}$
$\mathrm{W(D) = w' + 0}$
$\mathrm{W(D) = w'}$

Notice, then, that in a population of hawks, the rare doves will on average outperform the hawks because $W(D)$ is larger than $W(H)$. In other words, doves will invade the population and displace hawks because the average fitness of each dove (w') is on average higher than the average fitness of each hawk ($w' - c$). Hawks will not be able to resist an invasion of doves. But can a population of doves resist an invasion of hawks?

Consider next a population in which the frequency of doves is very high ($1 - p \approx 1$). Since doves rarely interact with hawks when the frequency of hawks is low ($p \approx 0$), the average fitness of a dove [$W(D)$] is determined by her interactions with other doves as follows:

$W(D) = w' + (1)[V(D \mid D)] + (1 - 1)[V(D \mid H)]$
$W(D) = w' + V(D \mid D)$
$W(D) = w' + 0$
$W(D) = w'$

What would happen if a rare hawk-like mutant were to appear on the

54. *See id.* at 40-41 (noting that when the baseline fitness is large in comparison to the effect of the behavior in question, gene frequencies change more slowly than if the baseline fitness is small).

scene? Since hawks are rare ($p \approx 0$), the hawk mutant will interact mostly with the doves and her average fitness [$W(H)$] is thus as follows:

$$W(H) = w' + V(H \mid D)$$
$$W(H) = w' + v - c$$

Thus, in a population of doves, the rare hawks will on average do better than the doves because $W(H)$ is larger than $W(D)$ when the baseline fitness is larger than the cost of fighting. Just as doves will invade a population of hawks, in this case hawks will invade a population of doves and eventually displace the doves because the average fitness of each hawk ($w' + v - c$) is on average higher than the average fitness of each dove (w') when v is greater than c. Accordingly, these results suggest that neither hawk nor dove is an evolutionarily stable strategy because neither strategy is able to resist invasion by the other. But is there some stable mix of hawks and doves? And if so, what is it? That is, in the long-run, what proportion of the population will be hawks, and what proportion will be doves?

To find this mixed or "polymorphic" population equilibrium, one must first determine the expected or average payoff (W) corresponding to each strategy across a large number of interactions. Since the expected payoffs depend on the overall frequency or proportion of hawks and doves in the population, again let p be the frequency of hawks in the population and $1-p$ the frequency of doves in the population. Then, assuming that individuals interact at random, I obtain the expected fitness of a hawk as follows:

$$W(H) = w' + (p)[V(H \mid H)] + (1-p)[V(H \mid D)]$$
$$W(H) = w' + (p)(-c) + (1-p)(v-c)$$
$$W(H) = w' - pc + v - c - pv + pc$$
$$W(H) = w' + v - c - pv \qquad (2.1)$$

Similarly, I obtain the expected fitness of a dove [$W(D)$] as follows (and, again, recall that the parameter w' is the average fitness or baseline fitness of all individuals in the population):

$$W(D) = w' + (p)[V(D \mid H)] + (1-p)[V(D \mid D)]$$
$$W(D) = w' + (p)(0) + (1-p)(0)$$
$$W(D) = w' + 0 + 0$$
$$W(D) = w' \qquad (2.2)$$

Having determined the expected fitness of hawks and doves, I next proceed to find the frequency at which there is an evolutionarily stable mix of hawks and doves in the population by setting $p = p'$ and $W(D) = W(H)$ and solving for p' as follows:

$$W(D) = W(H)$$
$$w' = w' + v - c - p'v$$
$$p'v = v - c$$
$$p' = (v - c)/v \qquad (2.3)$$

Notice the striking parallel between the results of this evolutionary population model and results of the standard two-player game-theoretic model in the previous subsection of this paper. Specifically, under the standard model an individual player's optimal mixed strategy is to play hawk with a probability equal to $(v - c)/v$.[55] Similarly, the equivalent evolutionary model demonstrates that the evolutionarily stable proportion of hawks in a large population is also equal to the same ratio: $(v - c)/v$.

In addition, like my previous model, the evolutionary model produces two qualitatively different outcomes depending on the ratio of v to c. When the value of the resource exceeds the cost of fighting ($v > c$), hawks will displace doves from the population, and the larger v is in relation to c, the greater the proportion of the population will consist of hawks. But when the cost of fighting exceeds the value of the contested resource ($v < c$), then doves will outperform hawks, and the larger c is in relation to v, the greater the proportion of doves will be. In both cases, the population will consist of a mix of doves and hawks, with the actual proportion of this mix depending on the magnitudes of v and c.

V. CONCLUSION

I conclude this paper by identifying the following three questions as fruitful areas for future research:

(1) What happens when the payoffs are asymmetrical instead of symmetrical?

In this paper, I have assumed for the sake of simplicity that the cost of fighting (c) and the stakes of the contest (v) are symmetrical for the players. In reality, however, although both players might prefer some form of change to the status quo, they will often disagree on the extent of the desired change. One player might prefer a radical or "hard" change to the status quo (the "hard player"), while the other player might prefer a small or "soft" change (the "soft player"). In other words, the stakes of the conflict and thus the cost of fighting might be asymmetrical for the

55. *Cf.* Equation 1.3, *supra* Part IV.B.

players.[56]

(2) What happens if the values of the parameters *v* and *c* change over time?

Another interesting question for future research is to consider the possibility that *v* and *c* might not be fixed but might change over time. That is, the payoffs might be dynamic instead of static. For example, the value of the contested resource might grow with time. By the same token, the cost of fighting might vary over time as tactics and technology change. Thus, one could build a model in which either *v* or *c* (or both) change by some constant *k*. This constant might be fixed in which *v* increases by some factor *k'* during each round of play, or it might be probabilistic, varying from 0 to 1 according to some random mechanism.

(3) Is there a link between payoffs in a given round and the outcome of future rounds?

Lastly, another interesting idea for future work is the possibility of the players becoming stronger or weaker over time, i.e., during successive rounds of play. One could imagine a model in which previous gains increase the probability of future gains—and in which losses during previous rounds of play increase the probability of future losses. The intuition here is that one's previous choices will not only have an effect on one's future choices, but will also affect the likely outcome of the future rounds of the game. For example, instead of the outcome of a hawk-hawk interaction or dove-dove interaction being decided randomly, as in the Maynard Smith model, the outcome of such interactions might be based on the relative strength of each player, which in turn would depend on the outcome of previous rounds of play.

Also, in this paper I do not consider the accumulated payoffs (both losses and gains) from previous rounds of play, since such payoffs are, in effect, sunk costs. But in real life, the outcomes of previous rounds of play do have an effect on the psychology of the players. Moreover, once one assumes that the resources available to the players are scarce or subject to some upper limit and that the selection and implementation of a strategy is not costless,[57] then it becomes imperative to keep track of losses and gains

56. For example, returning to H.R. 2499, the debate over Puerto Rico's constitutional status is, in essence, a strategic contest between hard and soft players in which the existing Commonwealth status serves as the status quo position. The NPP and the PIP support the statehood and independence options, respectively. Both options constitute hard changes to the status quo. The PDP, in contrast, prefers an "enhanced" or improved Commonwealth, a softer or more incremental change. But many members of the PDP as well as the PIP prefer the status quo to statehood; that is, they perceive the Commonwealth status as a "lesser evil" than statehood. *See supra* notes 24-26.

57. *See, e.g.*, R. H. Coase, *The Nature of the Firm*, 4 ECONOMICA 386, 390-91 (1937) (surmising that if there were no limits, the situation would be analogous to voluntary slavery).

during the rounds of play.

One possibility for doing this might be to present the model in visual form. For example, whether the players are contesting rights to land, access to water, or shares of revenue, the sum value of the contested resource (land, water, revenue) might be presented visually in the form of a circle. This circle, in turn, would consist of two colors, such a blue and green, with blue representing one player's share of the contested resource and green representing the other player's share. The idea here is to present visually the changes over time to each player's share of the contested resource during successive rounds of play.

* * *

Summing up, competing interactions over scarce resources or over the content of public policy can result in radically different outcomes. Consistent with Adam Smith's "invisible hand" metaphor of markets, some interactions might lead to a positive-sum equilibrium in which everyone benefits from mutual cooperation.[58] Other interactions, in contrast, might produce a negative-sum Hobbesian equilibrium in which everyone is worse off because of mutual defection.[59] For example, when conventions, coercion, and bargaining are not available for achieving a positive-sum outcome, a competitive interaction might result in a costly and protracted war of attrition.

Furthermore, negative-sum wars of attrition abound in the real world. Consider, once again, the centennial debate over Puerto Rico's constitutional status, the stand-off between the player's union and baseball club owners during the Major League Baseball strike/lock-out of 1994-1995, and the long-standing conflict between Israel and Palestine over disputed water rights and the construction of Jewish settlements in the West Bank. In all these conflicts, the contending parties are locked in a costly and protracted negative-sum war of attrition.

In this paper, I have attempted to determine the conditions under which a hawk-hawk interaction or costly war of attrition is most likely to occur, and I have shown that when the payoffs are symmetrical and bluffing is not permitted, the probability of a player choosing the hawk strategy (or the proportion of the population consisting of hawks) is a function of the stakes

58. *See, e.g.*, Robert L. Trivers, *The Evolution of Reciprocal Altruism*, 46 Q. REV. BIOLOGY 35, 45-46 (1971) (analyzing human reciprocal altruism and how all members can benefit when sharing food, tools, and knowledge).

59. *See, e.g.*, DAWKINS, *supra* note 50, at 203 (providing examples of the four types of outcomes possible under game theory and delineating how both players lose if both choose to "defect").

of the contest (*v*) and the cost of fighting (*c*) and increases as the numerical value of *v* increases and decreases as the value of *c* increases. The larger the stakes of the conflict are—that is, the higher *v* is in relation to *c*—the larger the probability of fighting (or the greater the proportion of hawks in the population). In the alternative, the larger the cost of fighting is—the higher *c* is in relation to *v*—the smaller the probability of fighting (or the smaller the proportion of hawks in the population). In real-life terms, this analysis suggests that certain public policy and legal disputes are more likely to result in intractable war of attritions where the stakes of the contest are larger in relation to the costs of fighting. This analysis also suggests that one way of preventing such wars of attrition is by increasing the cost of fighting relative to the value of prevailing.

