Deterring War in Outer Space: A Game Theoretic Analysis Incorporating Prospect Theory to Explore Decision Making under Uncertainty

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Abstract

Access to and protection of the commons of outer space is essential to global stability and prosperity. We rely on space for communication, navigation and imagery, including monitoring of arms agreements. These peaceful uses may be curtailed or destroyed entirely if terrestrial conflict were to extend to attacks against space assets. In the past 20 years, the U.S. has demonstrated a highly asymmetric reliance on space to project military power into theaters of war across the globe. In 2007, China successfully destroyed a satellite using an anti-satellite missile and Russia has conducted numerous anti-satellite missile tests recently. The actions of both China and Russia have reminded us the space environment is exceptionally difficult to defend, with the advantage going to the attacker. In fact, the potential for war in outer space has all of the attributes of a classic security dilemma. Almost any action taken in space can be misconstrued—defensive preparations, or even just normal use and exploration, can be easily mistaken as offensive preparations, destabilizing the status quo.

In considering the above characteristics of space conflict, analysts have concluded that war in outer space is "inevitable." Their conclusions are largely based on analyses that use a game-theoretic model of conflict vs. cooperation and assume that states are unitary, rational decision-makers seeking to maximize their expected utility. We built a game-theoretic model of space war to explore these conclusions. However, we changed two aspects of the traditional game-theoretic model. First, we substituted prospect theory in place of purely rational decision-making. Prospect theory argues that people tend to avoid risk when they are satisfied with the status quo, and tend to be risk acceptant or even risk seeking when they are dissatisfied with the status quo. Second, we applied prospect theory separately to multiple dimensions of state power, making our actors less "unitary."

Initial results suggest that prospect theory has a significant effect on results, and game play that drives players towards more symmetric sentiments (i.e., both satisfied with the status quo) reduces the intensity of conflict. Using prospect theory, our games result in deterrence of war over a wider range of asymmetries in the balance of power and in the offensive-defensive balance than a purely rational model would predict. This may present feasible options for establishment of a deterrence regime.

Acknowledgement

The game theoretic model of space war used in our analysis was developed by James Pita of Avata Intelligence, Venice, CA. It is one of the largest game theoretic models ever built.

The question of how conflicts will be fought in outer space should be a critical concern to citizens of all nations. Earth orbiting satellites are now within reach of a new category of destructive weapons: anti-satellite weapons that use kinetic, directed energy or cyber means. Military and intelligence satellites would be likely targets for such weapons in times of war, but commercial and international civilian services would certainly incur collateral damage. This is because space assets often provide both military and civilian services, such as navigation signals provided by the Global Positioning System, and because military functions run on commercial platforms, as is the case with many satellite communications providers. Sudden disruptions in satellite services would wreak havoc on many aspects of modern life, from banking transactions to weather forecasting, and from internet communications to navigation. Even if it were possible to attack only military and intelligence satellites, the orbiting debris created by hypervelocity collisions of kinetic weapons and spacecraft could cause a cascading series of accidents that would make entire orbits unusable for many generations.

Just such a future appears to have been contemplated by major space powers as they consider how dependency on space can be used as an exploitable vulnerability and take deliberate actions to strengthen their own counter-space capabilities. For example, in 2007, China successfully destroyed a satellite using an anti-satellite missile.[1] Demonstrating the capability undoubtedly sent a strong message to U.S. military decision-makers regarding China's ability to mount an effective threat to U.S. space-enabled assets.[2] In October 2016, Russia conducted its fifth test of an anti-satellite missile capable of degrading U.S. strategic communications and other systems critical to national defense.[3] The U.S. is also pursuing options for fighting conflicts in outer-space.[4]

In examining the characteristics of space conflict, many analysts have concluded that war in outer space is inevitable.[5] These conclusions are largely based on analyses that use a game-theoretic model of conflict vs.

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[1] "China's Anti-Satellite Test: Worrisome Debris Cloud Circles Earth," *Space.com*, February 2, 2007: http://www.space.com/3415-china-anti-satellite-test-worrisome-debris-cloud-circles-earth.html

[2] Whether or not China intended to send such a signal is in debate. None the less, US space policy analysts saw it as such, with some hypothesizing it was an attempt to bring the US to the negotiating table regarding the weaponization of outer space. Broad and Sanger, *The New York Times,* China Tests Anti-Satellite Weapon, Unnerving US, Jan 18, 2007. http://www.nytimes.com/2007/01/18/world/asia/18cnd-china.html

In in the 2007 Annual Report to Congress on Chinese military strength, the incident is cited as a demonstration of the ability to attack low earth orbit. The report further states "The direct ascent ASAT system is one component of a multi-dimensional program to generate the capability to deny others access to outer space." (Office of the Secretary of Defense 2000-2008, 11)

[3] "Russia has conducted the fifth test of a new anti-satellite weapon that could knock out US communications," *The Washington Free Beacon*, December 21, 2016: http://freebeacon.com/national-security/russia-conducts-fifth-test-new-anti-satellite-missile/

[4] In written testimony to Congress in 2016, Gen. Hyten (Commander of US Space Command) stated "<We are> fully occupied figuring out how to prepare to effectively fight conflict that extends into the space domain." http://spacenews.com/hyten-tells-senate-dod-needs-to-focus-on-space-control-battle-management-system/#sthash.bPRk7tyN.dpuf

[5] See Joan Johnson-Freese's *Space Warfare in the 21st Century, Arming the Heavens* (2017) for an eloquent delineation of how the assumption that space war is inevitable has become embedded in US space policy. Perhaps the most famous statement of the inevitability of space war is from the *Report of the Commission to Assess United States National Security Space Management and Organization Executive Summary* (January, 2001), which contemplates a "Space Pearl Harbor" and states in its findings that "…we know from history that every medium—air, land and sea—has seen conflict. Reality indicates that space will be no different. Given this virtual certainty, the U.S. must develop the means both to deter and to defend against hostile acts in and from space." This inevitability

cooperation and that assume that states function as rational "utility maximizers," who weigh their options and choose the one that will provide the greatest value (military, political, etc.). However, meddling in space is a risky proposition, and the rewards are far from certain, which makes it more difficult to determine which move (war, deterrence) has the greatest utility. How might we predict when major space powers perceive the reward worth the risk? Can they be deterred? In this paper, we discuss a game-theoretic model of space conflict that uses *prospect theory* to address this uncertainty by incorporating "sentiments" (i.e., states' perceptions of their relative standing under the status quo) into players' decision-making processes.

I. Methodology

While traditional game-theoretic models of conflict vs. cooperation assume that states are unitary, rational utility-maximizing decision-makers, our game theoretic model is instrumented to let us vary both balance of military power between players as well as the offensive-defensive balance for each player. Our model changes two aspects of the hypothesis that states act as unitary, rational expected utility maximizing decision-makers:

1. We substituted *prospect theory* in place of rational decision-making. While the state actors in our model are still utility maximizers, their perception of utility is now shaped by their *sentiment* (i.e., perspective) regarding their standing under the status quo rather than rational utility maximization.
2. We applied prospect theory separately to multiple dimensions of state power, making our actors less "unitary" in the way they derive their decisions.

We discuss the model in further detail below.

Prospect theory describes decision-making behavior in an environment dominated by uncertainty as dependent upon how an individual feels about the status quo (Daniel Kahneman and Amos Tversky, 1979). As a general principle, the theory argues that people tend to avoid risk when they are satisfied with the status quo, and tend to be risk acceptant or even risk seeking when they are dissatisfied with the status quo. The introduction of multidimensional prospects adds nuance to the discussion of a player's sentiment regarding the status quo. To explore those nuances, we conceptualize prospect theory not simply as a single dimensional curve, but as a multi-dimensional "sentiment map."[6] Using the map allows us to explore how a player's decision to attack vs. maintain the status quo can be predicted based on the direction a decision to attack would "move" each player on their sentiment maps.

Limitations of Our Approach. While our methodology is firmly grounded in the social science literature of psychology and deterrence, it remains based on a game-theoretic construct and, as such, has many of the drawbacks

is echoed by Forrest Morgan (2010, 18), when he notes "At some point, the conflict would reach a threshold at which the growing benefits of transitioning to destructive attacks on certain space systems would overtake the dwindling costs of doing so, and the enemy would escalate in space." In fact, our own work does show that there is a point at which war in space becomes inevitable. Our research is focused on how that point shifts under prospect theory.

[6] The sentiment maps used in our analysis were created by Bonnie Triezenberg in support of her dissertation for the PhD in policy analysis.

of the ‘rational actor model’ of decision-making and deterrence.[7] Our methodology still assumes that players will seek to maximize their expected utility—albeit now with an adjusted perception of reality. In reality, historic records show that it is rare for either individuals or states to consciously make decisions based on the complex calculus of maximizing expected utility. While the addition of multiple dimensions of power lets us analyze how a state actor’s “sentiments” regarding political vs. military power might play out in multidimensional space, we still assume that states have a “unified sentiment” for each dimension of power. As many authors and researchers have pointed out, state decisions are rarely the output of unitary actors and instead are the negotiated outcomes resulting from small groups of decision-makers, each undoubtedly with his or her own individual sentiments. Furthermore, those decisions are carried out by large organizations whose decisions are shaped by organizational culture and standard operating procedures. The actual steps that adversary states will take in pursuing space war or deterrence will undoubtedly be heavily impacted by the complex organizational models of the U.S. and international space community.

II. Game Theory and Prospect Theory in International Relations

The next sections provide a description of both game theory and prospect theory while also explaining in more detail how we used these approaches in our model. By necessity, our descriptions are brief and cannot do justice to the intricacies and elegance of the theories. Readers who are unfamiliar with the concepts would be well served to read Thomas Schelling’s classic work on game theory *The Strategy of Conflict* (Schelling 1960) and Daniel Kahneman’s highly accessible book *Thinking, Fast and Slow* (Kahneman 2011) in which he describes the pioneering work on prospect theory conducted with his colleague Amos Tversky (Kahneman and Tversky, Prospect Theory: An Analysis of Decision under Risk 1979). In our methodology, these theories complement each other to provide a more robust method for understanding decision-making under conditions of uncertainty and risk. In the descriptions below, we focus only on the specifics of our implementation that are pertinent to understanding the implications of our work to the analysis of strategic deterrence.

Game theory pertains to “the study of mathematical models of conflict and cooperation between intelligent rational decision-makers” (Myerson, 1991). Game theory came to prominence in the Cold War as a means of understanding whether the strategic balance of power could be used to deter nuclear war. Without large computers, game theory was primarily a theoretic model, occasionally using simple math, but largely constrained to qualitative analyses. Only in the last few years has it been possible to apply game theory quantitatively to complex issues of conflict and cooperation. The game-theoretic models used in these quantitative analyses solve a set of equations to determine the moves that maximize one player’s objective while the opponent simultaneously maximizes their own objective. As such, game theory requires a method to “keep score.”

[7] In their rigorous analysis of the Cuban missile crisis, Graham Allison and Philip Zelikov provide a vivid and compelling critique of the applicability of the rational actor model to games of cooperation and conflict (Allison and Zelikow 1999). Although they do not reference prospect theory in their work, the sentiments of players are shown to be a significant factor in their governmental policy model analysis of the crisis.

To keep score in our model, we adopted a construct used by U.S. military strategists, which examines critical dimensions of state power: political, economic, societal, information and infrastructure (PMESII).[8] We assess a score for each PMESII variable for each player, which means that our analysis is inherently multidimensional. For example, an attack against the U.S. Global Positioning System (GPS) used to navigate U.S. warships and guide precision bombs pays off militarily for an adversary, but, because that same satellite system is also essential to the everyday business and social transactions of billions of global users, the attack also creates a loss of societal, information and infrastructure (SII) that could prove escalatory. Furthermore, the GPS satellites carry a sensor for detecting nuclear events and an attack could be misconstrued as preparation for nuclear war, politically stigmatizing the attacker while creating sympathy for the U.S. The net payout would be a significant strengthening of U.S. political power on the international stage.

Therefore, all players in our model must weigh choices that could provide benefits in one aspect coupled with losses in another (e.g. military gains at the expense of political losses). Rather than playing one or two moves, our game theoretic model plays out over multiple years during which time the players have moves available every day. The results discussed in this paper used a 10year period, with a ground war beginning at the start of the second year.

While a traditional game-theoretic model provides insight into how players' objective values and goals impact their decisions to go to war in outer space or to maintain the status quo, it stops short of explaining how an adversary's feelings, or "sentiments," regarding the status quo impact his strategic decision calculus. For example, would a decision-maker who is dissatisfied with his military standing under the status quo be more or less inclined to attack an adversary's satellite than a rational weighing of alternatives would suggest? Would a decision-maker who enjoys a high political standing on the international stage feel more or less emboldened to attempt a belligerent act along these lines?

To move the game-theoretic analysis forward and allow us to map these sentiments, we turned to prospect theory for a model of how sentiments impact decision-making. Prospect theory is a cognitive-based approach to understanding risk-based decision-making. The theory was initially developed by economists Daniel Kahneman and Amos Tversky (1979) in an effort to resolve apparent inconsistencies in expected utility theory (the basis of game-theoretic models), which critics assert fails to accurately predict individuals' risk preferences. According to prospect theory, an individual's decisions in an environment dominated by uncertainty depend upon how the individual feels about the status quo. As a general principle, individuals tend to avoid risk when they are satisfied with the status quo. Conversely, individuals tend to be risk acceptant or even risk seeking when they are dissatisfied with the status quo. Prospect theory is based on observations that (a) individuals often undervalue gains and exaggerate the impact of a loss, and (b) humans are notoriously bad at evaluating probabilistic outcomes.[9]

These two effects combine to form the Prospect Curve shown in Figure 1. In the figure, "objective" gains and losses are shown on the horizontal axis. These objective values represent the modeler's best attempt to judge results

[8] Joint Chiefs of Staff, Joint Publication 3-0, "Joint Operations." August 11, 2011, http://www.dtic.mil/doctrine/new_pubs/jp3_0.pdf. Last accessed December 30, 2016.

[9] Kahneman offers many examples of how individual's mistaken perceptions of probabilities lead them astray. For example, one study found that most people think the probabilities of death by disease vs. death by accident are about equal. In reality, you are 18 times more likely to die from disease than accident. (Kahneman 2011, p. 138)

of particular moves using an objective measure (in our game, these are the metrics of state power). The vertical axis shows the "subjective" utility, which represents a player's perception of the results of the move. The S-shaped curve is a "utility function", mapping the objective expected payout of a decision to a subjective payout. As such, the mapping is based on a player's sentiment at the time the decision is made.

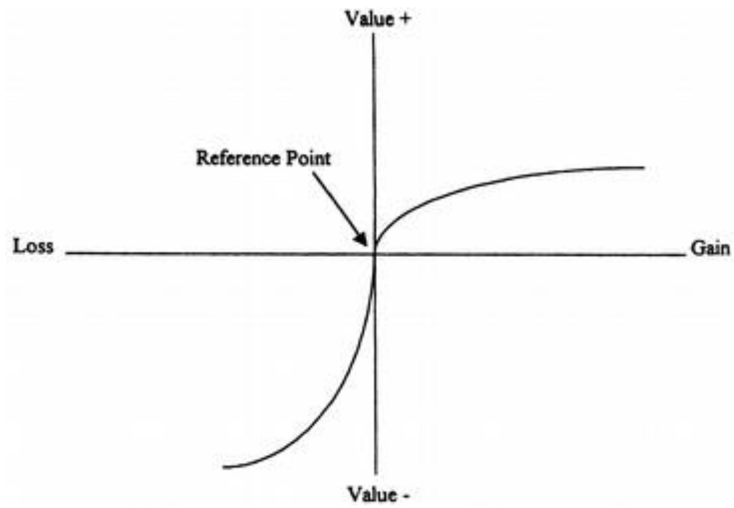

Figure 1. Prospect Theory S-Curve

Behavioral psychologists have conducted multiple laboratory experiments (typically with monetary payoffs) to determine the slopes of the prospect curve.[10] They have found that players are reasonably objective regarding an uncertain payout if the decision is structured as an opportunity to "win." In this case, the slope of the curve is ~1 and we term the decision "rational." However, the same player when faced with the same decision, but structured as an opportunity to "lose," will overvalue the probability of payout by a factor of two or three. Since these behavioral experiments are conducted for relatively low-stakes gambles, they represent play near the reference point of the prospect curve. However, further from the reference point, when players are evaluating large changes in objective standing, perceptions of value flatten for players in both the domain of gains (diminishing returns) and in the domain of losses (nothing left to lose). It is difficult to measure the magnitude of the gain or loss at which this flattening occurs given the ethical implications of putting test subjects into situations where the opportunity to experience large gains or losses is real. It is even more difficult to determine how the shape of the curve changes when individuals are operating under both fear and uncertainty, as occurs in times of war.[11] There is also limited research regarding how the shape of the prospect curve changes under group decision-making.[12] It is a limitation of the model used in this paper that measured laboratory values for prospects may simply not be applicative to games of deterrence in international relations. Therefore, we caution that only very broad conclusions should be drawn from our work regarding the impact of sentiments on deterrence of war.

Despite these limitations, the international relations literature has found merit in applying elements of prospect theory to the discourse on how leaders, and as an extension, states, make decisions in risky and complex environments. Scholars assert that prospect theory explains some fundamental weaknesses in traditional game-theoretic models' ability to predict decision-making behavior under conditions of risk because it recognizes that cognitive variables have a significant influence on risk orientation. Scholars describe risky state behavior as a

[10] See for instance Bosch-Domenech (2006) and Elsbach (1999).

[11] See for instance, Chanel and Chichilnisky (2009), Pratt (1964) and Yechiam (2015).

[12] It is important to note that we assume a "unitary" state decision maker in our calculations. We do not consider how the shape of the prospect curve changes under group decision making. One such study is Shupp and Williams (2008) exploration of how individual vs. small groups make decisions.

function of whether leaders of those states perceive themselves to be in a domain of gains or losses. Leaders of status quo states who are comfortable and invested in the current environment are considered to be operating in a *domain of gains* where the perception of a potential gain is less than its objective value, making the state unlikely to initiate risky behavior to obtain it. In contrast, leaders who are dissatisfied with the status quo environment are considered to be in a *domain of losses*. While a state's perceptions of both gains and losses are exaggerated, their perception of loss is less so, making a state in the domain of losses more willing to risk upsetting the status quo with the hope of improving their circumstances. Once the state in a domain of losses achieves those gains, it will likely become more risk averse and work to maintain the new status quo. For example, Rose McDermott (1992) applied prospect theory to President Carter's decision-making during the Iran hostage crisis. She explains that Carter chose to initiate a rescue mission in April 1980 because he perceived the United States (and the image of his administration) to be in a domain of losses. This feeling was likely amplified by Iran's Ayatola Khomeni who used the hostage issue as an embarrassment to the Carter administration. Thus Carter was willing to respond to the hostage crisis with active force despite the complexity of the plan and the fact that the various team members had never practiced the operation as an integrated team. [13] In a later effort, McDermott (1998) examined Carter's decision to allow the exiled Shah of Iran into the United States, as well as additional cases that analyze President Eisenhower's decision-making during the 1956 Suez Crisis and the 1960 U-2 Crisis. The common theme McDermott finds is that in each situation the choices made were a result of the way leaders framed their status as either in a domain of gains or losses. When leaders found themselves to be satisfied with the status quo they were reluctant to embark on risky foreign policies. Once the balance tipped toward a domain of strategic losses, leaders took steps to prevent or reverse these losses.

The international relations literature offers numerous qualitative examples of how prospect theory could be used to explain deviations from rational decision-making in international conflict. [14] However, much of the literature tends to view only one side of the conflict, with far less consideration of how an actor's *adversary's* interests, goals and perceptions impact their own decisions and course of action. There are exceptions, however. In Robert Jervis's "Psychology and Deterrence", six different authors examine the historical record of conflicts in the late 20th century, looking at both sides of conflict to highlight differences in the decision-making calculus of those seeking to

[13] The Iranian hostage crises began November 4, 1979 when more than 3,000 Iranians overran the US Embassy in Tehran. 66 Americas were seized and held hostage for over a year. An analysis of the risks inherent in the April 1980 operation to free the hostages, written by Charles Kamps for the Air & Space Power Journal (2006), can be found at http://www.au.af.mil/au/afri/aspj/apjinternational/apj-s/2006/3tri06/kampseng.html .

[14] For additional examples see Audrey McInerney (1992) who analyzes risky behavior by the Soviet leadership in the days leading up to the 1967 Six Day War between Israel and the armies of Egypt, Syria and Jordan. Applying the tenets of prospect theory, McInerney contends that the Soviets were operating from a loss domain and were thus willing to embark on a riskier path in order to arrest the potential for losses in influence in the region. Mark L. Haas (2001) draws similar conclusions in a Prospect Theory-driven analysis of the Cuban Missile Crisis. He contends that both Kennedy and Khrushchev engaged in risky decision making because each leader perceived that they were operating in a domain of losses on both international security and domestic political fronts. Cooler heads prevailed only when these leaders felt the probability of a worse outcome than the status quo was imminent. Stein and Pauly (1993) put forth an additional volume of case studies by a series of scholars who describe state decision-making as a function of how leaders framed the situation in terms of strategic losses or gains. See also, Cha (2002), McInerney (1992), and Taliaferro (2004).

change the status quo and of those seeking to maintain the status quo.[15] While the authors do not explicitly apply prospect theory, the basic tenets of the theory are upheld in their findings:[16] When bargaining appears hopeless and alternatives are perceived to be shutting down (perhaps amplifying feelings of being in a domain of losses), a determined adversary of the status quo will be driven to attack even when a rational weighting of gains and losses "should" deter that attack.[17]

We are not the first to consider how prospect theory could be incorporated into a quantitative game theoretic model to predict decision-making in games of cooperation and conflict. Jeffrey Berejikian used a simple game of "chicken" to show that prospect theory helps explain how deterrence breaks down when a nation state perceives itself to be in a domain of losses, but little work has been done to extend his work to more complex games.[18] Berejikian's analysis indicates that when both players' sentiments regarding their standing under the status quo are *symmetric* (i.e., both satisfied or both dissatisfied), deterrence is easier to achieve than rational game theory would predict. However, if there is an asymmetry in sentiments so that one player is satisfied but the other dissatisfied, deterrence is much harder to achieve.

All of the above studies underscore the importance of understanding the reference point from which states define their standing on the world stage. This reference point represents where they feel their standing "should be" in the international arena. The reference point is often (though not always) assumed to be equivalent to the status quo or to the status a player had at some time in the recent or even distant past. Since our goal in this paper is to provide a *quantitative* means to explore how the interaction of player sentiments regarding their status under the status quo impact decisions to wage war, we need to explicitly define the reference point in multiple dimensions of state power. Therefore, the reference point in our game is treated as an exogenous variable, allowing us to explore the full range of possible player sentiments and how those sentiments impact decision-making.

III. Game Model

The game model we used for our analysis is necessarily complex given that attacks and defenses of space assets are constrained by the dynamics of maneuvering in space, the capabilities of the weapons used, the defenses of the assets attacked and the myriad of ways in which both offensive and defensive means can be employed. In this section, we describe the decision models used by the players. By focusing on the cognitive models, we hope that others may find this paper helpful when introducing elements of "irrational play" (i.e., moves based on subjective

[15] Jervis, Psychology and Deterrence (1985), p. 3

[16] In Jervis's recent book, "*how statesmen think, the psychology of international politics*" (2017, 90), he examines the efficacy of prospect theory to explain leaders decision making and notes "Cutting losses after expenditure of blood and treasure is perhaps the most difficult act a statesman can take; the lure of the gamble that persevering will recoup the losses is often too great to resist."

[17] Gross Stein (1985) p. 55 and Lebow (1985) p. 119

[18] Jeffrey Berejikian (2002), "A Cognitive Theory of Deterrence," Journal of Peace Research, vol. 39, no. 2, pp. 165-183.

evaluations of gains and losses shaped by a player's sentiment) into game-theoretic models of realms far beyond space war.[19]

The proposed game-theoretic formulation is outlined with respect to the player, their payoff functions, the actions they can take (the things they can change), and the information they have access to. As shown in Figure 2, we use a two-player game in which each player's cognitive decision model is defined by both an objective and by a mindset. The player's objective is based upon the game score in the Political (P), Military (M), and Social, Infrastructure, and Information (SII) dimensions of state power. Mindset is a composite variable based on the level of escalation in the game, the player's sentiment regarding his standing in the status quo, and whether he prefers offense to defense. To simplify the results discussed in this paper, the player's mindset is defensive (he prefers defense over offense when considering war in outer space) and his sentiment regarding his standing under the status quo is impacted only by his reference point and not by escalation.[20] At each time step of the game (daily), each player has a set of actions and information available on which to base his decisions.

Information includes:

- The type and quantity of space assets belonging to each player
- The defensive capabilities of each asset
- The quantity and capabilities of weapons available for use.

Assets, weapons, and capabilities may be hidden from the adversary.

Actions include:

- Initiate attacks on the adversary's assets or weapons
- Initiate defenses against attacks
- Initiate investments in assets (including building or improving their defensive capabilities), weapons or intelligence gathering.

Payoff uncertainties define the expected effectiveness of attacks and defenses and the success of investments. Furthermore, payoff probabilities determine a player's future ability to project power from space and can alter future payoffs in the game.

We used the game to play a variety of *futures*. Each future is a state of the world defined by:

1. *A U.S. (Blue) objective value function and an opponent's (Red) objective value function.* The objectives are formulated as a weighting of the player's ability to project power (P, M and SII), the value they place on possessing anti-satellite weapons, and the value they place on creating vulnerabilities in their opponent's ability to project M and SII power from space during a ground war. The ratio of the players' dependencies on space to project power into a ground theater of war impacts the rational weighting of the benefit to a player of creating vulnerabilities in the opponent's ability to project that power during a ground war. This

[19] For those interested in the technical challenges facing those who would conduct or model war in space, an excellent (but slightly dated) tutorial can be found in Spacy (1999). More recent, but less technical, overviews of the space security challenge can be found in Morgan (2010).

[20] Exploration of the impact of escalation and offensive/defensive preferences is on-going.

ratio allows us to vary the balance of military power projected from space for each future. Asymmetries in this balance are a major factor in determining when deterrence can be achieved in game play.

2. *A set of initial conditions for the game, including the actual, or 'game truth' for assets, weapons, political capital, payoff uncertainties, player mindsets, etc. as well as each player's* perceptions *of their opponent's objective value functions, mindset, assets, weapons and capabilities.* For the results discussed in this paper, players are assumed to know their opponent's objective values and functions, but some assets, weapons and capabilities are hidden or uncertain. Structuring the initial conditions as different views of reality allows us to explore futures in which perceptions of adversary power differ greatly from actual power.

During game play, each player selects the actions that optimize his objective function, given his view of reality, including his view of his opponent's reality. A *strategy* is defined to be the series of moves the player takes in the game. In this paper, we discuss the strategies that result from the game only in general terms so as not to distract from the goal of understanding how sentiments impact decision-making. In rational play, we categorize strategies as to whether they generally seek to attack or seek to maintain the status quo and whether they favor the building of weapons vs. active defenses vs. system resiliency. When prospect theory is incorporated into the game, we contrast the resultant strategies as being more or less aggressive than those observed in rational play. The decision models used in the game are formulated as a function of both a player's objective and his mindset. Play is called *rational* if objectives are evaluated based on a player's observable game truth. Play is termed *irrational* if objectives are evaluated based on subjective evaluations of gains and losses shaped by the player's sentiment as postulated by prospect theory. The utility curves used by a player in evaluating objectives are shown in Figure 3 for the rational actor and for the irrational, or prospect theory, actor.

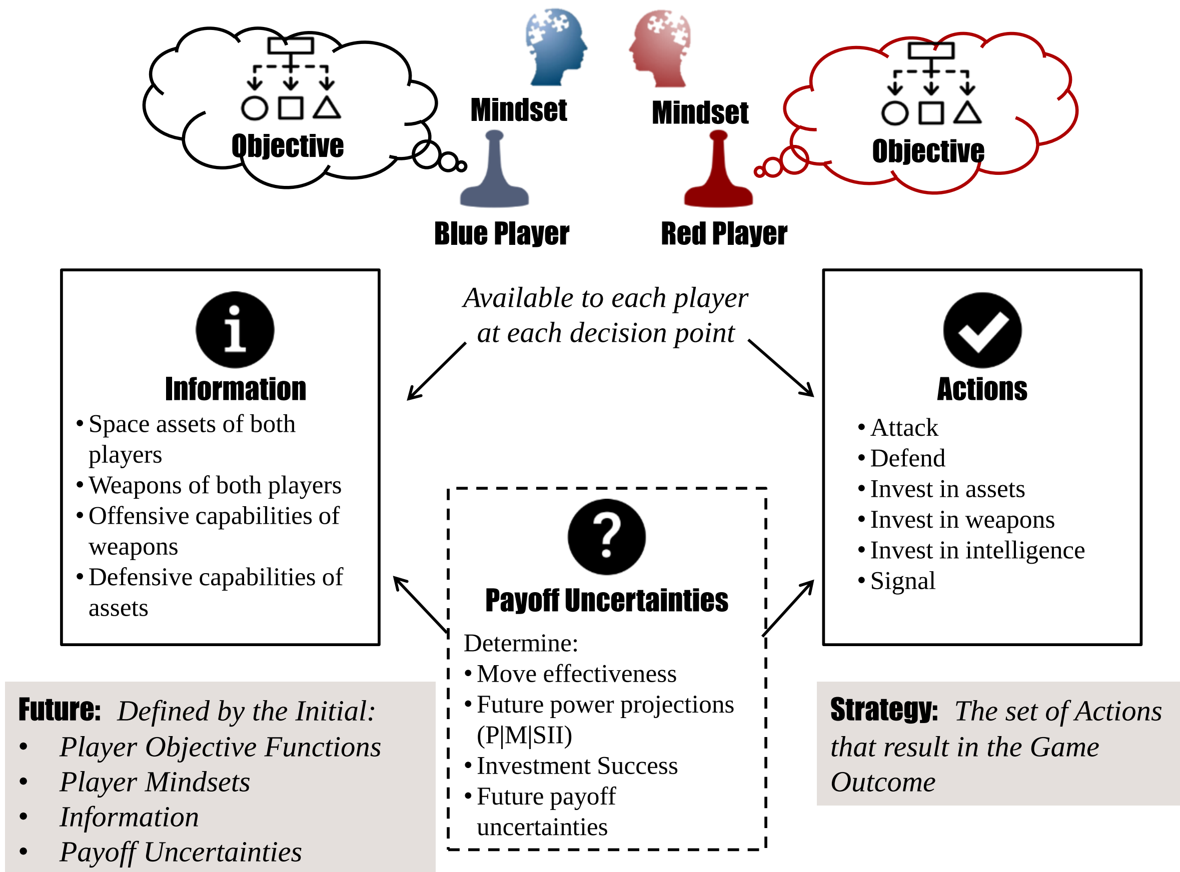

Figure 2. Basic Components of the Game Theoretic Model

The prospect curve maps objectively-evaluated gains and losses into contextually-perceived gains and losses using a non-linear transformation. For each move, the perceived value is a function of the objective gain or loss and the player's sentiment regarding his standing under the status quo. When a player feels that he is in a domain of losses (to the left of the origin as shown in the lower left region of Figure 3), he will perceive both gains and losses as being more impactful than they objectively are. When a player operating from a domain of losses evaluates a move that results in a net gain, his valuation of that gain is exaggerated and he will pursue it more aggressively than a purely rational player would. Similarly, if a move will result in a gain to his opponent relative to his own status, he will defend more aggressively. Conversely, when a player feels that he is operating at or above his reference point, he will perceive both gains and losses relatively objectively.

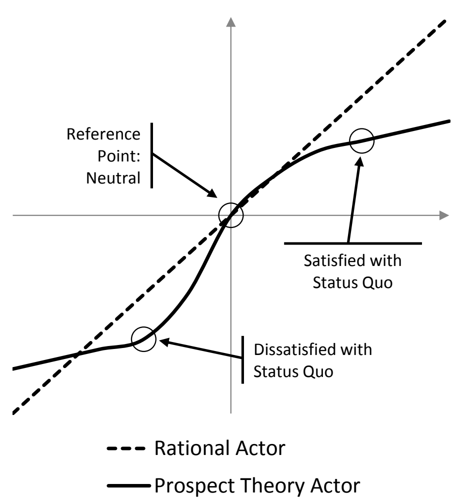

Figure 3. Utility of Rational Actor vs. Actors under Prospect Theory

However, larger gains/losses will saturate the player's perceptions and lead them to be less reactive to the magnitude of the gain/loss as represented by the 'flattening' of the curve shown in Figure 3. Behavioral economists term this play as being 'risk averse' and attribute it to the impact of diminishing returns.

As noted above, a key aspect of our game is that players apply prospects separately to each element of their objective function (P, M and SII). This reflects the fact that national states are not unitary and do not view all aspects of their power projection uniformly. A player may perceive himself to be in a domain of losses militarily, but in a domain of gains politically. Understanding the impact of prospects on game play thus becomes a multi-dimensional thought exercise which is difficult, but not impossible, to reason about without visualization aids. The aid that we created, a "sentiment map," is described and used in the observations section below.

IV. Observations on the Nature of this Competition

Before presenting the results of our game play, we want to make some broader observations on the nature of the competition. The first observation is that we have not yet been able to derive a quantitative metric to represent stability in the space domain, which can be an important component of the space competition. Due to its significant prior investment in space assets, the U.S. has a keen interest in maintaining stability in space. Further, as other nations continue to develop space capabilities, the preservation of space for the common good becomes a concern for all players. Thus, a player's objective may not be to 'win' a space engagement, but instead to maintain stability in the space domain, and thereby access to space assets.[21] One metric for stability was introduced in 1989 by Glenn Kent and David Thaler as a means for assessing mutual deterrence between two nuclear states; this method defines first-strike stability as "a condition that exists when neither superpower perceives the other as motivated by the posture of strategic forces to launch the first nuclear strike in a crisis."[22] The Kent-Thaler method provides a means for assessing stability when a strike is assumed to be highly escalatory and inflicting major damage. This assessment assumes "prompt catastrophic damage in the event of a deterrence failure," which is not necessarily true in the space domain. The post-Cold War space domain allows for numerous interactions and altercations outside of the use of nuclear forces, significantly increasing the complexity of determining one's advantage for striking first.[23] Other methods are therefore necessary for assessing our ability to achieve and maintain stability throughout the game. While this paper offers qualitative assessments of the region(s) under which deterrence of war in outer space is achieved, we have not yet derived a quantitative metric similar to the Kent-Thaler index. We continue to explore both escalation and arms race in our search for a quantified metric.[24] [25]

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[21] Morgan, 2010.

[22] Kent & Thaler, 1989.

[23] Morgan, 2010 explains that the use of space assets to support tactical wars has made it less clear that an attack on space is a prelude to nuclear war.

[24] Our escalation model is based on the last 5 stages of Freidrich Glasl's (1997) nine-stage model of escalation and Morgan's (2010) observations regarding the escalatory nature of specific moves in space war games. We then modify the prospect curves as suggested in the literature for decision making under fear and uncertainty See for instance, Chanel and Chichilnisky (2009), Pratt (1964) and Yechiam (2015).

[25] To better understand arms race, we are comparing the results of our model for different futures to the theoretical framework of arms race proposed by Lewis Richardson. Richardson posited that the probability of two

A second observation is that, as many experts on deterrence theory have noted, the ability to achieve deterrence is largely predicted by asymmetries in power and in offensive-defensive capabilities.[26] Our game is no exception to those rules. The asymmetric nature of space war is one that favors offense over defense. In space there is nowhere to hide, no terrain to "shape," and the ability to "run" is constrained by the amount of fuel a spacecraft carries. Given the extreme expense of carrying any extra weight into orbit, spacecraft carry only the minimum amount of fuel necessary for normal operations. If forced to use the fuel for defensive purposes, the spacecraft will shorten its operational life. In fact, forcing a spacecraft to take defensive maneuvers can be an effective means of denying the use of that spacecraft since few spacecraft are designed to continue service to users during maneuvers. However, the offensive-defensive balance can be restored by making spacecraft more resilient to attack, and hence reducing the effectiveness of offensive moves. Resilience can be increased by placing 'spare' spacecraft into orbit such that the loss of no single spacecraft has an adverse impact on the mission, by designing systems that use many smaller spacecraft as opposed to one large spacecraft or by 'hardening' spacecraft to specific attacks such as interference from cyber weapons or radiation bursts from nuclear weapons.

In our game, our analysis suggests that increasing the resilience of space systems to remove asymmetries in the offensive-defensive balance effectively deters attacks over a wide range of futures. In addition to the offensive-defensive balance (which can be changed through investments in assets and weapons), there are three additional symmetries in the game that are highly influential in determining when deterrence can be achieved and when it cannot. These asymmetries are summarized below and then discussed in more detail in the following sections:

- *The first is the rational asymmetry that arises from a player's dependency on space to project military power from space (i.e. the balance of power).* Given the relatively high U.S. utilization of space for military power projection, this asymmetry has led many experts to conclude that war in outer space is inevitable. If an opponent is significantly less reliant on space to project military power, in times of war, the temptation to deny U.S. access to space capabilities may override any concerns the adversary may have regarding destruction of the space domain.
- *The second asymmetry is that, when a player evaluates the gains and losses that occur after any particular move, the shape of the curve above where the player perceives his standing with respect to the status quo impacts how gains are perceived and the shape below that point impacts how losses are perceived.* If a gain is evaluated based on a flatter portion of the curve and the loss is evaluated based on a steeper portion, a rationally equal gain and loss will not be evaluated as neutral, but as a loss—resulting in the player being deterred from making that move.
- *The third asymmetry is that, as Berejikian has hypothesized, our game demonstrates that symmetric sentiments lead to less aggressive play than rational theory would predict and asymmetric sentiments lead to more aggressive play*.

nations engaging in war with each other depends on their stockpiles of weapons, and based on this assumption built a mathematical model with a set of differential equations determining the likelihood of conflict. See Williams (2002) for a description of the Richardson arms race model.

[26] For instance, Freedman (2004), Glaser (2010), Jervis, Cooperation under the Security Dilemma (1978).

Before proceeding to the detailed observations on these asymmetries, it is instructive to consider how three scenarios might ground our analyses.

Russia/U.S. Conflict in the Baltics. One scenario was based on a hypothetical Russia/U.S. conflict in the Baltics. Russia perceives that space is a vulnerable center of gravity for U.S. force projection and would likely seek to degrade U.S. satellite-based communications network and ISR capabilities. But why would Russia choose such risky behavior? And can Russia be deterred from further provocation? In this scenario, the theater of operations would be far from U.S. territory, but close to Russia's. Therefore, the U.S. would be relatively more reliant on space to project Military (M) and Social, Infrastructure and Information (SII) power into theater than Russia. In games that reflect this relative asymmetry, the value of U.S. space assets is three times more than for Russia. In such a conflict, we might further hypothesize that Russia perceives itself to be operating in a Political domain of losses given their prior sphere of influence in the Baltic region. However, rapid gains in the ground war could quickly change that perception, and it is instructive to consider how the conflict would play out under a variety of Russian and U.S. sentiments.

China/U.S. conflict in the South China Sea. We also wanted to play a more symmetric space power game to understand how rising space powers might impact deterrence. In this scenario both belligerents are fighting relatively far from their home territory. We assumed that China's recent substantial investments in space power have brought them to relative parity with the U.S. in their ability to use their space assets to project power into that theater. In such a scenario, one might expect that both China and the U.S. would be relatively content with the military and political status quo in space, but that could change rapidly as game play progresses. As with the Russia/U.S. Baltic scenario, we looked at a variety of Chinese and U.S. mindsets to understand the range of ways in which a game of space parity could play out.

Conflict under Highly Asymmetric Balance of Power. A third scenario we played is highly asymmetric with respect to space power. For this scenario we assume that the conflict is played close to, if not part of the opponent's homeland (for example, Russia in Crimea) and that the U.S. has high reliance on space assets but the adversary has not. In these cases, the U.S. is five times more reliant on space to project military power than its opponent. As with the other two scenarios, we played a variety of futures to determine the range of possible behaviors we might see.

Asymmetry of Dependency on Space Power. As discussed above, a primary determinant of a player's objectives with respect to space war is the ratio of the player's dependence on space to project military power. We observed that, when both sides are similarly dependent on space, with symmetrical offensive and defensive capabilities, our game occasionally resulted in deterrence of space war. However, if either player started with a slight advantage in defense or offense, deterrence was quickly lost. Introducing prospect theory—where each player evaluates their potential moves through the lens of the prospect curve shown in Figure 3—made the deterrence cases more stable. In fact, with prospect theory we achieved deterrence over the entire range of offensive/defensive imbalances studied.

In the scenarios involving three-to-one and five-to-one dependency on space, under rational play we found it virtually impossible to deter war in outer space once the ground war started. In fact, the only condition under which space warfare did not break out was when we started the game with both sides possessing no space weapons.[27] Any slight asymmetry in offensive or defensive capability, including first mover advantage, immediately plunged the players into space war. Introducing prospect play allowed us to achieve deterrence in significantly more, but not all, cases. Since the latter scenario of a five-to-one dependency ratio gives us the most compelling contrast between rational play and play under prospect theory, it is used as the illustrative case for the remaining observations discussed below.

Asymmetry of Perceptions of Gains vs. Losses. There is a second means by which prospects introduce asymmetry into game play. This asymmetry occurs when a player's perception of his status with respect to the status quo is a point on the prospect curve where the slope of the curve is changing significantly. Players at these points do not evaluate a potential gain from the same perspective that they evaluate a potential loss. A player who is neutral with respect to the status quo (i.e., at his reference point), when faced with choosing between an equal gain and an equal loss, is not agnostic as he would be under rational theory. Instead, he will exaggerate the potential loss while evaluating the gain somewhat rationally, which will sway him towards deterrence. Similarly, a player who is moderately happy with the status quo (i.e., is playing in the domain of gains) will see losses more rationally and gains as attenuated due to the curvature in the prospect curve, again swaying him towards deterrence. Conversely, a player who is moderately unhappy with the status quo (i.e., is playing in the domain of losses) will see the gains as exaggerated and the losses as attenuated and so will decide to attack.

While the discussion above allows us to understand how these asymmetries in perceptions of gains and losses play out in a single dimension, we need a more complex visualization to understand how gains and losses will be perceived by players in a multidimensional game. Consider again the case of an individual player's decision in a situation in which gains rationally equal losses, but now suppose that the gain is military and the loss is political. We call this the "rationally agnostic case" because, when evaluated objectively, the player's losses are exactly equal to his gains, and his choice of whether to move is literally the flip of a fair coin. In our space war game, such a move might be an attack that provides military gain but a political loss due to the perceived illegitimacy of the target or due to collateral damage. As examples, consider the destruction of a commercial satellite that has a dual military and commercial use, or the destruction of a military satellite using a kinetic weapon that generates debris and thus adversely impacts neighboring commercial satellites.

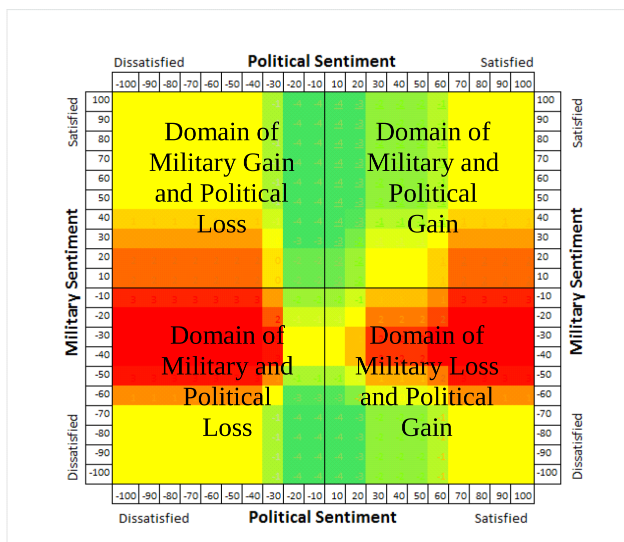

Figure 4. Sentiment map for when Military gain is offset by Political loss

[27] Although players built space weapons prior to the start of the ground war, they also built redundancy and resilience into their space assets, making the actual use of the weapons unattractive.

For this multidimensional decision, Figure 4 shows what we term a "sentiment map" illustrating how a player's feelings regarding his status with respect to the military and political status quo impact his decision. Yellow indicates that the player will be agnostic as to whether to attack or to maintain the status quo (in this case, the rational decision), green indicates where the player will be deterred and will thus maintain the status quo, and red indicates where he will decide to attack. If the player is satisfied with the status quo both militarily and politically (the upper right quadrant of the chart), he will generally be deterred for the same reasons he is deterred in uni-dimensional play: the political loss is exaggerated (he hates losing) while the military gain is not. In fact, play along a diagonal line drawn from the lower left (he is deeply dissatisfied with both his political and his military standing) to the upper right (he is deeply satisfied with both his political and military standing) of Figure 4 is identical to what we expect under prospect theory in unidimensional play. Away from that diagonal line, however, the player's perspectives regarding his political and military standing are not the same.

For the rationally agnostic situation shown in Figure 4, the player will attack when moderately unhappy with his military standing in the status quo almost independent of his perceptions regarding his political standing. However, small deviations in either a positive or negative direction militarily can achieve deterrence if the player is operating near his political reference point. Conversely, players who are feeling either extremely threatened or extremely strong in the political status quo may attack even when they are militarily in a domain of gains. These results suggests the ways in which offsets in one dimension of state power can be used to counter gains in another dimension. For example, when using economic sanctions to deter military action, diplomatic efforts to moderate an adversary's sentiments regarding their economic standing would enhance the possibility of achieving deterrence.

To explore sentiment maps further, we considered the scenario in which there is a five-to-one ratio in the U.S. player's dependency on space to project military power. In this case, military gains for the adversary clearly outweigh any political costs that an attack might invoke. The sentiment map for this case is shown in Figure 5. Even though the rational decision would be to attack, deterrence will hold and the status quo will be maintained as long as the player perceives himself to be neutral or in a domain of gains militarily *and* the adversary perceives his current political standing in a relatively neutral light. However, if the adversary perceives that even moderate military losses are having a negative impact—pushing him into a perceived domain of military losses—that player will attack quite strongly independent of their political sentiments.

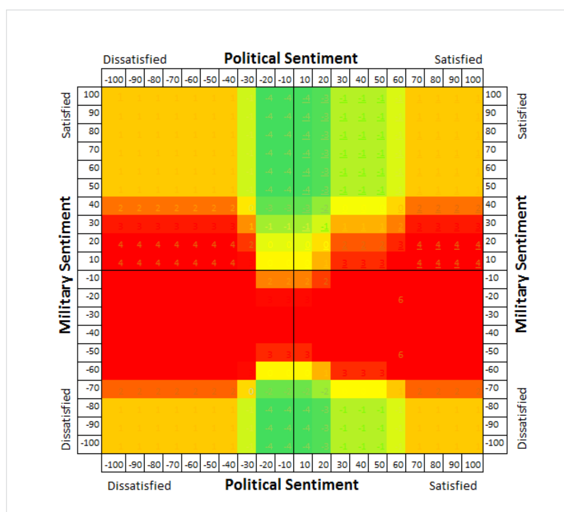

Figure 5. Sentiment Map when the Rational Decision is to Attack
(Military Gains outweigh Political losses)

Asymmetry of Sentiments between Players. Our last observation is that asymmetric sentiments between players leads to more aggressive play than rational game theory would predict, just as hypothesized by Berejikian. Consider again the five-to-one dependence ratio scenario where it is clearly in the adversary's rational best interest to attack U.S. assets in outer space, but it is in the U.S.'s rational best interest to maintain the status quo. We played three instances of this game, one when both the U.S. and the adversary are operating at their political and military reference points, one in which both are both dissatisfied with their political standing in the status quo (i.e., in a domain of losses), and one where both are satisfied with their political standing in the status quo (i.e., in a domain of gains). These cases are denoted as points 1, 2 and 3 respectively in the sentiment maps (one for each player where Blue is the U.S. and Red is the adversary) shown in Figure 6. The rational outcome of this scenario is that the adversary's best strategy is to attack U.S. assets in outer space using kinetic weapons, but to stop short of generating the debris that would lead to the total destruction of the geostationary orbit. In the face of this strategy, the best rational U.S. strategy is to maintain the status quo by refraining from making attacks against the adversary's assets (although the U.S. does conduct limited attacks against the adversary's weapons) and build redundancy and resilience into space assets. Arrows in Figure 6 indicate the direction that player sentiments would move based on this rational play. The adversary's attacks on U.S. assets induce a feeling of military loss on the part of the U.S. and of military gain of the part of the adversary. However, use of kinetic weapons creates orbital debris, creating sympathy for the U.S. and stigma for the adversary in the political realm.

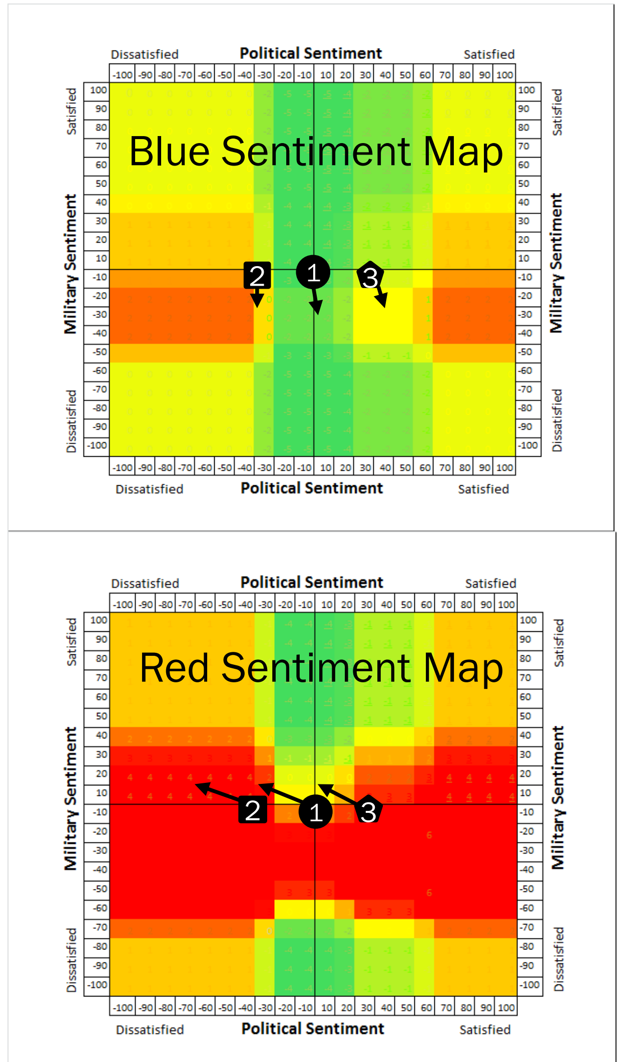

Figure 6. Impact of Prospects in the Scenario where Red rationally attacks and Blue rationally defends the status quo.

Running this same scenario with both players valuing their gains and losses through the lens of propect curves, we found that when starting from the condition where both players are neutral regarding their political standing in the status quo (Case 1), game play was twice as intense than it would be rationally.[28] The adversary again attacked with kinetic weapons, but more aggressively, destroying the use of geostationary orbit for all spacecraft, including his own. The U.S. also took more aggressive action, attacking the adversary's space assets with both cyber and kinetic weapons. We hypothesize that this increased intensity is due to the increased assymetry in sentiments that arise from game play as shown in Figure 6, by a means similar to that predicted by Berejikian. The attacks drove the U.S. into a domain where the best strategy was to do everything possible to maintain the status quo, but the U.S. drove the adversary into a domain where his best strategy was to attack even more aggressively. In a similar way, game play that drives players towards more symmetric sentiments should reduce the intensity of conflict.

To test this theory further, consider the case in whic both players are unhappy with the political status quo (Case 2). In this case, attacks by the adversary move his own sentiments to be slightly less aggressive, but those attacks also drive the U.S. player's sentiment to be more aggressive, with the net impact being that sentiments become *more symmetric* due to the attacks by the adversary. In this case, both players' actions closely mirror that seen in rational play. The adversary attacks, but not excessively, and the U.S. primarily defends the status quo.

Finally, we examined the case in which both players are happy with the political status quo. In this case, attacks on U.S. assets by the adversary will drive both players into a situation, when viewed through the lens of prospects, they are agnostic as to whether they should engage in further attacks. Not only are they agnostic, they are *symmetrically* agnostic. The result is that both players engage in attacks on the opponent's weaponry, but attacks on space assets are largely deterred. The lone exception is an attack on a U.S. asset by an adversary using a cyber weapon, a move that carries very little political stigma and so does not move them into the region of agnostic sentiment.

As these simple cases illustrate, prospects introduce in a multidimesional game both assymetries of player perceptions and assymetries of gain/loss evaluations that interact in complex ways. There appear to be several ways to achieve deterrence even when rational players "should" be in conflict. Similarly, there are multiple ways to induce a player to attack even when a rational player "should" be deterred. While our analysis is in its infancy, we believe that incorporating prospects into a game-theoretic model of multidimensional conflict provides additional ways of thinking about deterrence than were previously available.

V. Conclusion

Space war has all of the attributes of a classic security dilemma. Almost all actions taken in space can be misconstrued. This means that defensive preparations (or even just normal use of space assets and exploration) can be easily mistaken as offensive preparations, destabilizing the status quo. Additionally, space is relatively easy to attack and hard to defend. As nations become more dependent on space to project power into a conventional theater of war, most analysts have concluded that spillover of that war into outer space is "inevitable." These conclusions are derived from analyses based on a game-theoretic model of conflict vs. cooperation that assumes states are

[28] Our metric of the intensity of conflict in the space war is a function of the type of weapon used in attacks, the legitimacy of the target the weapon is used against and the number of attacks made.

unitary, rational expected utility maximizing decision-makers. Such models, however, sacrifice the rich nuances of reality for the sake of mathematical simplicity.

We built a game-theoretic model and instrumented it to let us vary the magnitude of military power between players as well as the offensive-defensive balance for each player. As expected, our model shows that, in highly asymmetric games, space war appears to be inevitable. If the adversary is signficantly less reliant on space to project military power than the U.S., in times of war the temptation to deny the U.S. access to space capabilities may override any concerns the adversary may have regarding destruction of the space domain.

We then changed two aspects of the traditional game-theoretic model. First, we substituted prospect theory in place of rational decision-making. While our actors are still utility maximizers, their perception of utility is shaped by their sentiment regarding their standing under the status quo. Second, our model considered multiple dimensions of state power, making our actors less "unitary."

Under prospect theory, our preliminary observations indicate that players discount moves that would result in large gains and/or losses. For moves that result in smaller gains and/or losses, players are less aggressive than rational play would predict when the players have symmetric sentiments regarding the status quo (i.e., when both are satisfied with the status quo or when both are dissatisfied with the status quo) and deterrence holds at higher levels of asymmetry in the balance of military power and the offensive-defensive balance. However, when the sentiments of the players are highly asymmetric (i.e, one player is satisfied with the status quo and the other is not), play is sugnificantly more aggressive than rational play would predict and deterrence can be nearly impossible to achieve under these conditions.

The introduction of multidimensional prospects adds nuance to the discussion of a player's sentiment toward the status quo. To explore those nuances, we conceptualized prospect theory not simply as a single dimensional curve, but as a multi-dimensional "sentiment map." Using the map allowed us to explore how a player's decision to attack vs. maintain the status quo can be predicted based on the direction a decision to attack would "move" each player on their sentiment maps. Attacks that move players toward more symmetric sentiments are deterred while attacks that move players to more asymmetric sentiments cannot be deterred.

We believe that our observations regarding the impact of 'asymmetry in sentiment' may prove to be an important addition to the international communities understanding of deterrence and the dynamics of cooperation and conflict. However, our work is still based on a game-theoretic construct and, as such, it has many of the drawbacks of that model of deterrence. For example, while prospects allow us to explore how a state player's sentiments with respect to the status quo introduce additional asymmetries that impact deterrence, our methodology still assumes that all players are seeking to maximize expected utility—albeit, now with an adjusted perception of reality. Furthermore, while the addition of multiple dimensions of power lets us analyze how sentiments regarding political vs. military power might play out in multidimensional space, we are still assuming that states have a 'unified sentiment' for each dimension of power. As many authors and researchers have pointed out, state decisions are rarely the output of a single state actor and are instead the negotiated outcomes of small groups of decisions makers, each undoubtedly with their own individual sentiments. As such, game theoretic models such as ours offer only one explanation of deterrence and should never be regarded as "predictive."

Is space war "inevitable"? Our work offers hope that it is not. While the offensive-defensive balance in space may never be symmetric, investments in redundancy and resilience of space assets can lessen the impact of those asymmetries. Asymmetric use of space to project military power is lessening as Russia reinvests in space and China invests. This asymmetry is further reduced by U.S. investments in alternatives that lessen its military reliance on space assets.

Perhaps more important, our work indicates that, if nation states do apply something akin to prospect theory in making decisions to wage war, sentiment matters. Diplomatic initiatives aimed at shaping the sentiments of nations with respect to their position within the status quo can have a dramatic impact on deterrence of war in outer space. Our work demonstrates that *symmetric* sentiments can make deterrence significantly easier to achieve across a wider asymmetry of the offensive-defensive balance or a wider asymmetry of the military power projection balance. However, it also shows that *asymetric* sentiments can make deterrence almost impossible to achieve even in situations where the balance of power and the offensive-defensive balance are relatively symmetric.

Unfortunately, it is not a simple thing to visualize how sentiments impact deterrence that plays out in multiple dimensions of state power. Spacecraft support a state's ability not just to project military power, but to project power in the social, infrastructure and information domains. Often these two aspects of power are supported on a single spacecraft, making it impossible to attack one without the other being impacted. Furthermore, there is a stigma associated with violating norms regarding the peaceful uses of space that may directly impact a state's ability to project political power. Therefore, in considering the application of prospect theory to war in outer space, we believe it is essential to understand how sentiments regarding political, military and social power interact to promote deterrence. In this paper, we have discussed only a few cases illustrative of the interactions between sentiments regarding political and military power impact the game. We chose these cases because the two-dimensonal interactions are easier to visualize than the complex multi-dimensional space that our game is played in. Analysis across that multidimensional space continues and we find evidence that the principles of symmetriic and assymetric sentiments described in this paper are determining factors in predicting deterrence.

Works Consulted

Allison, Graham, and Phillip Zelikow. *Essence of Decision, Explaning the Cuban Missile Crisis, 2nd Edition.* New York: Addison Wesley Longman, Inc., 1999.

Bayliss, John, James Wirtz, and Colin Gray. *Strategy in the Contemporary World, 4th Edition.* Oxford, United Kingdom: Oxford University Press, 2013.

Berejikian, Jeffrey. "A Cognitive Theory of Deterrence." *Journal of Peace Research, Vol. 39, No. 2*, 2002: 165-183.

Boettcher, William A III. "The Prospects for Prospect Theory: An Emperical Evaluation of International Relations Applications of Framing and Loss Aversion." *Political Psychology, Vol. 25, No. 3, Special Issue (Part Two): Prospect Theory* , 2004: 331-362.

Bosch-Domenech, Antoni and Joaquim Silvestre. "Reflections on Gains and Losses: a 2x2x7 Experiment." *Journal of Risk and Uncertainty, 33 No. 3*, 2006: 217-235.

Broad, WJ, and David Sanger. "China Tests Anti-Satellite Weapon, Unnerving US." *The New York Times.* Jan 18, 2007. http://www.nytimes.com/2007/01/18/world/asia/18cnd-china.html (accessed February 2017).

Cha, Victor D. "Hawk Engagement and Preventive Defense on the Korean Peninsula." *International Security, Vol. 276, No. 1*, 2002: 40-78.

Chanel, Olivier, and Graciela Chichilnisky. "The Influence of Fear in Decisions: Experimental Evidence." *Journal of Risk and Uncertainty 39, no. 3*, 2009: 271-298.

Elsbach, K and P.S. Barr. "The effects of mood on individuals' use of structured decision protocols." *Organic Science, 10(2)*, 1999: 181-198.

Farnham, Barbara. "Roosevelt and the Munich Crisis: Insights from Prospect Theory." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 205-235.

Freedman, Lawrence. *Deterrence.* Cambridge, UK: Polity Press, 2004.

Gertz, Bill. "Russia has conducted the fifth test of a new anti-satellite weapon." *The Washingtom Free Beacon.* December 21, 2016. http://www.businessinsider.com/russia-conducted-test-anti-satellite-weapon-2016-12 (accessed December 2016).

Glaser, Charles L. *Rational Theory of International Politics, the Logic of Competition and Cooperation.* Princeton, NJ: Princeton University Press, 2010.

Glasl, Fredrich. *Konfliktmanagement. Ein Handbuch fuer Fuehrungskraefte, Beraterinnen und Berater.* Bern: Verlag Paul Haupt, 1997.

Gross Stein, Janice. "Calculation, Miscalculation and Conventional Deterrence I and II." In *Psychology and Deterrence*, by Robert Jervis, 34-88. Baltimore, MD: The Johns Hopkins University Press, 1985.

Gruss, Mike. "Hyten tells Senate DoD needs to focus on space control, battle management system." *Space News.* September 2016, 2016. http://spacenews.com/hyten-tells-senate-dod-needs-to-focus-on-space-control-battle-management-system/ (accessed March 2017).

Jervis, Robert. "Cooperation under the Security Dilemma." *World Politics, 30,1*, (1978): 167-214.

—. *how statesmen think, the psychology of international politics.* Princeton: Princeton University Press, 2017.

—. *Perceptions and Misperceptions in ternational Politics.* Princeton, NK: Princeton University Press, 1976.

—. *Psychology and Deterrence.* Baltimore, MD: The Johns Hopkins University Press, 1985.

Johnson-Freese, Joan. *Space Warfare in the 21st Century; Arming the Heavens.* London and New York: Routledge, Taylor and Francis Group, 2017.

Joint Chiefs of Staff. "Joint Operations." *Joint Publication 3-0.* August 11, 2011. http://www.dtic.mil/doctrine/new_bubs/jp3_0.pdf (accessed December 2016).

Kahneman, Daniel. *Thinking, Fast and Slow.* New York: Farrrar, Strauss amd Giroux, 2011.

Kahneman, Daniel, and Amos Tversky. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica, Vol.47, No.2*, 1979: 263-292.

Kamps, Charles. "Operation Eagle Claw: The Iran Hostage Rescue Mission." *Air& Space Power Journal.* September 21, 2006. http://www.au.af.mil/au/afri/aspj/apjinternational/apj-s/2006/3tri06/kampseng.html (accessed March 2017).

Knight, Frank. *Risk, Uncertainty and Profit.* New York: Sentry Press, 1921.

Levy, Jack S. "An Introduction to Prospect Theory." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 171-186.

-- "Loss Aversion, Framing and Bargaining: The Implications of Prospect Theory for International Conflict." *International Political Science Review / Revue internationale de science politique, Vol. 17, No. 2, Crisis, Conflict and War. Crise, conflit et guerre* , 1996: 179-195.

--."Prospect Theory and International Relations: Theoretical Applications and Analytic Problems." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 283-310.

--. "Prospect Theory, Rational Choice, and International Relations." *International Studies Quarterly, Vol. 41, No. 1*, 1997: 87-112.

Luttwak, Edward N. *Strategy: The Logic of War and Peace.* Cambridge, MA: The Belknap Press of Harvard University Press, 1987.

Mahnken, Thomas G. *Competitive Strategies for the 21st Century; Theory, History and Practice.* Stanford, CA: Stanford University Press , 2012.

McDermott, Rose. "Prospect Theory in International Relations: The Iranian Hostage Rescue Mission." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 237-263.

McInerney, Audrey. "Prospect Theory and Soviet Policy Towards Syria, 1966-1967." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 265-282.

Moltz, Clay. *The Politics of Space Security. Strategic Constraint and the Pursuit of National Interests.* Standford, CA.: Stanford University Press, 2011.

Morgan, Forest E. *Deterrence and First Strike Stability in Space.* MG-916-AF, Santa Monica, CA.: RAND Corporation, 2010.

Office of the Secretary of Defense. "Selected Excerpts on Chinese Space and CounterSpace Activites from the Annual Reports of the Military Power of the People's Republic of China." Congressional Annual Report, 2000-2008.

Pratt, J.W. "Risk Aversion in the Small and in the Large." *Econometrica 32 (1-2)*, 1964: 122-136.

Schaub, Gary Jr. "Deterrence, Compellance, and Prospect Theory." *Political Psychology, Vol. 25, No. 3, Special Issue (Part Two): Prospect Theory* , 2004: 389-411.

Schelling, Thomas C. *The Strategy of Conflict.* Cambridge, MA: Harvard University Press, 1960.

Shafir, Eldar. "Prospect Theory and Political Analysis: A Psychological Perspective." *Political Psychology, Vol. 13, No. 2, Special Issue: Prospect Theory and Political Psychology*, 1992: 311-322.

Shupp, Robert D, and Arlington W. Williams. "Risk Preference Differentials of Small Groups and Individuals." *The Economic Journal, Vol. 118, No. 525*, 2008: 258-283.

Snyder, Glenn H. "Deterrence and Power." *Journal of Conflict Resolution* , 1960: 163-178.

Spacy II, William L. *Does the United States Need Space-Based Weapons.* Maxwell Air Force Base, Alabama: Air University Press, 1999.

Williams, A. "Richardson Arms Race Model." 2002. http://shakti.trincoll.edu/ pbrown/armsrace.html (accessed July 2016).

Yechiam, Eldad. "The psychology of gains and losses: More complicated than previously thought: Attention and Strategic Thinking can Influence Responses to Gains and Losses." *Psychological Science*, Jan 2015.