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Modeling Nuclear Proliferation: Expanding Input Variable Sets

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1. Introduction

Quantitative tools have been developed to analyze and nuclear proliferation events. However, the results from the current models show weaknesses in the model. This work is an attempt to improve upon existing models by adding new variables based on the understanding of nuclear proliferation scenarios.

2. Understanding Nuclear Proliferation

Importance of understanding the scenarios of nuclear proliferation in developing quantitative model development for proliferation assessment has been noted in a previous paper [1]. This work is an extension of that work. There are two ways to acquire the nuclear material. The first one is by producing nuclear weapons material through building nuclear fuel cycle technological capability, such as enrichment and reprocessing. The other way is through illicit/secret trading of nuclear materials and technological assistance from nuclear weapons state. Current quantitative tools tend to be focused on the first scenario but not the second one.

3. Introducing New Variables

This work introduces two new sets of variable to enhance proliferation modeling capability. The first variable considered is the existence of sensitive nuclear technology or infrastructure assistance from other country.

The second variable considered is the dispute against the major nuclear states. In previous model there is a variable that analyzes the number of disputes against other states, but it does not specify the characteristics of the dispute. For example, it cannot distinguish whether the dispute involves the nuclear weapons state or not.

4. Methods

In this study, the variables from Li et al. [2] were used for the dataset. Data on existence of sensitive nuclear assistance was added by using the Kroenig's work [3]. This variable shows whether the country received sensitive nuclear assistance from other state or not. Another new variable included was 'UNvote' based on the UN General Assembly Voting Data [4] to determine whether the nation expressed the opinion against the US. How this data was used in the analysis is explained in Table I.

Table I: Scoring method for the variable 'UNvote'

US	Target Country	Score
Yes	No	-2
No	Yes	-2
Yes/No	Abstain/Absent	-1
Same vote		2
Abstain/Absent	Abstain/Absent	1
Abstain/Absent	Yes/No	-
Anything	Not a member	-

The panel data 'UNvote' was calculated as following.

$$unvote_{ij} = \text{vote score of country } i\text{, year } j$$
$$= \frac{\sum_{\text{country}=i,\ \text{year}=j} Score}{\#\text{ of votes in country } i\text{, year } j}$$

Including two variables described above, historical proliferation actions in this calculation were characterized by four levels as same as previous studies [2][5]. Each level is defined as in Table II.

Table II: Four levels of proliferation

Level	Name	Description
0	No interest	No proliferation attempts
1	Explore	Country considered nuclear weapons and conducted some exploratory work
2	Pursue	Country started a nuclear weapons development program
3	Acquire	First explosion/assembly of nuclear weapon

The proliferation risk is calculated for 114 countries, and some nations were selected to be analyzed by security needs and existence of any hostile relation with nuclear weapons states.

For the analysis, multinomial logistic regression model, Weibull survival model and Cox proportional hazard model were used in this study to compare the result with the previous model [2]. Stata 9.2 was used to determine the coefficients of the variables and to estimate proliferation probability.

5. Results

Figures 1 through 5 show the results of comparison of the estimated proliferation risk using the new variables. The comparison includes multinomial logit model, the Weibull mode, and the Cox model. The models successfully predicted some new cases like India and Pakistan while maintaining previous successful prediction like Iran. Unfortunately, the models were inaccurate in predicting the Libya case (Figure 4 and 5). Libya received weapons grade material and weapons technology from Pakistan while they pursued nuclear weapons through the 'explore' and 'pursue' stage.

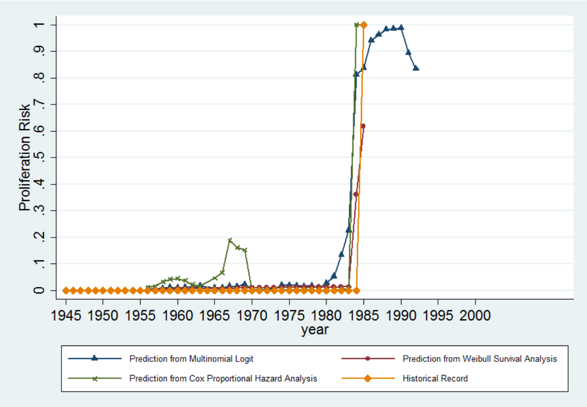

Fig. 1. Predicted proliferation risk of Iran: Pursue.

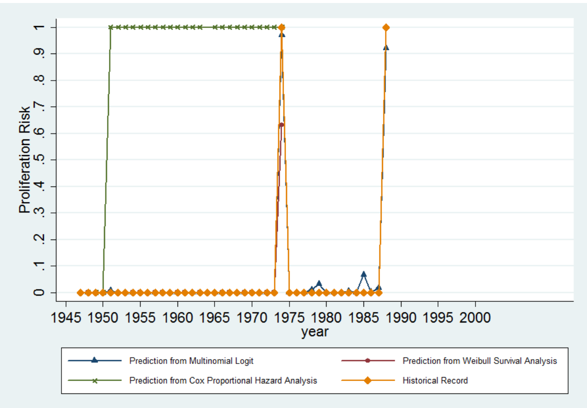

Fig. 2. Predicted proliferation risk of India: Acquire.

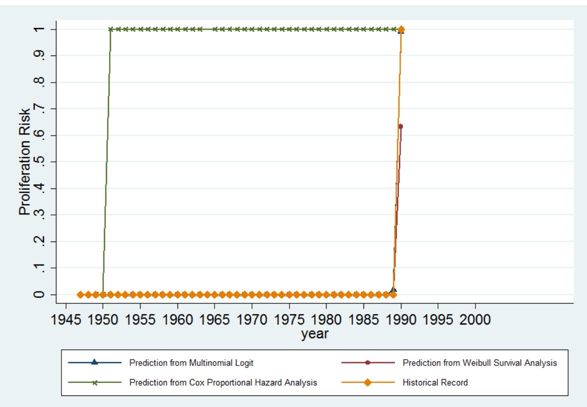

Fig. 3. Predicted proliferation risk of Pakistan: Acquire.

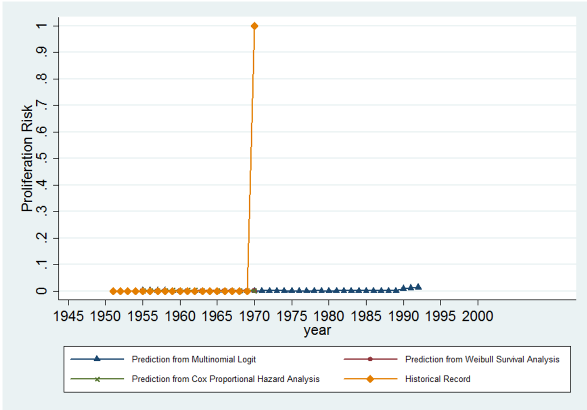

Fig. 4. Predicted proliferation risk of Libya: Explore.

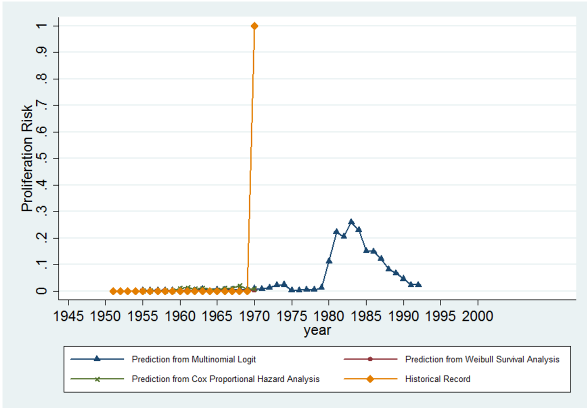

Fig. 5. Predicted proliferation risk of Libya: Pursue.

The most significant change with the addition of new variables comes from multinomial logistic analysis. Figures 6 through 10 show the comparison of the estimated proliferation risk with and without new variables by using the multinomial logit model. Some false positive cases like Japan in Figure 6 and Jordan in Figure 7 were fixed. Some new successful cases like Brazil, India, and Pakistan in Figures 8 through 10 came out.

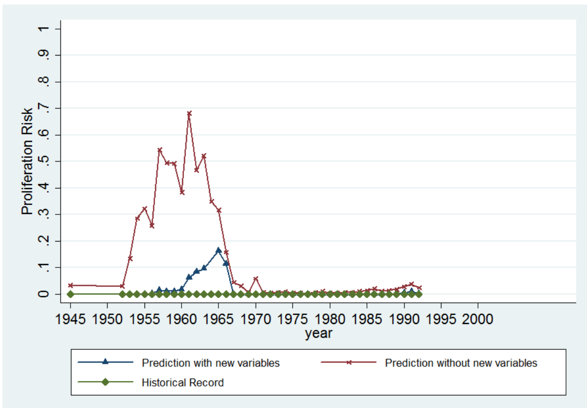

Fig. 6. Proliferation risk comparison of Japan: Pursue.

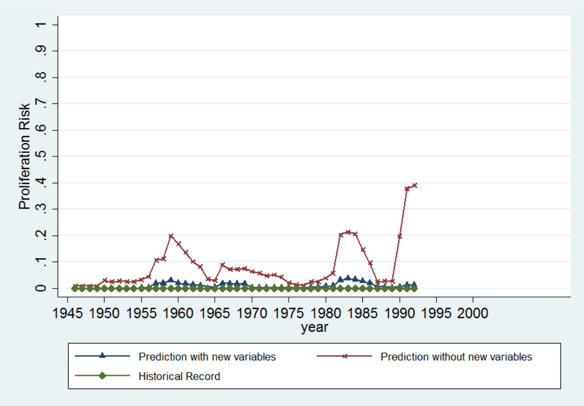

Fig. 7. Proliferation risk comparison of Jordan: Pursue.

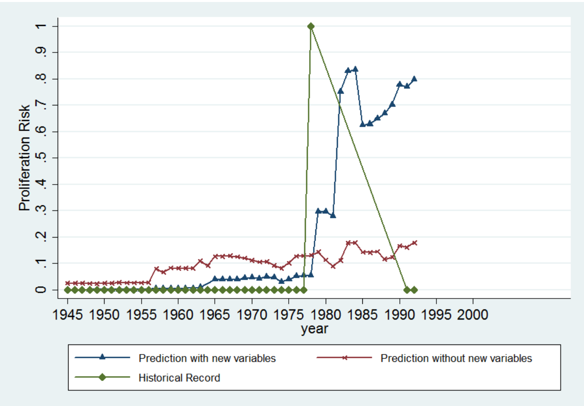

Fig. 8. Proliferation risk comparison of Brazil: Pursue.

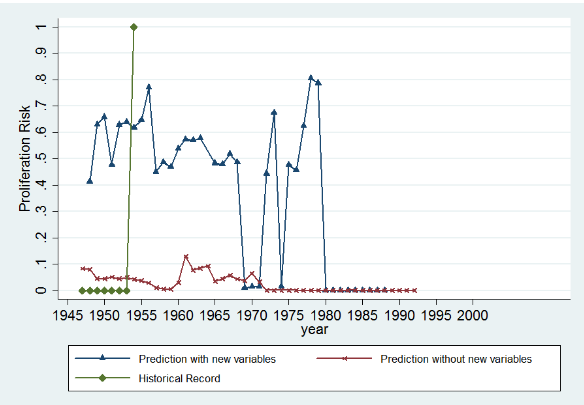

Fig. 9. Proliferation risk comparison of India: Explore.

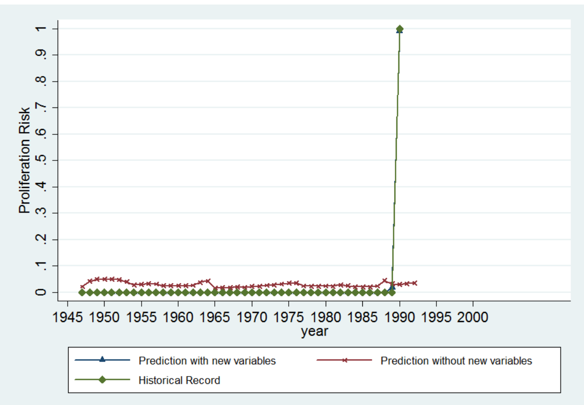

Fig. 10. Proliferation risk comparison of Pakistan: Acquire.

6. Discussion

Addition of new variables made in this study was found to be successful for the cases like India, Pakistan, Iran, and Iraq. The common characteristic of these new successful cases is that they received a sensitive nuclear assistance. Libya is an exception, because the historical data says it had received sensitive nuclear assistance from 1997 by Pakistan. To predict Libya case, the nuclear cooperation with Pakistan in 1970s should be modeled. Further research on modeling the nuclear cooperation with proliferation-friendly nuclear states or with a state who is currently exploring/pursuing nuclear weapons is required.

Variable 'UNvote' also seemed to have positive effect on the modeling. Figure 6 and 7 show the decrease in false positive prediction in the case of Japan and Jordan. Both of these countries did not receive any sensitive nuclear assistance. Also, Figure 8 shows new successful match with historical record for Brazil. In this case, 'UNvote' was effective in describing the potential conflict between Brazil and the US and improved the modeling capability.

The model still has weaknesses. For example, this model cannot predict the renunciation of nuclear weapons program. In the use of the variable 'UNvote' there is a gap in the data which requires examination of historical records. Further research will continue to address these issues.

7. Conclusion

In this study, two more variables were added to existing dataset to enhance the nuclear proliferation prediction. The results showed enhancement of modeling capability for some countries, but some limitations still exist. Future work will include by adding new variables and improving database to further enhance proliferation modeling capability.

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