

Toward a Quantitative Approach to Nuclear Deterrence Policy

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About Me



- I work at Sandia National Laboratories on digital assurance for nuclear weapons
- I've worked in NW since ~2013, at the lab since 2011
- I do deterrence research on the side (Project on Nuclear Gaming and Econonuclear study)
- I got my PhD in physical chemistry from USC in 2010
- I have a Bachelor's in chemistry and Spanish from Loyola University
- I live in Livermore
- I have three children named after emperors (Ekaterina, Constantine, and Victoria)

Wargaming and

DATA FOR DETERRENCE

In 2014, Russia invaded Crimea

- The U.S. Cold War adversary invades a sovereign state in Europe
- Concern for western markets and trade deals impact the West's resulting sanctions
- The West threatens Russia with exclusion from SWIFT
- Russia responds with threats of a renewed Cold War



Image Credit: <http://english.alarabiya.net/en/News/middle-east/2014/03/14/Crimea-could-join-Russia-within-year.html>



Image Credit: <http://blogs.nvcc.edu/damiller/category/crimea/>

What are the implications of the Crimea conflict for nuclear deterrence?

To deter, a nation must be credible and capable:

- Threats of retaliation must be credible:
 - Principled
 - Rational
- The nation must be capable (or perceived as capable) of retaliation:
 - Executable
 - Painful
- If sanctions harm the sanctioner as much as the sanctioned, can threatening economic punishment be perceived as rational?
- How do cross-domain dynamics and interconnectedness affect deterrence?

How can we examine this problem quantitatively?

- Academic approach:
 - Create a database of conflict data that includes variables such as trade between nations, military capability, economic strength, and others
 - Look for correlations between these variables and conflict initiation
- Issues that plague the research:
 - Data is sparse and variables may not comprise a complete basis
 - Basis set changes over time as new variables are introduced (nuclear weapons, direct foreign investment)

We designed a controlled experiment to gather data on conflict: a wargame

This game, called Signal, is:



Replicable

Can be easily played by any interested party

Controllable

We can control variables and introduce new variables as appropriate

Instrumentable

We designed our game to answer specific questions

Neutral

The experimenter does not participate directly in the experiment

Signal is designed to study conflict as it relates to deterrence and escalation



Incorporates “elements of deterrence”, including

- Military
- Economic
- Political/diplomatic

Incorporates “dynamics of deterrence”, including

- Bargaining
- Signaling
- Uncertainty

The online version is instrumented to gather data on player moves

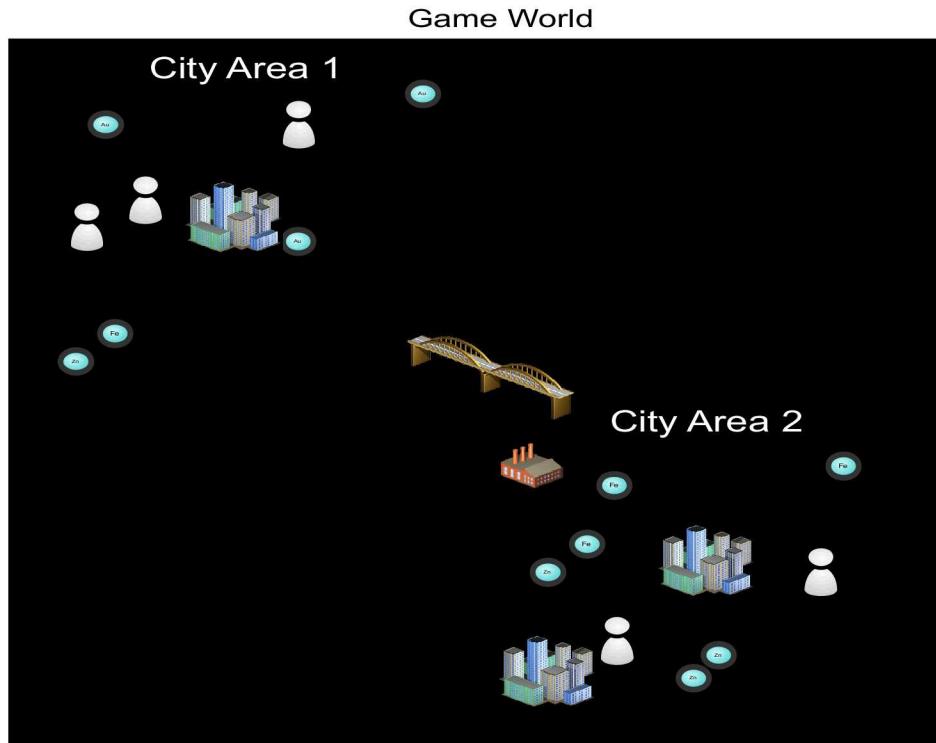
- The e-game is intended to collect data from large, diverse player bases, potentially worldwide
- Large datasets allow for statistical analysis and observation of unexpected moves
- A chat function collects metadata on player rationale



Before PoNG, there was
ECONONUCLEAR

The “Econonuclear” study performed early concept validation

- We used data from “GameX”, a browser-based game
- In GameX, guilds build economic and military relationships and enter into conflict
- We operationalized game data and compared to IR literature



GameX data were categorized according to MIDs designations

- We performed logit regression to test for variable correlations with conflict.

MIDS VARIABLE	GAME X VARIABLE
Dyadic Trade (Dyadic Trade is trade between two states)	Trade between Guilds
Contiguity	Share a Border
Alliance	Is Foe ≠ TRUE
Capabilities Ratio	Combat Strength Ratio, Economic Strength Ratio, Size Ratio

Variable	Odds Ratio, β	Standard Error	p
Intercept	0.00	2.86	<0.001
Symmetry	56,887.24	2.84	<0.001
Economic strength ratio	1.44	0.43	0.391
Combat strength ratio	0.76	0.17	0.110
Size ratio	0.52	0.09	<0.001
Contiguity	0.24	0.04	<0.001
Alliance	12.86	0.05	<0.001

Next steps: finding the
EIGENNUKES

EigenNukes: analysis using AI (actually, just matrix algebra)



$$y = \theta_0 + \theta_1 x_1 + \dots + \theta_n x_n$$

Linear equation with economic “predictor” variables x_n , dependent variable y (conflict), and coefficients θ_0

$$\begin{bmatrix} \theta_1^1 & \theta_2^1 & \theta_n^1 \\ \theta_1^2 & \theta_2^2 & \theta_n^2 \\ \theta_1^3 & \theta_2^3 & \theta_n^3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_n \end{bmatrix}$$

Design Matrix

x_1 = trade volume
 x_2 = alliance
 x_3 = capabilities ratio
 x_4 = size
 x_5 = geographical proximity

...

Use eigen decomposition to perform principal component analysis

- $AX = Y$
- $PDP^{-1} = A$
- $PDP^{-1}X = Y$
- $DP^{-1}X = P^{-1}Y$
- $DX' = Y'$
- The equation on the prior slide takes this form
- Eigen decomposition of A
- Eigenvalues of variables (D) in new coordinate set (X')

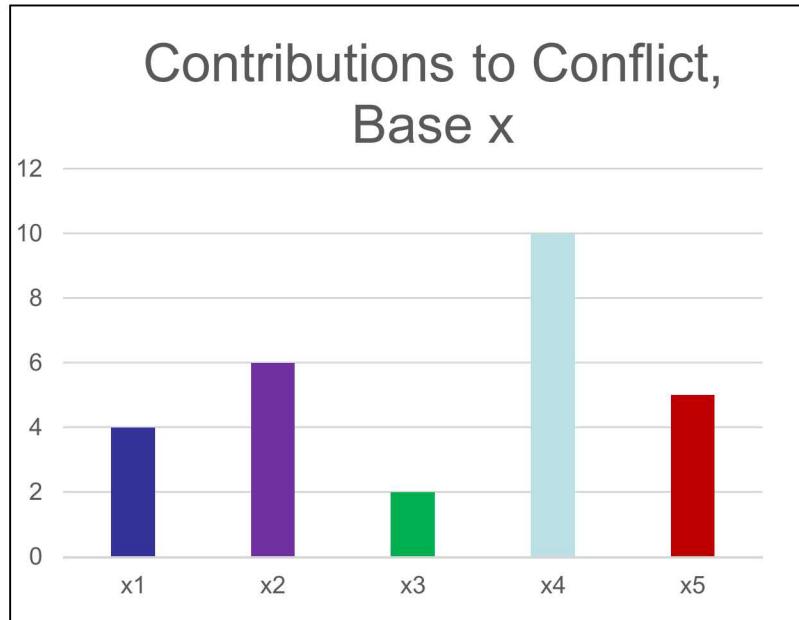
Can we find a new characteristic basis of conflict variables?

- Matrix diagonalization yields eigenvalues: a value of the contribution of each principal component
 - It also returns the eigenvectors: a characteristic basis of variables

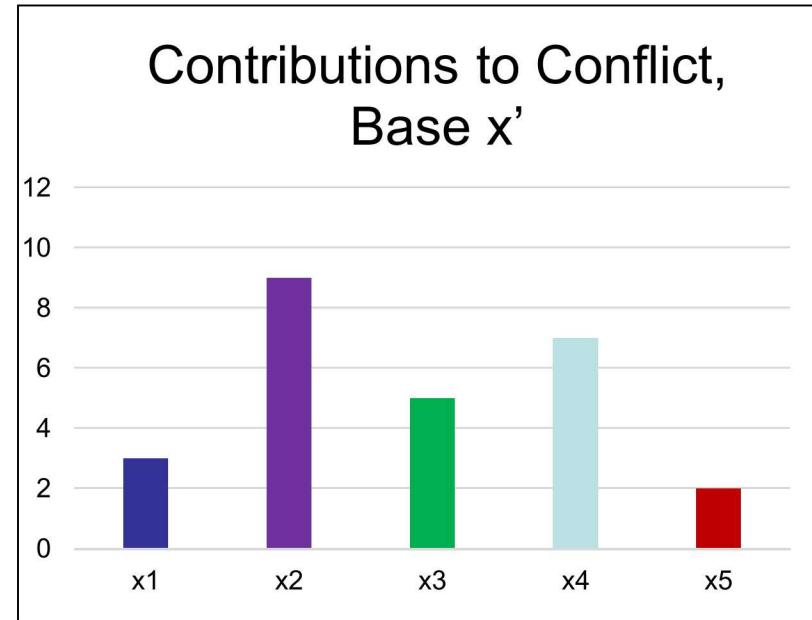
$$\begin{bmatrix} \theta_1^1 & \theta_2^1 & \theta_n^1 \\ \theta_1^2 & \theta_2^2 & \theta_n^2 \\ \theta_1^3 & \theta_2^3 & \theta_n^3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} \rightarrow \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ \vdots & \vdots & \vdots \\ 0 & 0 & \lambda_n \end{bmatrix} \begin{bmatrix} x'_1 \\ x'_2 \\ x'_3 \\ \vdots \\ x'_n \end{bmatrix}$$

Design Matrix
Eigenvalues
New basis

What might a new basis look like?



$$\begin{bmatrix} \text{size (large)} \\ \text{trade volume} \\ \text{capability} \\ \text{foreign investment} \\ \text{democracy} \end{bmatrix}$$



$$\begin{bmatrix} \text{large democracies with low capability} \\ \text{countries that trade with dependent power} \\ \text{low geographic contiguity with allies} \\ \text{foreign investment in allies} \\ \text{states with high trade asymmetries} \end{bmatrix}$$

What is the path forward?



- Perform predictive analysis to anticipate player moves (based on statistics)
- Use analytics to “decide” optimal moves under a given set of conditions
- Create the next generation of game

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