Quantifying Correlations between International Relations and Nuclear Proliferation Status[1]

Nathaniel Mahowald,* Bethany L. Goldblum,* Thomas Hickey,* James Kornell†

*Nuclear Science and Security Consortium, University of California, Berkeley, California 94704, USA
†National Security Technologies, LLC, Special Technologies Laboratory, Santa Barbara, California 93111, USA
nathanielmhld@berkeley.edu

INTRODUCTION

The spread of nuclear weapons remains a grave concern. Unfortunately, the influence of political and economic relations on nuclear proliferation is not well understood, and is further complicated by complex interplay between internal and external factors. Here, we present a new method for quantifying correlations between international relations and proliferation. This work builds on quantitative political science investigations of the relationships between proliferation and alliances, macroeconomic ties, conflicts,[1] and nuclear cooperation agreements (NCAs).[2]

Network science provides a framework for analysis of these complex systems. A multilayer network model was constructed in which the countries of the world are represented as nodes linked by international relations. The alliances, macroeconomic ties, conflicts, and NCAs between nations were quantified using node-based metrics and plotted against the proliferation stage of a nation as determined by Singh and Way.[3] The correlation between these variables and the Singh and Way proliferation stage is quantified using a linear correlation coefficient as a function of year. The distribution of these correlation coefficients as a function of year are presented here, and analyzed to identify generalized trends in the relationship between proliferation and the various forms of international associations.

RESEARCH DESIGN

Each of the four international relationships – threat, alliances, NCAs, and trade – form a layer in the multiplex network. The links are built on historical data from the period 1955-1993. Following Barrat, *et al.*, link weights are assigned in proportion to the intensity of the connections in the different network layers.[4] For a given node, each international relation is coded as the dyadic relation between two nodes summed over all node links.

Conflict

The threat, T, that state j poses to state i is a function of their conflict intensity, I, and their relative strengths, S:

$$T_{ij} = I_{ij} \times (1 - S_{rel}(i_j)). \quad (1)$$

Here, conflict intensity is quantified using the dyadic Militarized Interstate Disputes (MID) database.[5] The military strength is a product of the conventional military strength, quantified using a Composite Index of National Capability (CINC) score from the Correlates of War project,[6] and the nuclear capability, a two-valued variable to distinguish nuclear-armed nations. The relative military strength is then the military strength of state i divided by the sum of the strengths of i and j.

Alliances

The relative alliance commitment, A_{ij}, of state i from j is the sum of the strength of the alliance commitments issued by j to i:

$$A_{ij} = \sum a_{ij} \quad (2)$$

where alliance commitments, a_{ij}, are coded into five categories. These are, from lowest to highest strength: consultation pacts, nonaggression pacts, neutrality pacts, offense pacts, and defense pacts. Codings of alliance strength come from the canonical Alliance Treaty Obligations and Provisions (ATOP) project.[7]

Nuclear Cooperation Agreements

Similarly, the nuclear cooperation agreement metric, N_{ij}, that a state i receives from state j is calculated as the sum of each individual NCA, n_{ij}:

$$N_{ij} = \sum n_{ij}. \quad (3)$$

where the individual NCAs, n_{ij}, are coded into three categories. These are, from lowest to highest strength: safety related agreements, non-safety related agreements, and sensitive nuclear assistance.[8]

Trade

Trade dependence, D, measures the total trade between two states as a fraction of each state's Gross Domestic Product

[1]This report was prepared as an account of work sponsored by an agency of the United States Government.

(GDP). For two states, i and j, the trade dependence, D_{ij}, of state i on j equals its exports to j, Ex_{ij}, plus its imports from j, Im_{ij} divided by its GDP:

$$D_{ij} = \frac{Ex_{ij} + Im_{ij}}{GDP_i}. \tag{4}$$

METHODS

On a year-by-year basis, the threat, alliance, NCA, and trade metrics for all nations are plotted against the known historical cases of nuclear weapons acquisition, pursuit, and exploration.[3] This is illustrated in Fig. 1.

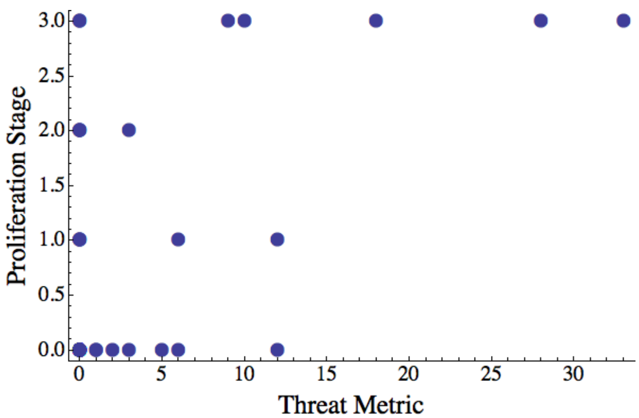

Fig. 1. In the above example from 1974, each nation's threat metric is plotted directly against its proliferation stage. While all the world's nations are depicted, many nations share similar proliferation stage and threat levels, indicated here by overlapping data.

The degree of association between each pair of variables was quantified for each year using the Pearson correlation coefficient, which ranges from positive one to negative one. The Pearson coefficient r is calculated with the normalized variances and covariances of x and y:

$$r^2 = \frac{\sum((x_i - \bar{x})(y_i - \bar{y}))^2}{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2} \tag{5}$$

The Pearson coefficient was chosen because the metric takes large outliers into account while discarding smaller more trivial trends in the data. The correlation coefficients are then plotted as a function of year to provide a macroscopic view of the trend of the correlation of the variables over time.

RESULTS AND DISCUSSION

Each of the international relations metrics provided coherent patterns when analyzed using our approach.

Conflict

The correlation of conflict and weapons pursuit has varied throughout the nuclear age, as represented in Fig. 2. The

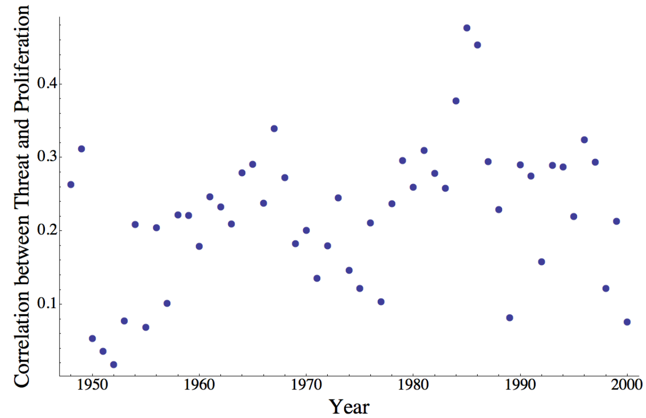

Fig. 2. Correlation coefficient between the conflict metric and proliferation stage as a function of year.

peaks and troughs represented in the data trend with historical GDP growth.[9] Overall, degree of conflict positively correlates with proliferation stage over the time frame analyzed, which is consistent with other models and analyses.[10] The apparent lack of a general trend warrants further analysis. Investigation of the correlation between proliferation and specific commodities as well as metrics of trade dependence may provide additional insights.[11]

Alliances

Following the mid-1950s, the correlation between alliances and proliferation steadily and consistently decreases as a function of time, owing perhaps to the decrease in prevalence of highly-interconnected nations pursuing nuclear weapons. The data suggest that alliances are becoming less predictive of weapons pursuit as a function of time. This may reflect the impact of the global norm against proliferation.[12]

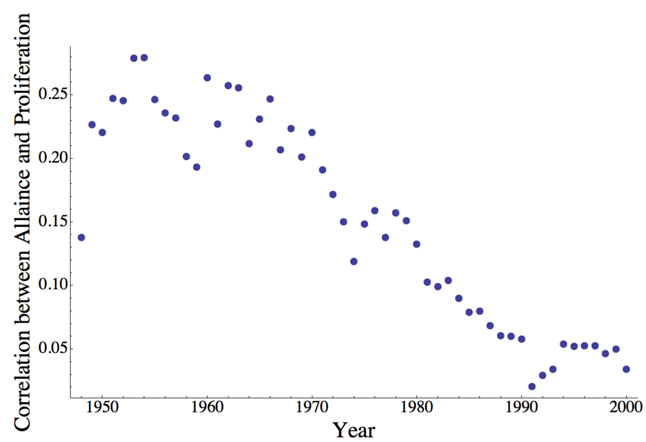

Fig. 3. Correlation coefficient between the alliance metric and proliferation stage as a function of year.

Nuclear Cooperation Agreements

The NCA metric consistently has the highest correlations with proliferation (as high as 0.8, though there is a distinct downward trend emerging). As nuclear cooperation agreements decrease in exclusivity and are offered to nations not likely to proliferate, their importance as an indicator may decrease. It should be noted that even in recent years, an NCA is still the most positively-correlated indicator.

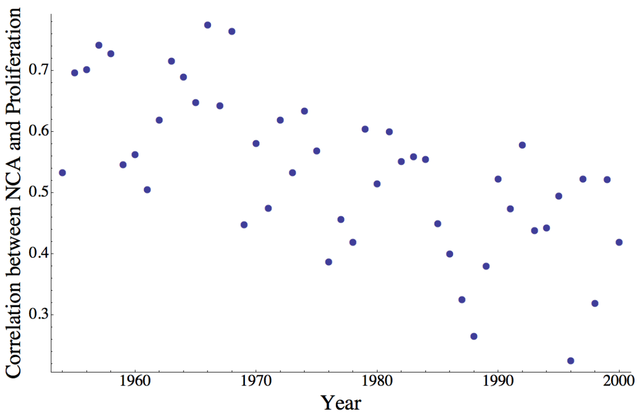

Fig. 4. Correlation coefficient between the nuclear cooperation agreement metric and proliferation stage as a function of year.

Trade

All of the correlation values for trade are negative, which may speak to the power of trade to potentially dissuade proliferation activity. Trade progressively becomes more negatively correlated until 1990, when there is a sharp turn back towards 0 correlation. The data suggest that trade is, then, a negatively associated factor when assessing a nation's proliferation stage. This interpretation is consistent with rationalist expectations of the normative and pacifying effects of an interdependent economy.[13]

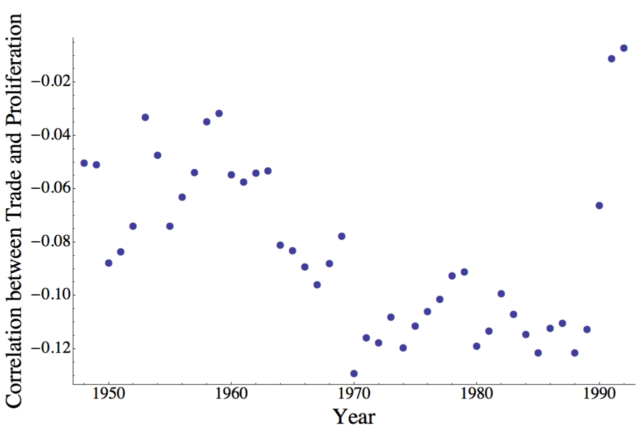

Fig. 5. Correlation coefficient between the trade metric and proliferation stage as a function of year.

CLOSING REMARKS

This work provides a new method for quantifying correlations between international relations and nuclear weapons proliferation. Such an approach supplements existing methods in the literature through the addition of a systematic year-by-year analysis. This flexible framework for experimentation can be refined in resolution and presents varied opportunities for further research. Specifically, comparison of this work to canonical literature from quantitative international relations data, as well as an analysis of country specific case studies. Both the methods and results herein provide important insights for global nuclear security and nonproliferation research.

ACKNOWLEDGMENTS

This material is based upon work supported by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number(s) DENA0000979.

REFERENCES

[1] E. GARTZKE and J. DONG-JOON, “Bargaining, Nuclear Proliferation, and Interstate Disputes,” *Journal of Conflict Resolution*, **53** (2009).

[2] M. FUHRMANN, “Spreading Temptation: Proliferation and Peaceful Nuclear Cooperation Agreements,” *International Security*, **34**, *1* (2009).

[3] S. SINGH and C. R. WAY, “The Correlates of Nuclear Proliferation: A Quantitative Test,” *Journal of Conflict Resolution*, **48**, *6*, 859–885 (2004).

[4] A. BARRAT, M. BARTHÉLEMY, R. PASTOR-SATORRAS, and A. VESPIGNANI, “The Architecture of Complex Weighted Networks,” *Proceedings of the National Academy of Sciences of the United States of America*, **101**, *11*, 3747–3752 (2004).

[5] D. M. JONES, S. A. BREMER, and J. D. SINGER, “Militarized Interstate Disputes, 1816?1992: Rationale, Coding Rules, and Empirical Patterns,” *Conflict Management and Peace Science*, **15**, *2*, 163–213 (1996).

[6] J. SINGER, S. BREMER, and J. STUCKEY, “Capability Distribution, Uncertainty, and Major Power War, 1820-1965,” in B. M. RUSSETT, editor, “Peace, War, and Numbers,” Sage, pp. 19–48 (1972).

[7] B. A. LEEDS, J. M. RITTER, S. M. MITCHELL, and A. G. LONG, “Alliance treaty obligations and provisions, 1815?1944,” *International Interactions*, pp. 237–260 (2002).

[8] M. FUHRMANN, “Taking a Walk on the Supply Side: The Determinants of Civilian Nuclear Cooperation,” *Journal of Conflict Resolution*, **53**, *2*, 181–208 (2009).

[9] J. STERMAN, “An Integrated Theory Of The Economic Long Wave,” *Futures*, **17**, *2*, 104–131 (1985).

[10] S. D. SAGAN, “Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb,” *Center for International Security and Cooperation*, **21**, 54–86 (1997).

[11] Z. MAOZ, “The Effects of Strategic and Economic Interdependence on International Conflict Across Levels of Analysis,” *American Journal of Political Science*, **53**, *1*, 223–240 (2009).

[12] D. REITER, “Security Commitments and Nuclear Proliferation,” *Foreign Policy Analysis* (2014).

[13] E. SOLINGEN, “Nuclear Logics: Contrasting Paths in

East Asia and the Middle East," *Princeton University Press* (2007).