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Toward a Quantitative Approach to Data Gathering and Analysis for Nuclear Deterrence Policy

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Introduction

The doctrine of nuclear deterrence and a belief in its importance underpins many aspects of United States policy; it informs strategic force structures within the military, incentivizes multi-billion-dollar weapon-modernization programs within the Department of Energy, and impacts international alliances with the 29 member states of the North Atlantic Treaty Organization (NATO). The doctrine originally evolved under the stewardship of some of the most impressive minds of the twentieth century, including the physicist and H-bomb designer Herman Kahn, the Nobel Prize-winning economist Thomas Schelling, and the preeminent political scientist and diplomat Henry Kissinger. Following the collapse of the primary U.S. nuclear adversary, the Soviet Union, however, the amount of scholarship dedicated to studying this important topic declined markedly. Since then, the world has undergone many rapid transformations. Important new technologies, including the internet and artificial intelligence, have permeated all elements of society and transformed the nature of everything from manufacturing to business to combat. As the internet has connected people, business and investment have connected nations and state economies have become deeply intertwined. Because of this, the nature of international relationships itself has changed.

This year, the United States will complete another Nuclear Posture Review. As national leadership contemplates the role of nuclear weapons as part of our international political and military doctrine, it must now consider the changed nature of the world and the ramifications of these changes. Deterrence has become "cross-domain", where conflict escalation dynamics that might lead to nuclear use can also include cyber, economic, and space elements, interplaying with each other in potentially complex and unanticipated ways. As the nature of strategic deterrence has changed, so must the approach to studying and developing deterrence doctrine. The technologies that have transformed society can also help to simplify highly complex problems and, used properly, bolster our understanding of the complicated interplay of forces that, whether unintentionally or through deliberate policy action, we harness to shield the nation from an act of nuclear aggression by an adversary state. Our team of researchers at the University of California, Berkeley, Sandia National Laboratories, and Lawrence Livermore National Laboratories is developing a capability that leverages the remarkable power of the internet and advancements in machine learning to study nuclear deterrence in a new, data-driven way, using a war game conducted online that explicitly ties back to academic conflict research.

Soon after the advent of the Cold War and building on work begun in RAND and academia, military planners adopted war games as an approach to understanding conflict escalation dynamics that might lead to the use of a nuclear weapon.[1] Although criticized for lacking in scientific rigor in their design, execution, and analysis,[2] war games provide an approach to prepare for events that have little historical

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precedent, such as nuclear conflict. These games can incorporate both computer models and human decision makers. Scenario-based, they can be useful for exploring available options within a given hypothetical event, including options that might not occur to an analyst outside of the game framework.[3] While such exploration is valuable, quantitative post-game analysis is made difficult by the typical game format, which limits the number of plays, the number of players involved, and the ability to capture data in a reproducible way. Specifically, the circumscribed number of turns within a war game yields small data sets not suitable for statistical analysis; the small player base leads to outcomes biased by the individual expertise and personalities of the players themselves; and data may be captured imperfectly in the form of written narratives by human rapporteurs. Because of these limitations, results are typically not analyzed across multiple wargames, although recently there has been some effort to comprehensively compare decisions made within wargames to decisions that the public would make regarding the willingness to use nuclear weapons.[1] In general, war gaming is more useful in illuminating tactical approaches within a given escalation scenario than it is in informing broader strategic decision-making and the effects of particular policies on the dynamics of conflict. As such, a strategic nuclear deterrence architecture is difficult to examine comprehensively using a typical war gaming approach.

For a quantitative approach to analyzing the effects of an overall doctrine on conflict outcomes, we turn to the academic literature. Professors in the fields of Policy and International Relations study the effects of particular policies and conditions on the likelihood of conflict between states using the Military and Interstate Disputes (MIDS) data from the Correlates of War Project (correlatesofwar.org), which comprises a database of data on conflict, political alliances, military and economic strength, trade, and other indicators going back more than fifty years (approximately since the start of the Cold War). Extensive statistical analysis, typically linear regression analysis, has been performed on this data in publications spanning multiple decades (and drawing mixed conclusions about correlations between and among the variables). While this approach to analyzing war is more quantitative (and thus reproducible) than war gaming, it also suffers from drawbacks. First, though data capturing the same parameters across multiple conflicts is available, the MIDS data does not include all the metadata contributing to a given decision leading up to a conflict, and thus may leave crucial information out of the analysis. Second, the data is encoded in dyad-years, which leads to two distinct problems: long conflicts (the Korean War is an example) make outsized contributions to the sample; and the analysis only accounts for relationships between pairs of states (dyads), when in fact conflicts and the decisions surrounding them often involve networks of multiple states. Third, when studying nuclear escalation dynamics, data from purely conventional wars are inadequate to the job. Finally, more generally, this type of analysis is simply too broad and high-level to apply to strategic deterrence and to study potential escalation dynamics within a given deterrence framework.

In order to comprehensively and quantitatively study nuclear deterrence and conflict escalation that might lead to the use of a nuclear weapon, we have formulated an approach that combines the strengths of a war game (including the ability to explore a broad decision-space, record interactions among multiple players, and examine decisions in real time, capturing the available metadata) with the reproducible, mathematical methodology of the conflict literature. We are designing an online computer war game that enables us to explicitly track and store data in a way analogous to the Correlates of War Project, potentially allowing us to compare analysis of war game data directly to academic research. In addition to MIDS variables, however, we also have the opportunity to track other

variables of interest at our discretion, and to record metadata in the form of player conversations through a built-in chat feature. Using the online format, we have the ability to expand or contract our player base as desired, broadening the player demographic to gather large datasets across a diverse knowledge and experience base for purposes of statistical analysis and to explore the full parameter space, while also maintaining the ability to limit particular game instantiations to one or more select groups of players, such as subject matter experts in the area of nuclear policy or military strategy.

While still undergoing development, the game currently comprises a virtual world of states that occupy territory on a virtual landscape, control resources, and have the ability to trade with each other or enter into conflict with each other, both conventional and nuclear. Trade and conflict are both incentivized by the uneven distribution of resources among states. Players have some goals, or "victory conditions", in common, but individual players also have unique, hidden victory conditions, meant to capture the unique motivations of different states in the real world. The game is designed to explicitly capture data on MIDS variables such as trade, alliance, military and economic strength, and geographical contiguity. In addition, we have designed features into the game to capture important elements of deterrence such as signaling interactions between states, as well as allowing for uncertainty in both signaling intentions to other players and in success, should one player choose to attack another. We plan to use this game to explore specific research questions, while at the same time populating a database with MIDS-like data that can be analyzed retroactively using statistical methods, including modern methods from the discipline of data analytics, and even compared to real-world data from the Correlates of War Project. The database will be made freely available to the public, for use by academics and analysts performing conflict research.

Proof of Concept

Before embarking on a new war game design, and in order to demonstrate the viability of our proposed approach, we performed some preliminary analysis. There were three primary questions that we intended to answer before proceeding:

1. What do experts on deterrence and nuclear policy think of our approach? Will the results of our proposed war game be valuable to them?
2. Is there good reason to expect that data from online games is valuable in evaluating real-life problems?
3. Can we use data that we already have from an online game, perform some simple analysis, and draw preliminary conclusions about the viability of online game data in general to answer the questions that we're interested in answering?

To answer the first question, we talked to multiple experts[4] in the areas of International Relations, deterrence, and nuclear policy. With one exception, we were encouraged by all to pursue the development of the war game as a way of supplementing existing data and methods of studying the deterrence problem. The dissenting expert considers clarity in the deterrence problem to be antithetical to deterrence itself; essentially, the more ambiguity and uncertainty that exists concerning states' willingness and intent to use nuclear weapons, the better nuclear deterrence works. The others opined that clarity in signaling intentions and objectives only helps to strengthen a deterrence posture; that data relevant to the deterrence problem are needed and would be valuable to academics; and that data from a war game would be a useful substitute for real-world conflict data.

To address the second question, we looked at academic research that explores the relationships between online and real-world behaviors, and thus the usefulness of virtual worlds in studying real-world problems. Unsurprisingly because of the huge potential for internet-based experiments as a source of data for behavioral experiments, this is an active area of academic inquiry. In one investigation, researchers assessed the Big-5 personality traits (openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism) of 1,040 World of Warcraft Players and examined parallels between these traits and player behavior in the online game.[5] In this work, statistically-significant correlations were found between online behavior and player personality traits. As an example, extraverted players tended to exhibit extravert behaviors in the context of the games, such as frequently collaborating in groups. Another study found real-world patterns in economic behaviors in an online game context.[6] In general, participants in Massively Multiplayer Online Games (MMOGs) such as World of Warcraft tend to demonstrate significant investment in and emotional connection with their online avatars, which become a reflection of the players themselves. Emergent, complex social behaviors are often observed in the game context, such as long-term acts of in-game espionage conducted against virtual adversaries.[7]

Finally, having addressed the first two questions, we performed a preliminary proof-of-concept using 739 days of online game data gathered as part of an earlier, unrelated research effort. The game in question is a browser-based game which will be referred to here as Game X, and which is premised on a virtual world in which players can perform several actions that emulate real-world behaviors, such as purchasing things of value, forming alliances and trade relationships, and engaging in conflict. The purpose of our analysis was to take actions performed over the two years of data gathering and "operationalize" them: map them to variables in the Correlates of War database, and then directly apply the methodology from a single, simple example paper from the academic conflict literature to see how the online results compare to the real-world results from the paper. The paper chosen was Professor Katherine Barbieri's 1996 article *Economic Interdependence: A Path to Peace or a Source of Interstate Conflict?*[8] Though the methodology employed by the paper has detractors within the IR community, the purpose of our effort was not to draw conclusions about economic interdependence and conflict; but rather to demonstrate that analysis of online game data can be compared directly to results from academic research.

The Barbieri paper evaluates 14,341 dyad-years (a dyad is a two-state relationship, and a dyad-year reports data for that relationship in a given year) over the period 1870-1938. The primary explanatory variables used in her analysis are *Salience*, an indicator of the importance of the trade relationship to the dyad; *Symmetry*, which attempts to quantify the difference in importance of that relationship between the two partners, and *Interdependence*, which measures *Salience* and *Symmetry* together. The *Salience* and *Symmetry* variables are derived using *Trade Share*, a measure of trade between the dyad compared to the overall amount of trade conducted by a partner within the dyad.

$$Trade\ Share_i = \text{Dyadic Trade}_{ij} / \text{Total Trade}_i$$

$$Salience = \text{Sqrt}(TradeShare_i * TradeShare_j)$$

$$Symmetry = 1 - |\ TradeShare_i - TradeShare_j\ |$$

$$Interdependence = Salience * Symmetry$$

Again, the purpose of the analysis here is not to support or critique the author's methodology, but simply to duplicate it and compare the Game X analysis to the results of the article. In addition to these explanatory variables, several control variables were used in Barbieri's regression analysis, such as *Contiguity*, *Alliance*, and *Capabilities Ratio*. Our analysis included a *Contiguity* indicator, in which lack contiguous properties held by two guilds (the game version of sovereign states) was encoded as "0" and existence of contiguous properties was encoded as "1". *Alliance* was coded as "1" if neither guild in a dyad had designated the other as a foe, and "0" otherwise. In lieu of *Capabilities Ratio* we used *Combat Strength Ratio, Economic Strength Ratio,* and *Size Ratio,* since these indicators were measured and tracked individually within the game context. The *Capabilities Ratio* variable from the Correlates of War Project is a relative measure of the Composite Index of National Capabilities (CINC) scores of the states within a dyad. The CINC score is based on the population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure of a state.

The analysis presented here used a linear mixed effects regression model, run using the lme4 package for R. The results are best compared to Barbieri's Full Model of Militarized Disputes, which included all of the explanatory variables in the model, and modeled all dyadic disputes, not just major wars. Our analysis similarly includes all disputes between pairs of guilds.

Table 1. Comparison of Game X linear regression coefficients to those from Dr. Katherine Barbieri's 1996 paper *Economic Interdependence: A Path to Peace or a Source of Interstate Conflict?*

	Game X			**Barbieri**		
Variable	*β*	*SE*	*p*	*β*	*SE*	*p*
Salience	463.27	131.95	<0.001	-22.64	6.69	≤0.01
Symmetry	16.01	4.33	<0.001	-4.46	0.80	≤0.01
Interdependence	-490.88	140.78	<0.001	26.60	7.28	≤0.01

As seen in Table 1, the correlations between the explanatory variables and the dependent conflict variable reported in the Barbieri paper do not agree with those from the Game X analysis. A large, positive value of both *Salience* and *Symmetry* from the Game X analysis indicate that the more important trade relationships are between guilds, and the more symmetric they are between the trading partners, the more likely those guilds are to enter into conflict with each other (although the mathematical definition of these variables within the context of the article may not be the ideal way to capture these two quantities). Similarly to the Barbieri paper, *Interdependence* reflects an opposite correlation to conflict to that of both of its composite variables (unrealistic but logical given the way that the variable is defined mathematically). As in Barbieri's paper, *Salience* is a stronger indicator than *Symmetry* of conflict likelihood.

From this analysis, it is unclear why opposite conclusions emerge about the relationships between the dependent and independent variables from Game X and Barbieri's work. She includes the *Joint Democracy* control variable in the regression, which the Game X data does not account for, but which is not a strong predictor of conflict in her model. The Barbieri paper is not explicit about the regression methodology used, further complicating the comparison.

Conclusion and Future Work

In the 20 intervening years between the publication of *Economic Interdependence: A Path to Peace or a Source of Interstate Conflict?*, much work has been published in academia on the relationship between economic interdependence and conflict disputing the article's methodology and results and suggesting that the relationship may not be as simple as a negative or positive correlation between trade volumes and military disputes. If we are to continue to explore correlations between conflict and MIDs variables in future work, we would like to redefine the explanatory variables from the paper, include additional variables that capture important interstate relationships, and improve upon the simple linear regression techniques used to identify correlations. However, the purpose of this study was not to analyze the relationship between trade and conflict, but to demonstrate that online game data can be operationalized in such a way as to make direct comparisons between it and data from academic research. This we have successfully done, although if we want to make future direct comparisons between academic literature and online research, we will need to explore ways to quantify all of the variables, such as *Joint Democracy*, that are included in the academic analysis. This is something to think about explicitly as we move forward with our online game design. A game that explores nuclear deterrence will need to explicitly capture nuclear conflicts and nuclear capabilities, and will preferably also capture variables that are highly relevant to interstate relationships in the modern age but are not explicitly included in Correlates of War, such as *Foreign Direct Investment*, which today constitutes a much larger percentage of interstate economic interactions than trade.[9] Ideally, variables such as *Capability Ratio* would also capture important modern capabilities such as competency in cyberspace.

The time for renewed and energetic study of strategic nuclear deterrence is now, and our team of researchers from academia and the national laboratories is applying itself to that study with a full complement of modern methods. By leveraging the lessons of several decades of war gaming, applying the quantitative constructs of academia, and harnessing the data-gathering power of the internet coupled with state-of-the-art techniques in artificial intelligence, we hope to provide national decision makers with an empirical tool to inform nuclear deterrence policy deliberations, including future Nuclear Posture Reviews.

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