OPTIMIZATION OF NUCLEAR, RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL TERRORISM INCIDENCE MODELS THROUGH THE USE OF SIMULATED ANNEALING MONTE CARLO AND ITERATIVE METHODS

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Jesse A. Coyle

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OPTIMIZATION OF NUCLEAR, RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL TERRORISM INCIDENCE MODELS THROUGH THE USE OF SIMULATED ANNEALING MONTE CARLO AND ITERATIVE METHODS

Approved by:

Dr. Chaitanya Deo, Advisor
School of Nuclear & Radiological Engineering
Georgia Institute of Technology

Dr. Shatakshee Dhongde
School of Economics
Georgia Institute of Technology

Dr. Nolan Hertel
School of Nuclear & Radiological Engineering
Georgia Institute of Technology

Date Approved: [Date Approved by Committee]

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF SYMBOLS AND ABBREVIATIONS	viii
SUMMARY	ix
CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	5
3 MODEL METHODOLOGY	13
Simulated Annealing Optimization	13
Application to Parametric Regression Methods	16
Non-parametric Simulation	19
4 DATA SUMMARY	22
Dependent Data	22
Economic Development Model	23
Political Risk Model	30
5 REGRESSION RESULTS	45
Economic Development Model	45
Political Risk Model	53
6 SIMULATION RESULTS	55
7 DISCUSSION	62

Economic Development Model 62

Political Risk Model 63

Simulations 65

Future Work 65

REFERENCES 67

LIST OF TABLES

	Page
Table 1: Economic development model independent variables & sources	25
Table 2: Political risk model independent variables & sources	34
Table 3: Econ dev. Model: negative binomial cross sectional results: Monterey data	48
Table 4: Econ dev. model - negative binomial cross sectional results: GTD data	50
Table 5: Econ dev. model - negative binomial panel results:	52
Table 6: Political risk model: negative binomial panel regression	53

LIST OF FIGURES

	Page
Figure 1: Predicted probabilities of Poisson and negative binomial Models	46
Figure 2: Pearson residuals for Poisson and negative binomial Models	47
Figure 3: Histogram of historical and simulated yearly CBRN incidents	55
Figure 4: Variogram of historical and simulated yearly CBRN data	56
Figure 5: Historical and simulated yearly CBRN incidents	56
Figure 6: Histogram of historical and simulated quarterly CBRN incidents	57
Figure 7: Variogram of historical and simulated quarterly CBRN data	58
Figure 8: Historical and simulated quarterly CBRN incidents	58
Figure 9: Extrapolated yearly CBRN Incidents	59
Figure 10: Histogram of extrapolated yearly CBRN Incidents	60
Figure 11: Extrapolated quarterly CBRN incidents	60
Figure 12: Histogram of extrapolated quarterly CBRN Incidents	61

LIST OF SYMBOLS AND ABBREVIATIONS

ΔE	Change in energy
k_B	Boltzmann's Constant
T	Temperature
β'	Regression Coefficient Vector
$\hat{\gamma}$	Semi-variogram function
CBRN	Chemical, Biological, Radiological, and Nuclear
START GTD	National Consortium for the Study of Terrorism and Responses to Terrorism Global Terrorism Database

SUMMARY

A random search optimization method based off an analogous process for the slow cooling of metals is explored and used to find the optimum solution for a number of regression models that analyze nuclear, radiological, biological, and chemical terrorism targets. A non-parametric simulation based off of historical data is also explored. Simulated series of 30 years and a 30 year extrapolation of historical data are provided. The inclusion of independent variables used in the regression analysis is based off existing work in the reviewed literature. CBRN terrorism data is collected from both the Monterey Institute's Weapons of Mass Destruction Terrorism Database as well as from the START Global Terrorism Database. Building similar models to those found in the literature and running them against CBRN terrorism incidence data determines if conventional terrorism indicator variables are also significant predictors of CBRN terrorism targets. The negative binomial model was determined to be the best regression model available for the data analysis. Two general types of models are developed, including an economic development model and a political risk model. From the economic development model we find that national GDP, GDP per capita, trade openness, and democracy to significant indicators of CBRN terrorism targets. Additionally from the political risk model we find corrupt, stable, and democratic regimes more likely to experience a CBRN event. We do not find language/religious fractionalization to be a significant predictive variable. Similarly we do not find ethnic tensions, involvement in external conflict, or a military government to have significant predictive value.

CHAPTER 1

INTRODUCTION

Introduction to CBRN Terrorism

Over the past 30 years, the use of Chemical, Biological, Radiological, and Nuclear (CBRN) weapons by sub-state actors has become a major/significant concern in many nations around the globe. A brief review of the open-source literature on CBRN terrorism by the National Defense University's Center for Counterproliferation Research suggests that CBRN incidence may be on the rise due to the increased availability of materials throughout the world (National Defense University 2002). The public has become largely desensitized to traditional terrorism attacks, and previous attack methods may not be seen as an effective way for terrorist organizations to achieve their goals. The shock value and fear-inducing properties of CBRN weapons can provide a means for terrorist organizations to revitalize the effectiveness of their efforts (National Defense University 2002). The devastating capability of these weapons motivates research to understand their acquisition and deployment.

Research in the areas of network theory, psychology, econometrics, and many other fields, are commonly applied to further the understanding of the dynamics of terrorism. Econometric analysis of terrorist motivation, targets, and incident locations is a particularly active area of research. Yet while traditional terrorism is actively examined in an econometric framework, little work has been done with a focus on CBRN terrorism. Are leading indicators of conventional terrorism also significant predicators of CBRN terrorism targets and can a future series of CBRN incidence data be simulated with similar statistical properties to the historical data? These are the main questions to be investigated.

We use the U.S. Department of Defense's definition of terrorism to classify attacks as acts of terrorism. The U.S. Department of Defense defines terrorism as "The calculated use of unlawful violence or threat of unlawful violence to inculcate fear; intended to coerce or to intimidate governments or societies in the pursuit of goals that are generally political, religious, or ideological (Hoffman 2006)."

CBRN terrorism is often associated with Weapons of Mass Destruction (WMD), however a CBRN terrorism incident does not require the attack to inflict mass casualties, nor does it require lethality from an attack at all. If a CBRN agent is sought after, acquired, or used, it is classified as a CBRN incident in this study.

Research on CBRN terrorism is limited due to the general lack of available data on CBRN terrorism. Few databases compile data on CBRN incidents and those that do have relatively few accounts of CBRN terrorism compared with conventional terrorism.

One prominent resource available for data on CBRN incidents is the regularly updated Monterey Institute's Weapons of Mass Destruction Database (Monterey Institute of International Studies 2010). It is comprised of more than 1100 events dating back to 1900 relating to the use of chemical, biological, radiological, and nuclear weapons. Events are classified by type, including politically, ideologically, and criminally motivated incidents. An advanced search feature also allows the user to locate incidents by a variety of criteria including year, weapon type, location, and perpetrator name or group.

An alternative database exists and is known as the Global Terrorism Database (GTD) (National Consortium for the Study of Terrorism and Responses to Terrorism 2010). It is provided by the National Consortium for the Study of Terrorism and Responses to Terrorism and includes more than 87,000 events from 1970 through 2008. Unlike the Monterey Database, it is comprised of both conventional and CBRN terrorism events. The GTD database can be used and compared with results from the Monterey database to determine if the results are database dependent.

In order to determine if the same factors that affect conventional terrorism also influence CBRN terrorism a regression analysis is employed. This will determine the relative impact of each variable in predicting counts of CBRN incidents. In order to run a regression model a dataset must first be constructed, and is done so from a variety of sources. We collect data on variables that have proven to be significant in regards to conventional terrorism. Based off of previous work, hypotheses are developed for the independent variables and their possible relation to CBRN incidence.

Two major regression models are constructed, the first is an economic development model based off of work by Blomberg & Hess (2005) and the second is a political risk model based off of work by Ivanova & Sandler (2007). The economic development includes variables such as national and per capita GDP and trade openness. The political risk model looks at corruption, rule of law, religious and military involvement in government and government stability as well as additional variables. The economic development model is run as both a cross sectional regression with values averaged over the 30 year period, and as a panel regression with independent observations recorded for each country-year. The political risk model is run as panel regression as well.

With the datasets constructed a series of regressions are performed to provide coefficients for each socio-economic variable, stating its individual contribution to the prediction of CBRN incidents. The regression models are broken down into subsets of variables based on the previous regression analyses described above. Significance levels for each variable are reported indicating if a variable is contributing to the predictive value of the model. From the regression coefficients each of our previously developed hypotheses are assessed.

Following the regression analysis, generation of new data via simulated annealing is explored. Generating new data series can provide data on expected count frequencies in the future. This approach assumes the underlying properties involved in generating historical data continues unchanged in the future.

The remainder of the paper is structured as follows. A review of the literature on econometric terrorism studies follows in chapter 2. Chapter 3 describes regression models and simulated annealing optimization. Chapter 4 provides a data summary for both dependent datasets as well as for all independent variables included. Regression results are presented in chapter 5. Simulated annealing results follow in chapter 6. A discussion of the results follows in chapter 7.

CHAPTER 2

LITERATURE REVIEW

Krieger and Meierrieks (2011) surveyed recent work on empirical investigations on the causes and targets of terrorism. They found that large populous countries were likely targets of transnational terrorism. In addition to population they generalized that social stress and weak institutions attract terrorism. They found that target countries of terrorism are chosen based on economic success. They dismiss popular hypotheses that democracy, education, and religion are predictive of terrorism venues. Overall they found the most important determinants of terrorism to be politically and demographically founded.

Klitgaard et. al. (2005), used data on economic and political freedom and tested the impact of these variables on the occurrence of transnational terrorist events. Data on terrorism was sourced from both the ITERATE dataset (Mickolus 1982) and the U.S. State Department's Patterns of Global Terrorism report for years spanning 1996-2002 (US-State-Department 2004). Independent variables include a wide range of political and economic freedom indicators gathered from a variety of sources including the Economic Freedom of the World Index (James D. Gwartney 2004), Penn World Tables (Heston, Alan et al. 2002), World Development Indicators (The World Bank 2010), Freedom House Index, and Polity-IV dataset (Marshall, G. et al. 2000). A binomial logistic regression was performed using a dichotomous dependent variable. Although economic freedom indicators had relatively little explanatory value for predicting terrorism, greater per capita income was associated with higher probabilities of terrorism, whereas more trade was associated with decreased probability of terrorism. A non-linear relationship between political freedom and terrorism was discovered. A small increase in democracy from none at all was found to increase terrorism, however further increasing democracy led to a decrease in terrorism.

Alberto Abadie (2006) focused on factors explaining international terrorism. Data was used from the World Market Research Center's Global Terrorism Index which is a comprehensive index of 186 countries and their potential risk for terrorism events (World Market Research Center 2004). Combining this index with a set of independent economic and political data from the World Bank (The World Bank 2010) and Freedom House Political Index (Freedom House Inc. 1973-2009), an ordinary least squares regression analysis was performed for the year 2003-2004. Abadie's (2006) results were similar to those found by Klitgaard et. al. (2005).Economic indicators do not provide conclusive predictive results for terrorism incidents. Political freedom is found to be a significant predictor and exhibits a similar non-linear relationship. Terrorism is expected to rise during transitions from autocracies to democracies.

James Piazza (2006) examined conventional terrorism incidents and their casualties spanning the years 1986-2002. Data on terrorist incidents in 96 countries worldwide was used from the annual U.S. State Department's Patterns of Global Terrorism reports (US-State-Department 2004).

Employing an ordinary least squares regression, he determined whether poverty, inequality, and poor economic development are root causes of terrorism. Consistent with the earlier studies, Piazza found that the economic indicators have little predictive value for terrorist incidents and casualties. He finds democratic and political variables to have some predictive value for either incidents or casualties. The only variable that was a significant predictor for both terrorism incidents and casualties was population. More populous, socially diverse states attract more terrorism than their smaller ethnically and religiously homogenous counterparts. Populous states with multiparty political systems are more prone to terrorism than less populous states with up to three political parties (Piazza 2006).

Ivanova and Sandler (2007) used data on CBRN terrorism rather than traditional terrorism. The Monterey Institute's Weapons of Mass Destruction Terrorism Database is the source of CBRN incidence counts for the years 1988-2004. An odds ratio methodology was employed to determine if there was any association or correlation between variables of interest. The odds ratio test of democracy showed a strong and clear association with increased CBRN terrorism. A strong and significant correlation between CBRN terrorism and rule of law was also found. The honesty of a state, measured by a lack of corruption attracts CBRN terrorism, but the association is not as strong as with democracy and rule of law. In addition to the odds ratio tests, Ivanova and Sandler also estimated a negative binomial regression model. This confirmed the odds ratio findings for democracy and rule of law, yet found the opposite influence of honesty on CBRN terrorism. The regression coefficient for honesty was negative suggesting honest regimes are less likely to experience CBRN terrorism than dishonest regimes. Analysis from odds ratio testing and regression models suggest that wealthy, democratic states with a strong rule of law will tend to attract CBRN terrorism (Ivanova and Sandler 2007).

Krueger and Laitin (Krueger, Laitin et al. 2008) analyzed the origins and targets of terrorism by estimating a negative binomial regression analysis on the data. Terrorism incident data was used from the U.S. State Department's Patterns of Global Terrorism reports for years spanning from 1981-2002 (US-State-Department 2004). Results from the analysis showed that political oppression was a major factor in the country of origin of the attack perpetrator. Poverty did not have strong relationship to the origins of terror. Countries with high levels of economic achievement were shown to be the primary victims of terrorist attacks (Krueger, Laitin et al. 2008).

Jose Tavares (2004) used ordinary linear regression analysis to examine a cross-country dataset covering years from 1987 to 2001. Dependent terrorism data was obtained from the dataset of the International Policy Institute for Counter-Terrorism (International Policy Institute for Counter-Terrorism 2003). Independent variables used in the study included various economic and political freedom indicators. Additional controls such as population, illiteracy rate, ethnic, linguistic, and religious diversity were also included. It was seen that higher income per capita is associated with increased rates of terrorism. Democracy and political development do not increase vulnerability to terrorist attacks. Similarly trade openness was not associated with increased terrorist attacks. Linguistic diversity was shown to be significant and positively correlated with terrorism incidence. Ethnic and religious diversity displayed the opposite effect and were correlated with reduced terrorism incidence. Finally, a larger share of population living in urban areas and increased rate of literacy were positively correlated with increased terrorism (Tavares 2004).

Li and Schaub (2004)used negative binomial regression techniques to analyze terrorism data from the ITERATE dataset (Mickolus 1982). They used data on 112 countries for the years spanning 1975-1997. A variety of economic indicators such as trade, foreign direct investment and economic development and political indicators such as democracy, government capability, and country size were included. Contrary to the initial hypothesis, they found that increased trade and foreign direct investment did not significantly increase terrorism. GDP per capita was shown to be significant and inversely related to terrorism where as controls of size, government capacity and democracy were all shown to be significant and positive contributors to increased terrorism incidence (Li and Schaub 2004).

Eubank and Weinberg (2001) used data on terrorist events from the ITERATE dataset (Mickolus 1982) and found that most terrorist events occurred in stable democracies with perpetrators of the attack also emanating from stable democracies.

Quan Li (2005) also sought to examine the role of democracy on transnational terrorism. Using negative binomial regression analysis he looked at terrorism data from the ITERATE dataset (Mickolus 1982) on 119 countries from 1975 to 1997. Agreeing with his initial hypothesis, he finds that democratic participation reduces the incidence of transnational terrorism. He also finds that institutional constraints attract terrorism. From the inclusion of control variables he found economic development as measured by GDP per capita to be associated with reduced terrorism. Nations undergoing regime changes were found to be more susceptible to terrorism. Large countries with highly capable and stable regimes were found to attract terrorism.

Drakos and Gofas (2006) used negative binomial and zero-inflated negative binomial regression analysis on the National Memorial Institute for the Prevention of Terrorism (MIPT)Terrorism Knowledge Base (MIPT-RAND 2004). Data on 153 countries during the period 1985-1998 was analyzed. Independent variables in their study included economic indicators such as trade openness, GDP growth rate, and life expectancy and other variables such as polity index, population density, education, and interstate conflict. It was seen that previous (local) terrorist events were correlated with increased terrorism rates. Interstate conflict was shown to increase levels of terrorism. Trade openness was shown to have a negative overall effect on terrorism. A key finding from the study is the relation of democracy to increased terrorism activity. The only variable found to be significant in the zero-inflation model for the prediction of zero counts of terrorism was polity. Increased polity is found to significantly reduce the odds of observing a zero count. This leads to the prediction that democracy does not have a large impact on terrorism, rather non-democratic states tend to underreport acts of terrorism and thus appear to have fewer terrorist incidents (Drakos and Gofas 2006).

Bravo and Dias (2006) use data from the MIPT database (MIPT-RAND 2004)for the years 1997-2004. They focused specifically at deprivation and geopolitical factors of terrorism and utilized an ordinary least squares approach. Their main findings were that terrorism was associated with reduced levels of development, literacy rate, and ethnic fractionalization. Levels of mineral reserves, non-democratic regimes, and participation in international organizations were negatively associated to incidents of terrorism.

Dreher and Fischer (2010) looked at the role of government decentralization on terrorism incidence. They utilized a negative binomial regression on 109 countries with data from the MIPT Database (MIPT-RAND 2004) for the years 1976-2000. They find that fiscal decentralization, which is spending across all levels of government, shows a reduction in transnational terrorism. They also found that political decentralization, which represents decision making across all levels of government, is not related to transnational terrorism incidence. Population was found to be strongly correlated with increased transnational terrorism and GDP per capita was not shown to be significant. When social fractionalization measures were added, they did not show significance.

Dreher and Gassebner (2008) sought to find out if political proximity to the United States was subject to increased terrorist attacks from abroad. They analyzed 116 countries from the MIPT Terrorism Database from 1975-2001 (MIPT-RAND 2004) using a negative binomial regression analysis. They hypothesized that nations voting in agreement with the United States in the United Nations General Assembly were more prone to transnational terrorism. Their results confirmed their hypothesis. They also included a number of control variables similar to those used by Piazza (2006). They find that greater government fractionalization is associated with increased terrorism. They did not find GDP per capita to have any influence on transnational terrorism incidence. Population was found to be significant and positively related to transnational terrorism. In addition they found that the level of political freedom in a country did not influence terrorism incidence, but rather increasing political freedom was associated with decreased terrorism incidence. It is a transition of political freedom that matters.

Blomberg and Hess (2005) analyzed the economic determinants of transnational terrorism. Data on transnational terrorism was taken from the ITERATE dataset (Mickolus 1982), which includes data on 179 countries from 1968-2003. A censored linear regression approach was used to conduct the regression analysis. Various subsets of economic indicators were also used and various groupings of dependent variable data were broken down by relative national income level. Their results showed that economic development in high income countries was associated with a high number of transnational terrorism incidents. Economic development in low income countries had the opposite effect and was associated with reduced levels of transnational terrorist incidents.

CHAPTER 3

MODEL METHODOLOGY

Simulated Annealing Optimization

Simulated annealing is a numerical optimization technique based off of an analogous process for the slow cooling of metals. It has the ability to locate a global minimum in the presence of many possible local minima. It is essentially a random walk through a defined parameter space. As with annealing in metals, it involves a slow cooling of a system in order to find its minimum energy. When metals are heated and slowly cooled defects can be removed and atoms find their way to lower energy states, reducing the overall energy of the system. The same process is done numerically with a defined energy function, with a slow cooling mechanism allowing the algorithm to escape local minima in its search for the global function minimum.

The Simulated Annealing Algorithm

In order to begin with simulated annealing, one must first define a score function for the problem at hand. The goal of simulated annealing is to find the global minimum of this defined score function. First the algorithm starts with an initial state, with score of this position is calculated via the previously mentioned score function. The first computed score becomes the current minimum score of the function.

A new point in the search space is determined via a Markov chain and once again evaluated. If this score is less than the currently determined minimum, the new score is set to be the new minimum and the current position is set as the solution point. At this point we see simulated annealing accepting only moves that reduce the current score of the problem. However, if a move is suggested that increases the score of the function, it may be accepted according to what is known as the metropolis criterion, developed by Metropolis (1953). The probability of accepting a move that increases the energy of the system is given by equation 1.

$$P(\Delta E) = \exp(-\Delta E / k_B T) \qquad (1)$$

Where ΔE represents the change in energy of the proposed move, k_B is the Boltzmann constant, and T is the current temperature of the system. From the metropolis criterion we can see that large changes in energy change are accompanied by a smaller probability of acceptance. Similarly, as the temperature of the system is reduced the probability of metropolis acceptance is reduced. This probability of accepting energetically unfavorable moves is what allows the algorithm to escape local minima in hopes of finding the global minimum.

The simulated annealing algorithm proceeds by reducing the temperature of the system after a designated number of steps at the current temperature. As the temperature is reduced, the algorithm should hopefully approach the solution. When the final specified temperature is reached, the current state of the system is reported.

In this implementation of the algorithm, the GNU Scientific Library for C is utilized. This library contains a number of methods necessary for simulated annealing (Galassi and Theiler 2011). The most important function is the simulated annealing solve function which calls all other functions to perform the optimization. It takes a number of parameters including the initial parameter specification, the energy of the system, a step function, and a distance function. It also requires additional parameters specifying the number of iterations, Boltzmann constant, maximum step size, temperature dampening factor, initial and final temperature values.

Next, the functions being called by the solve function must be specified. Starting with the energy function, also known as a score function, we must define the function to be minimized. Of course this varies depending on the problem. In the parametric regression modeling traditional estimators are used as the score functions. For the linear model a sum of square residuals is used while Poisson and negative binomial models use their respective log-likelihood functions. For the non-parametric simulations a moments based objective function is minimized.

A step function must be specified as a method of moving to the next candidate in the function space. In the parametric based regression implementation we choose a step length defined in the input parameters and individually step each member of the current point vector. If a current point in space is represented by $R(x_{1,n}, x_{2,n}, x_{3,n}, ... x_{i,n})$, with n representing the current iteration, then the step function will adjust each point x_j according to equation 2.

$$x_{i,n+1} = Rand \times 2 \times Step\_Size - Step\_Size + x_{i,n}, \qquad (2)$$

$Rand$ represents a random number on the interval $[0,1)$.

A large step size allows the method to generate points that are further apart in the function space. The non-parametric stepping function is similar, except modified so only integer steps are made.

The simulated annealing solve function will now call each of the aforementioned functions until the final temperature is reached. A log function provides the current iteration, point, temperature, energy, and best energy found during the annealing process.

Application to Regression Methods

Regression methods involve fitting some parameterized function to an observed response. The most basic regression model is that of a linear model. Typically referred to as ordinary least squares (OLS), it involves fitting a function a function of the form given in equation 3.

$$Y_i = X_i{}'\beta_i + \varepsilon \qquad (3)$$

Where Y is the response variable, X'_i is a vector of observed independent data, β_i is a vector of parameters to be determined, and ε_i is the error term. In order to find the parameters that best fit this model, the error must be minimized over all observations N. In this case typically the square of the error term is minimized to penalize larger errors more severely. As described above the error term to be minimized is given in equation 4.

$$\sum_N \varepsilon_i^2 = \sum_N (Y_i - X_i^{'}\beta_i)^2 . \qquad (4)$$

The score function to be minimized has been determined and now simulated annealing algorithm can be applied to search the parameter spaced defined by β_i. The vector of parameters that minimizes the squared error function provides the optimal solution for the regression model. In order to test the functionality of the simulated annealing code, a number of linear regression examples pulled from Gujarati (2003) were duplicated and confirmed that the simulated annealing code was able to find the proper solutions.

Applying simulated annealing to a linear model was the first step, however CBRN incidences are reported as count variables and can only exist in the positive domain. For this reason, more appropriate regression models are available.

A Poisson regression is commonly used to model count data. The Poisson probability distribution is given by equation 5.

$$f(y_i \mid x_i) = \frac{u_i^{y_i} e^{-u_i}}{y_i!} \quad (5)$$

Where y_i is the observed number of events (in this case terrorist incidents), u_i is the expected number of events occurring during the given time interval. u_i is parameterized by a log linear model according to equation 6.

$$\ln(u_i) = X_i^{'} \beta^{'} \quad (6)$$

$X_i^{'}$ is a vector of independent variable data and $\beta^{'}$ is a vector of predictive coefficients to be measured.

In order to apply simulated annealing to a Poisson regression, a score function has to be determined. A way to assess the fit of data to a Poisson model is by looking at the likelihood function. If the probability of observing count y_i given independent data x_i is given by equation 5, then the probability of observing all counts given the independent data, also known as the likelihood, is given by the product of the individual probability density functions. This yields probability of observing the observed outcomes given the set of parameters and independent data. The likelihood function for a Poisson model is given in equation 7.

$$L(u_i \mid y_i) = \prod_{i=1}^{n} \frac{e^{-u_i} {u_i}^{y_i}}{y_i!} \qquad (7)$$

It is often easier to find the maximum of this function if the natural logarithm is taken, yielding the log-likelihood function in equation 8.

$$\log L(u_i \mid y_i) = \sum_{i=1}^{n} \{ y_i X_i^{'} \beta - \exp(X_i^{'} \beta) - \ln(y_i!) \} \qquad (8)$$

In order to maximize this function, its negative is used as the score function. Minimizing this function over all observations in the dataset will yield the best possible parameter estimates for β'.

One assumption made by the Poisson regression is equality between the mean and variance.

$$u = E(Y) = VAR(Y) \qquad (9)$$

Since the data being worked with is over dispersed with a variance larger than the mean, a more appropriate regression model is available. The negative binomial regression is often used for count data that exhibits high over dispersion. The negative binomial model is a modification of the Poisson model with the introduction of an over dispersion parameter α. This gives the model the ability to more appropriately handle over dispersion of the data. The expected value u_i remains the same as in the Poisson model, however the variance is now given by the following relationship.

$$VAR(Y) = u_i + \frac{u_i}{\alpha^{-1}} \qquad (10)$$

Note that as α becomes increasingly small, the variance will approach the expected value and the negative binomial distribution will converge to the Poisson distribution. In order to determine the likelihood function we start with the probability distribution function given below.

$$f(u_i \mid y_i) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})} (\frac{1}{1 + \alpha u_i})^{\alpha^{-1}} (\frac{\alpha u_i}{1 + \alpha u})^{y_i} \qquad (11)$$

The link function for the negative binomial model remains the same as in the Poisson. Taking the product of probabilities across all possible counts yields the likelihood function.

$$L(u_i \mid y_i) = \prod_{i=1}^{n} \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})} (\frac{1}{1 + \alpha u_i})^{\alpha^{-1}} (\frac{\alpha u_i}{1 + \alpha u})^{y_i} \qquad (12)$$

Taking the log we arrive at the log-likelihood function for the negative binomial regression

$$\log L(u_i \mid y_i) = \sum_{i=1}^{n} \exp\{y_i \ln(\frac{\alpha u_i}{1 + \alpha u_i}) - (\frac{1}{\alpha}) \ln(1 + \alpha u_i) + \ln \Gamma(y_i + \frac{1}{\alpha}) - \ln \Gamma(y_i + 1) - \ln \Gamma(\frac{1}{\alpha})\} \qquad (13)$$

Minimizing this function with the simulated annealing algorithm should find the optimum parameter vector for a negative binomial fit.

Non-Parametric Simulation

In addition to minimizing negative log likelihood functions for linear, Poisson, and negative binomial models simulated annealing can be used for non-parametric fitting. Lokupitiya and Borgman (2005) used simulated annealing to simulated hurricane and storm incident data. Using a similar methodology, CBRN series of incident counts are generated using simulated annealing.

Given a historical series of counts, provided by the START Global Terrorism Database, a simulated series of equal length is created while retaining key statistical properties of the original series. These statistical properties include the mean, semi-variogram, skewness, and kurtosis. Additionally, series of double length and series extrapolated from the historical data are also generated.

The semi-variogram is included to maintain the correlation structure and distributional dependence of the original series. The semi-variogram is given by the following estimator provided by Cressie (1993).

$$\hat{\gamma}(\tau) = \frac{1}{2|N(\tau)|}\sum_{N(\tau)}(Y(t_i) - Y(t_j))^2, \tau = 1,2,... \qquad (14)$$

Where $N(\tau) = \{(t_i, t_j) : |t_i - t_j| = \tau, i, j = 1,2,...,n.$ $|N(\tau)|$ is the number of distinct pairs for lag τ .

The mean, skewness, and kurtosis are measures of the first, third, and fourth moments respectively. Combining these properties together a score function for the simulated annealing algorithm is formed.

$$F(Y') = \sum_{\tau}[\hat{\gamma}_H(\tau) - \hat{\gamma}_S(\tau)]^2 + [mean_H{}^2 - mean_S{}^2]^2 + [skewness_H^{(2/3)} - skewness_S^{(2/3)}]^2 + [kurtosis_H^{(1/2)} - kurtosis_S^{(1/2)}]^2 \qquad (15)$$

$\hat{\gamma}$ is the semi-variogram of a configuration, *H* represents historical data, and *S* represents simulated data.

Simulated annealing proceeds as before in the parametric fitting examples. We first initialize a configuration with the same mean as the historical data being compared. After each iteration, two points of the configuration are incremented by a step of 1. One position is increased while the other is decreased. As before, an initial and final temperature must be specified, along with the number of iterations for each temperature step.

CHAPTER 4

DATA SUMMARY

Dependent Data

Data on CBRN incidents is collected from two databases including the Monterey Institute's WMD Terrorism Database (Monterey Institute of International Studies 2010) and START'S Global Terrorism Database. The Monterey Database is comprised entirely of CBRN incidents while the START database tracks CBRN and conventional incidents.

Events from the Monterey Database and START GTD are counted if they were politically or ideologically motivated. Incidents are also classified by event type. Additionally we are interested in removing false cases / hoaxes from the dataset. Therefore we include only those incidents involving an acquisition, attempted acquisition, possession, or threat with possession of a CBRN weapon. Events dating back to 1968 are catalogued, yet due to the majority of events occurring recently, we collect data for the years spanning 1980-2009.

The START database includes information on more than 98,000 terrorist attacks dating back to 1970. In order to compare regression results we use the same yearly span as before, 1980-2009. While this database includes both conventional and CBRN incidents, it allows us to easily filter out the conventional incidents and focus on CBRN events.

Independent Data

Economic Development Model

For the economic development model we collected data on a total of 208 countries, not all of which have complete data available, resulting in a max number of observations of 178. The World Bank provides data on three key independent variables including measures of Gross Domestic Product (GDP), trade openness, and literacy rate (The World Bank 2010). Gross domestic product was averaged for the years 1980-2009 and given in terms of constant 2005 purchasing power parity. A per capita measure is also included. Trade openness is measured by the ratio of imports and exports to GDP. Values were also averaged over the thirty year period. Literacy rate is measured for the adult population, those over the age of 15.

Data on linguistic and religious fractionalization is provided by Alesina et al (2003). The method for determining indices of fractionalization is given in equation 16.

$$FRACT_j = \sum_{i=1}^{N} S_{ij}^2 \qquad (16)$$

where s_{ij} represents the share of group i (up to N groups) in county j. Data used in calculating fractionalization indices includes more than 1,055 linguistic groups and 294 religious specifications on more than two hundred countries. A higher fractionalization value signifies a large number of groups.

A binary variable for democracy is included and determined by data from the POLITY-IV project, the most widely used database on regime change and authority

(Marshall, G. et al. 2000). If the POLITY variable is greater than 7 on average for the years 1980-2009, the democracy variable is coded as 1, and 0 otherwise. If the POLITY variable is not available for a country, the LIEC and EIEC scores reported in the appendix of Blomberg and Hess (2005) are used. The LIEC and EIEC scores represent legislative and executive electoral competitiveness and come from the Database of Political Institutions (Beck 2001). If LIEC and EIEC add up to fourteen the country is coded is considered a democracy, and not otherwise. Regional binary control variables are included for countries in Sub-Saharan Africa and Asia to account for any regional effects.

Table 1: Economic development model independent variables & sources.

Independent Variable	**Description**	**Source**
National GDP	Total gross domestic product of the nation. (Constant 2005 Intl. PPP)	World Bank Global Development Indicators
GDP per Capita	National GDP divided by the population. (Constant 2005 Intl. PPP)	World Bank Global Development Indicators
Trade Openness	Sum of the value of imports and exports as a percentage of national GDP (%)	World Bank Global Development Indicators
Democracy	Binary variable: 1 if democracy, 0 otherwise. Considered a democracy if polity variable is greater than 7. (1 or 0)	POLITY – IV Project
Language Fractionalization	$Fract = 1 - \sum_{i=1}^{N} s_i^2$	**A.** Alesina (2003)
Religious Fractionalization	$Fract = 1 - \sum_{i=1}^{N} s_i^2$	A. Alesina (2003)
Asia	1 if located on the Asian continent, 0 otherwise.	N/A
Africa	1 if located on the African continent, 0 otherwise.	N/A

National wealth as measured by GDP is a good indicator of the size and power of a nation. Li and Schaub (2004) and Li (2005) find increased size and government capacity of a nation to attract terrorism. One would expect countries with large national GDP to be of significant size and government capacity. Dreher and Gassebner (2008) find population size related to terrorism occurrence. Countries with large populations also tend to have a large national GDP. Blomberg and Hess (2005) show national GDP to be positively related to terrorism incidence with countries grouped from all income levels. Due to general agreement in the literature the following hypothesis is made.

Hypothesis 1: Countries with large national GDP are attractive targets of CBRN terrorism.

Typically economic wellbeing at an individual level is measured by Gross Domestic Product (GDP) per capita. There is no consensus in the literature on whether or not economic factors are good indicators of terrorism. Piazza (2006) finds that economic development as proxied by Human Development Index (United Nations 2004), is not related to terrorism incidence. Abadie (2006) and Dreher and Gassebner (2008) also find a lack of significance for economic development. Tavares (2004) finds that per capita GDP is associated with an increasing number of total terrorist attacks. Burgoon (2006) finds government capacity to be associated with increased terrorism and government capacity is largely reflective of per capita GDP. Krueger and Laitin (2008) also echo the same findings. Still others have found the opposite to be true suggesting economic success reduces terrorism incidence. Li and Schaub (2004) and Bravo and Dias (2006) find that increasing GDP per capita reduces the likelihood of a terrorist attack on home soil. The main comparison paper for the economic development model finds per capita

GDP positively influencing terrorism in all income and high income countries while negatively influencing terrorism in low income countries. Due to a lack of agreement in the literature, results similar to those from the comparison paper are expected.

Hypothesis 2: GDP per capita positively attracts CBRN terrorism in high and all income country groups. The opposite is expected in low income countries

Trade openness is defined as the ratio of the sum of imports and exports to the GDP of a nation. As trade openness increases, national perception from other nations is likely to improve due to the willingness to work with others and develop relationships abroad. Tensions between trading partners should be expected to decrease and provide less incentive for transnational terrorism between the two. From the literature, Drakos and Gofas (2006), Kurrild-Klitgaard, et. al. (2005), and Blomberg and Hess (2005) all find trade openness to be associated with reduced terrorism events. Li and Schaub (2004) find that trade indirectly reduces transnational terrorism by promoting economic development, although it is not significant in itself. Tavares (2004) also finds a lack of significance for trade openness in his work. Due to the general agreement in the literature on the effect of trade openness on traditional terrorism, the same effect is hypothesized for CBRN terrorism.

Hypothesis 3: Countries open of trade are less attractive targets of CBRN terrorism.

Democracy as a political indicator commonly used throughout the literature. Presence of democracy can be measured by a binary variable and the degree of democracy can be measured by a continuous variable. In many cases it is measured by the Polity-IV index from the Polity Project (Marshall, G. et al. 2000). Abadie (2006) showed a democratic state does not necessarily promote terrorism, but rather the transition from autocracy to democracy tends to increase terrorism. The same transitional vulnerabilities were found by Klitgaard et. al. (2005). Dreher and Gassebner (2008) found the opposite to be true, with a transition of increasing political freedom tending to reduce transnational terrorism incidence. Blomberg and Hess (2005), Eubank and Weinberg (2001), Li and Schaub (2004), and Burgoon (2006) associated high levels of democracy with increased terrorist attacks, while Bravo and Dias (2006) found that the opposite was true. Tavares (2004) suggested that increasingly democratic states reduced the economic impact of terrorist attacks but they do not reduce the incidence of terrorism. Li Quan (2005) found that increased democratic participation reduced the number of transnational terrorism incidents. He also found that a system of increased checks and balances limited the effectiveness of government to oppose terrorism.

A positive correlation between democracy and terrorist incidence may be due to the ease of penetration of terrorist organizations into more democratic states. Enhanced freedoms associated with democracies allow for enhanced maneuverability of organizations, reducing cost and risk. Democracy may also positively correlate with terrorism due to underrepresentation of terrorist incidents by non-democratic nations. Ivanova and Sandler (2007) found a strong correlation between democratic states and increased CBRN terrorism.

Hypothesis 4: Democratic states are more attractive targets than their non-democratic counterparts.

Literacy rate is used as a proxy for educational achievement. Blomberg and Hess (2005) and Krueger and Laitin (2008) found that literacy rate was negatively associated with transnational terrorism in low-income countries and insignificant in all others. Bravo and Dias (2006) found low levels of literacy associated with higher terrorist incidence, while Tavares (2004) found illiteracy to be associated with reduced terrorism. However, Klitgaard et al. (2005) found literacy rate to be independent from terrorism incidence. An initial hypothesis is that well-developed nations can dedicate more resources to international affairs than those countries with more pressing developmental issues domestically. Increasing involvement in international affairs may result in ideological conflicts with terrorist organizations, resulting in a higher likelihood of CBRN incidence.

Hypothesis 5: More educated states attract CBRN terrorism.

Blomberg and Hess (2005), Krueger and Laitin (2008), and Dreher and Fischer (2010) found that language fractionalization is not a significant factor in predicting traditional terrorism. Klitgaard et al. (2005) found language fractionalization to be of statistical significance but they did not find a consistent positive or negative relation across models. Tavares on the other hand found linguistic fractionalization to be significant and positively related to terrorism incidence. Increasing linguistic fractionalization could be an indicator of ethnic tolerance and may ease ethnic tensions within and abroad and result in fewer CBRN incidences. On the other hand, high fractionalization creates more opportunities for disagreement between groups leading potentially to political disagreements and political violence. Language fractionalization is not consistently significant in the literature, however we include it for comparison with Blomberg and Hess (2005).

Hypothesis 6: Language fractionalization does not hold a significant association with CBRN incidence.

As with language, Blomberg and Hess (2005) found a lack of significance and consistency with religious fractionalization. Krueger and Laitin (2008), and Dreher and Fischer (2010) found religious fractionalization to have no effect on the targets of terrorism. Klitgaard et al. (2005) and Tavares (2004) found religious fractionalization to be negatively associated with terrorism. Piazza (2006) found no significance for religious diversity by itself, yet when combining population and religious diversity he found more populous, ethnically and religiously diverse nations to be at greater risk for a terrorist attack. He argued that nations with large ethnic and religious fractionalization are more prone to also feature a large number of political parties. Large numbers of political factions may reduce political stability, foster extremist activities, and lead to political violence. On the other hand, as with linguistic fractionalization, increasing religious fractionalization could ease ethnic tensions domestically and abroad and reduce motivation for CBRN terrorism. As with language fractionalization, it is included to be consistent with Blomberg and Hess (2005).

Hypothesis 7: Religious fractionalization is not significantly indicative of CBRN terrorism venues.

Political Risk Model

For the political risk model panel data on 61 countries was examined. Yearly data for the panel model spans from 1984 to 2009. The International Country Risk Guide is the main provider of the panel data.

A measure of democracy is provided by the Polity-IV project (Marshall, G. et al. 2000). It contains data on 163 countries from 1800 to 2009. The democracy indicator is rated from zero to ten and is a composite of three separate measures including competitiveness of political participation, the openness and competitiveness of executive recruitment, and constraints on the chief executive. A higher score indicates a more democratic regime.

Law and order is given a max score of 6, with each component given a max of 3 points. Law measures the strength and impartiality of the legal system while order measures whether or not the law tends to be obeyed.

Corruption is measured on a scale of 0 to 6 and includes a variety of measures. It is concerned with corruption in the form of excessive patronage, nepotism, job reservations, favor-for-favors, secret party funding, and close ties between business and politics.

GDP is provided by The World Bank's World Development Indicators (The World Bank 2010). Data is provided on a yearly basis and used for the years 1984-2009. The values of GDP are logged before coded into the dataset.

Ethnic tension is scored on a scale between 0 and 6 and measures the degree of tension within a country attributable to racial, nationality, or language divisions. Low scores indicate high tension, while high scores indicate a tolerance for such ethnic divisions.

Socio-economic condition is a variable scored from 0 to 12 points and is comprised of three separate sub-components. These components include unemployment, consumer confidence, and poverty. A high score is representative of very low risk while a low score is indicative of very high risk.

Internal conflict is measured from 0 to 12 and measures the actual or potential of intrastate political conflict on governance. It is comprised of three sub-components including civil war / coup threat, terrorism/political violence, and civil disorder. A high score is given to countries with no civil or armed opposition towards the government and when the government does not engage in direct or indirect violence against its own people.

Similar to internal conflict, external conflict is scored from 0 to 12 and is comprised of three sub components. These include war, cross-border conflict, and foreign pressures. Thus it captures both violent acts in war and cross-border conflict and non-violent acts in foreign pressures. Non violent acts include trade restrictions, withholding of aid, territorial disputes, and sanctions. As with internal conflict a high score indicates a low risk and a low score is indicative of high risk.

Government stability measures the ability of the government to carry out its objectives and its ability to remain in office. It is measured on a scale from 0 to 12 and is comprised of three sub-components including government unity, legislative strength, and popular support.

Military government is measured on a scale of 0 to 6 and measures the involvement of the military in political proceedings. A military takeover may represent high risk since it may be an indication that the government is unable to function effectively. Military involvement in an unstable government may provide temporary stability, although in the long run the system of governance is likely to become corrupt and develop an armed opposition.

Religious tension is scored from 0 to 6. Tensions may increase as a single religious group seeks to dominate society and government and replace civil law by religious law. Tensions may also rise as one religious group seeks to exclude others from the political and social process. Suppression of religious freedom also contributes to religious tension. Religious tension may result in inappropriate policies in government or create civil unrest with an increased potential for civil war.

A summary of the political risk variables is provided in table 2 below.

Table 2: Political risk model independent variables & sources.

Independent Variable	**Description**	**Source**
Democracy	Democracy Rating from 0-10	POLITY IV Project
Rule of Law	Rating from 0-6	International Country Risk Guide
Honesty (Lack of Corruption)	Rating from 0-6	International Country Risk Guide
GDP Per Capita	In terms of 2005 International PPP	The World Bank
Socio-economic Conditions	Rating from 0-12	International Country Risk Guide
Ethnic Tensions	Rating from 0-6	International Country Risk Guide
Gov. Stability	Rating from 0-12	International Country Risk Guide
Internal Conflict	Rating from 0-12	International Country Risk Guide
External Conflict	Rating from 0-12	International Country Risk Guide
Military Involvement	Rating from 0-6	International Country Risk Guide
Religious Tensions	Rating from 0-6	International Country Risk Guide

Democracy is an important regime characteristic which has been studied extensively in relation to terrorism incidence, although its influence on terrorism is not perfectly clear. According to Martha Crenshaw (1981), a major condition that fosters terrorism is a lack of opportunity for political participation. The denial of power to the people can create dissatisfaction amongst citizens, increasing the likelihood of turning to terrorism as an alternative way to have their voices heard. Eubank and Weinberg (2001) also argue that increased political participation will reduce the instances of terrorism. Under a democratic regime all ethnic, religious, and racial groups are permitted to participate in the political process and thus have a greater chance of achieving their political goals peacefully. This should reduce the number of those citizens that turn to violence. Another view on democracy suggests democratic governments are more susceptible to terrorism. Jeffrey Ross (1993) contends that democratic regimes offer the freedom of movement, media, and proliferation of narrow-based social issues which may promote terrorism. Empirical results on democracy's influence on terrorism seem to largely link democracy with increased terrorist activity. Eubank and Weinberg (2001), Blomberg and Hess (2005), Li and Schaub (2004), and Burgoon (2006) all found this positive association between democracy and terrorism. Li Quan (2005) and Bravo and Dias (2006) found the opposite to be true with democratic participation leading to reduced transnational terrorism. It is hypothesize that any increased movement and freedom allowed under a democratic regime will encourage terrorism and overshadow any reduction in terrorism caused by expression of political beliefs through peaceful means.

Hypothesis 1: Increasingly democratic states are more attractive targets for CBRN terrorism.

Ivanova and Sandler (2007) include rule of law as a regime characteristic in their study on CBRN incidents. Countries with a strong rule of law employ fair and just systems to uphold the law and find the majority of citizens obey said law. They find that rule of law is positively correlated with increased CBRN incidents within a country. Terrorists may seek targets with a strong rule of law as a show of strength and to demonstrate that perhaps the government is weaker than publicly accepted. In David Fromkin's *Strategy of Terrorism* (1975) it is suggested that terrorists believe they can bring about government collapse by demonstrating public authorities are powerless to enforce law and order.

The opposite argument suggests a country with a fair legal process could have implications on preventing terrorist attacks within its borders. As Laura Dickinson (2001) states "… a process that is widely perceived as fair strengthens the multilateral intergovernmental efforts needed to combat terrorism. At the same time, such a process may gain greater acceptance within societies around the world, thereby at least playing a part in helping to defuse the resentment toward the United States that may be one of the root causes of terrorism." While this statement is focused on the United States, it is easily transferable to any other nation around the globe. However based off of the result of law and order in Ivanova and Sandler's (2007) previous work, hypothesis 2 is stated below.

Hypothesis 2: States with a strong rule of law attract CBRN terrorism.

Corruption is another regime characteristic included in the previous work on CBRN terrorism by Ivanova and Sandler(2007) . The results of their odds ratio testing and regression approach demonstrate different associations of corruption with CBRN terrorism. Honesty is found to be negatively associated with CBRN terrorism in the regression approach, and positively associated in the odds ratio examination. The Whitehouse has suggested that corruption is positively associated with increased terrorism stating in its periodically published *National Security Strategy of the United States of America (2002)* "…poverty, weak institutions, and corruption can make weak states vulnerable to terrorist networks and drug cartels within their borders." Louise Shelley (2004) finds that terrorist organizations, transnational crime, and often found together in regions with shadow economies. Recent transnational crime groups are less dependent on long-term sustainability, allowing them to operate in regions of political corruption and chaos. Often transnational crime provides source funding for terrorist organizations suggesting a positive link between terrorism and corruption. Dishonesty in government could also hinder attempts at peaceful reform through democratic ideals, leading minority groups to engage in violent means to achieve their goals.

Das, DiRienzo et al. (2007) found a non-linear relationship with regards to corruption and terrorism. Their results showed corrupt regimes to experience more terrorism as this "…can generate feelings of repression in the disadvantaged parties." They also back up former President Bush's comments that "corrupt governments are generally weak and unable to patrol borders and enforce order, making them susceptible to terrorism." In addition they found low government corruption to be associated with increased terrorism risk. Countries with lower corruption attract terrorism indirectly since they tend to be freer and wealthier.

Hypothesis 3: Honest governments experience reduced CBRN terrorism incidence.

As described previously in economic development model, there exists no general agreement in the literature on per capita wealth's relation to terrorism incidence. Many find economic variables to be insignificant in their relation to terrorism venues, others suggest targets of terrorism tend to be well off financially. Still others say improving economic conditions tend to discourage terrorism, particularly in low income states.

Brian Burgoon (2006) states "Popular intuition suggests that poverty and low income spur terrorism by causing suffering and grievances that, in turn, fuel political extremism and terrorism." Economic deprivation may create social discontent and anger, enticing some to turn to political violence (Gurr 1970). Former president George W. Bush has stated "Poverty does not transform poor people into terrorists and murderers. Yet poverty, corruption and repression are a toxic combination in many societies, leading to weak governments that are unable to enforce order or patrol their borders and are vulnerable to terrorist networks and drug cartels" (2002).Krueger and Laitin (2008) find no economic basis for the source of terrorism yet they find that "…the targets are countries that bask in economic success." Ivanova and Sandler (2007) also find wealthy nations to be targets of CBRN terrorism. Based off the previous findings from Blomberg and Hess, a similar result is expected as in the economic development model.

Hypothesis 4: Increasing individual wealth in higher income countries is associated with increased CBRN incidents. Gains in individual wealth in lower income countries may reduce CBRN incidents.

A measure of ethnic tension is also included in the model. Martha Crenshaw (1981) suggests ethnic-tensions as a cause of terrorism. She writes "The first condition that can be considered a direct cause of terrorism is the existence of concrete grievances among an identifiable subgroup of a larger population, such as an ethnic minority discriminated against by the majority. A social movement develops in order to redress these grievances and to gain either equal rights or a separate state; terrorism is then the resort of an extremist faction of this broader movement." Piazza (2006) and Bravo and Dias (2006) found more diverse societies more likely to experience terrorism. Dreher and Fischer (2010) included ethnic fractionalization in their regression analysis however they found it insignificant. Brian Lai (2003) hypothesized that ethnic discrimination could lead to acts of terrorism based off of work by Gurr (1970). This ethnic discrimination could be both political and economical and either a result of formal exclusion or underrepresentation. His results confirmed his initial hypothesis as he states "Political and economic deprivation of a group is likely to increase the number of terrorist incidents against a state…" (Lai 2003). Ethnic tensions are predicted to catalyze any discontent of sub-state actors, possibly leading them to pursue physical violence.

Hypothesis 5: Countries with increasing ethnic tensions are more likely to experience a CBRN incident.

Similar to national wealth, this more specifically measures poverty, unemployment, and consumer confidence. Burgoon (2006) argues that "…social welfare policies -- including social security, unemployment, and health and education spending -- affect preferences and capacities of social actors in ways that, on balance, discourage terrorism: by reducing poverty, inequality, and socioeconomic insecurity, thereby diminishing incentives to commit or tolerate terrorism, and by weakening extremist political and religious organizations and practice that provide economic and cognitive security where public safety nets are lacking." He finds that reducing poverty and socioeconomic insecurity through social welfare policies, terrorism incidence is reduced. Piazza (2006) states "…the average national unemployment rate for each country, would be expected to bear a significant positive relationship with terrorism, as unemployment precipitates the stress of idle workers who might suffer from unmet economic expectations and therefore turn to political violence, as predicted by Gurr's ''relative deprivation'' model" (Gurr 1970) . We expect better socio-economic conditions to reduce terrorism incidence.

Hypothesis 6: Nations with more favorable socio-economic conditions can less likely to experience a CBRN attack.

One might expect internal conflict to mainly influence domestic terrorism and not affect international terrorism, yet this is not the case. Both international and domestic terrorism can grow out of civil war or lead to it, but such a conflict transformation is more likely when terrorism is domestic" (Sambanis 2008). The motivators behind a fully fledged civil war and terrorist beginnings are not necessarily the same, however Sambanis provides evidence that overreaction by a state regime to terrorist activities may end up rallying support for terrorist organizations leading to escalated conflict. "Indiscriminate use of state repression in response to terrorism serves to mobilize the masses including moderates who would not otherwise support the terrorists." He states further "…terrorism and civil war are adjacent phenomena. Terrorists with legitimacy become revolutionaries and failed rebellions can give way to sporadic terrorist violence by the remnants of rebel armies." Lai (2007) states "Governments involved in a civil war are not likely to have the resources available to effectively control their territory, allowing groups to organize without fear of government reprisals." This should make it easier for terrorist groups not only to form, but to carry out attacks as well. Thus the following is hypothesized.

Hypothesis 7: Nations involved dealing with internal conflicts can expect increased CBRN incidence.

States involved in military conflict with another party must have their differences either economically, politically, or ideologically. This may influence fringe groups to resort to acts of violence against innocent people of the opposing nation, whether they are domestic or abroad. Conversely, terrorist goals may not be aligned with national goals or ideals so external conflict may not affect those with extreme views likely to take part in terrorism. Li and Schaub include external conflict as a dichotomous independent variable and find that while the coefficient is positive, it is not significant. According to Lai (2007) , devotion to an external conflict may consume resources necessary to secure borders and monitor terrorist groups. He states "In addition to a civil war, states involved in an interstate war are also likely to have less ability to control their own borders. Similar to the effects of involvement in a civil war, interstate conflict can potentially create a situation where a government's resources are unavailable to address internal problems." A country's focus on an external enemy may leave them vulnerable to terrorism, whether it is domestic or international, regardless of the national alignment of the terrorist organization. The following prediction is made for external conflicts relation to CBRN terrorism.

Hypothesis 8: Nations involved in external conflicts are subject to increased CBRN terrorism likelihood.

According to Frey and Luechinger (2002), government stability can help reduce terrorist attacks. The attraction of violent actions on the part of terrorists is diminished as they prove to have less effect on the political stability …" If terrorists do not achieve the end result they were looking for, it may demotivate them to continue with violent attacks. One could also see the argument the other way, as a government proves its stability it becomes a more attractive target to those seeking to destabilize it, as it may demonstrate terrorist group's capabilities. Eubank and Weinberg (2001) find that stable democracies were much more likely to be the target of terrorist attacks compared to insecure democracies. "Perhaps civil wars and other forms of high magnitude political violence tend to occur in weak, insecure democracies, as they enter or sometimes exit the democratic column. This does not appear to be the case with terrorism however. It is the stable, secure centripetal democracies which are the most vulnerable to terrorist violence; that is where the events occur most frequently, that is where their perpetrators and victims tend to come from" (Eubank and Weinberg 2001). Crenshaw (1981) suggests why stable democracies might be more susceptible to terrorism. She states, "Perhaps terrorism is most likely to occur precisely where mass passivity and elite dissatisfaction coincide. Discontent is not generalized or severe enough to provoke the majority of the populace to action against the regime, yet a small minority, without access to the bases of power that would permit overthrow of the government through coup d'état or subversion, seeks radical change. Terrorism may thus be a sign of a stable society rather than a symptom of fragility and impending collapse." It is therefore hypothesized that stable governments are attractive targets.

Hypothesis 9: Government stability is can promote CBRN incidence.

Military governments are also investigated. A capable military government may be willing to use physical force more quickly against possible threats than a traditional government operation, which could hinder the motivations of terrorists. Crenshaw (1981) notes that military regimes in the past have crushed terrorist organizations in their respective countries. De la Roche (1996) suggests that military regimes could be more susceptible to terrorism when she states "Invasions, military dictatorships, and other patterns of domination provide fertile conditions for terrorism." Kittner (2007) notes the culture of violence caused by the presence of military regimes in Latin America. A culture of violence is more likely to passively accept terrorism than a non-violent one. It is predicted that a culture of violence and domination cultivated by a military government will encourage terrorism and overpower any reduction in terrorism caused by a display of physical force.

Hypothesis 10: Militarized governments are more likely to experience CBRN terrorism than non-militarized governments.

Religious tension has been examined in the past in relation to terrorism. Fearon and Laitin (2003) examined the effect of religious fractionalization on civil war and found it not to be significant. As discussed previously, both domestic and international terrorism can be born out of civil wars. Religious tensions increase if one religious group is dominant over all others or has significant power in influencing national politics. Iannacone and Berman (2006) write "Conflict and militancy becomes common, however, where the state favors one religious group over another (or there is an expectation that the state will do so after it is established), thereby raising the stakes for all sides." They continue to argue that sectarian groups can become effective terrorists if they feel they can benefit by increasing their political power. A reduction in state support of religion reduces the financial and protective benefits received from government, making political involvement much less attractive for religious sects. Removal of religion from politics reduces the potential for one religious group to have immense power over the opposition.

Hypothesis 11: Religious tension is can attract increased CBRN terrorism.

CHAPTER 5

REGRESSION RESULTS

Economic Development Model

The most basic regression model available is the ordinary least squares model. This model is not entirely suited for count data with high over dispersion. The result table for the OLS economic development model is available in the appendix.

Due to a large number of zero counts a traditional OLS squares regression approach is shown to be biased and inconsistent. Censored regression models have been developed for dealing with this situation. One such censored regression model is the Tobit model (Tobin 1958). The standard Tobit model involves a dependent variable that is left-censored at zero. The Tobit model is described by equations 17 and 18.

$$y_i^* = x_i^{'}\beta' + \varepsilon_i \qquad (17)$$

$$y_i = \begin{cases} 0 \ if \ y_i^* \leq 0 \\ y_i^* \ if \ y_i^* > 0 \end{cases} \qquad (18)$$

y_i^* is a latent variable which is not observed, x_i is a vector of independent data, and β is vector of unknown coefficient parameters (Cameron 1998). Tobit results can also be found in the appendix.

Neither OLS nor Tobit models are ideal for analyzing count data so a Poisson model is used as well. The Poisson regression results can be found in the appendix. The

Poisson model improves the significance of many of the coefficients yet is still not the best regression model available for this purpose. Since our data is not only count data, but over dispersed count data, we can upgrade from a Poisson regression model to a negative binomial model. Improvement can be seen in figure 1 below looking at the predicted probabilities of both the Poisson and negative binomial vs. the observed probabilities.

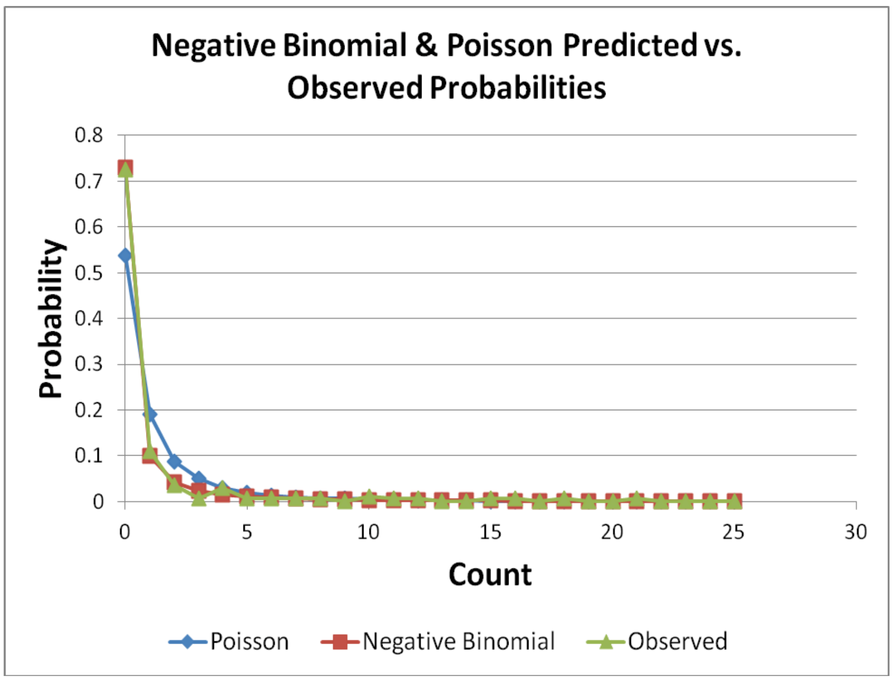

Figure 1: Predicted probabilities of Poisson and negative binomial Models.

The negative binomial model more accurately predicts the zero and low counts than the Poisson model does. The poisson model underpredicts the zero frequency and overpredicts the frequency of the low counts.

Figure 2 shows the reduction in pearson residuals by utilizing a negative binomial regression rather than a Poisson model.

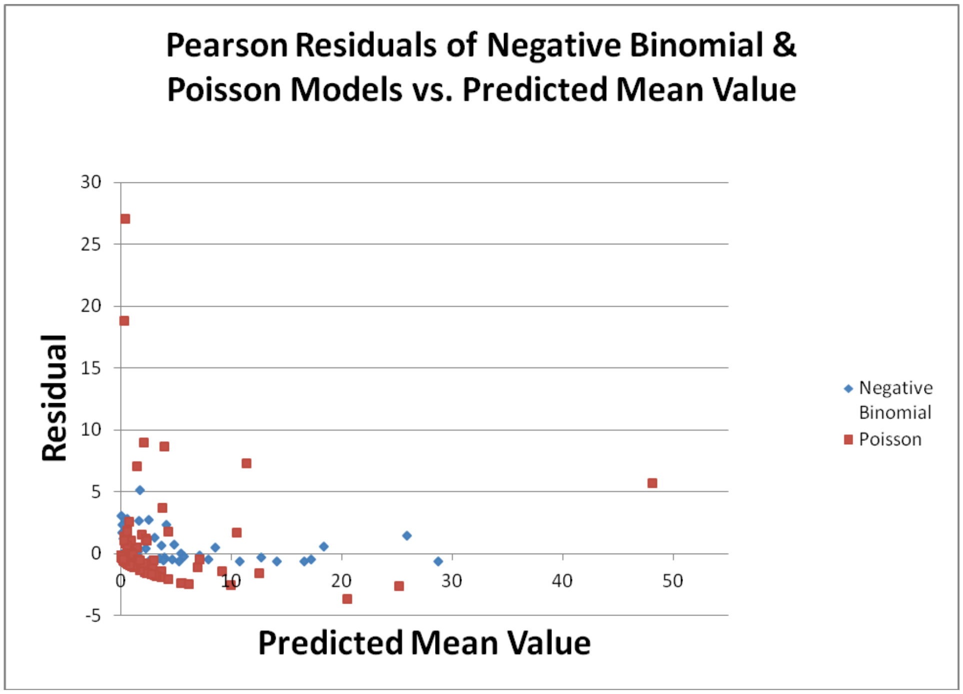

Figure 2: Pearson residuals for Poisson and negative binomial models.

The results from the negative binomial regression model can be found in table 3 below.

Table 3: Econ development model: negative binomial cross sectional results: Monterey data.

	All Income			Low Income			High Income		
	1	2	3	1	2	3	1	2	3
GDP	**1.266*** **	**1.246*** **	**1.040*** **	**1.598*** **	**1.650*** **	**1.035*** **	**0.995*** **	**0.871*** **	**0.790*** **
	(6.78)	(7.00)	(6.47)	(4.23)	(4.27)	(2.89)	(4.98)	(4.89)	(4.57)
GDP/Cap	**-1.200*** **	**-1.538*** **	**-1.300*** **	**-1.585** **	**-2.483*** **	**-1.825** **	-0.618	**-0.743***	**-0.812***
	(-3.47)	(-4.01)	(-3.98)	(-2.17)	(-3.05)	(-2.23)	(-1.43)	(-1.65)	(-1.82)
Trade	**1.312** **	**1.137** **	0.571	**3.239*** **	**2.562*** **	**2.050** **	0.0653	-0.594	-0.740
	(2.35)	(2.34)	(1.15)	(3.19)	(3.70)	(2.49)	(0.12)	(-1.04)	(-1.39)
Democracy	**1.497*** **	**1.679*** **	**2.085*** **	-0.831	-1.385	-0.0931	**1.318** **	**1.103** **	**1.659*** **
	(2.78)	(3.04)	(4.46)	(-0.76)	(-1.12)	(-0.06)	(2.51)	(2.00)	(3.26)
Literacy Rate		**2.603***	**2.599***		**4.419** **	2.097		**5.563** **	**8.979*** **
		(1.66)	(1.86)		(2.17)	(0.91)		(2.12)	(2.99)
Lang		-0.314	0.359		1.415	0.921		1.781	1.574
		(-0.33)	(0.38)		(0.96)	(0.52)		(1.50)	(1.52)
Religion		-0.567	0.200		**-4.192** **	-0.887		-0.270	-0.400
		(-0.61)	(0.24)		(-2.40)	(-0.33)		(-0.27)	(-0.43)
Asia			**1.624*** **			**15.63*** **			**1.632*** **
			(4.04)			(12.47)			(3.46)
Africa			-0.387			**13.76*** **			0.870
			(-0.58)			(12.52)			(0.89)
Constant	**-27.33*** **	**-25.02*** **	**-20.89*** **	**-40.54*** **	**-34.50*** **	**-36.77*** **	**-20.56*** **	**-18.88*** **	**-19.44*** **
	(-6.17)	(-6.28)	(-4.83)	(-3.60)	(-3.66)	(-4.58)	(-3.76)	(-3.66)	(-3.57)
N	175	164	164	64	62	62	111	102	102
F									
LL	-186.5	-183.8	-176.9	-61.79	-58.45	-56.18	-119.2	-117.3	-113.6
LL (Null)	-220.6	-217.3	-217.3	-73.67	-73.08	-73.08	-145.5	-142.7	-142.7
Alpha	3.709	3.496	2.779	3.032	2.586	1.834	2.969	2.751	2.231

National GDP is positive and significant in across all income levels. GDP per capita is also highly significant yet shows a negative relationship with CBRN terrorism. Trade openness is found to be positive and significant in lower income countries. Democracy is positive and significant excluding low-income countries. Literacy rate is also positive and significant in most models. Neither language nor religious fractionalization has any predictive value for CBRN terrorism venues.

The negative binomial cross sectional regressions were also run against data from the START Global Terrorism Database to see if results were comparable. Results from the GTD data are provided below in table 4.

Table 4: Econ development model: negative binomial cross sectional results: GTD data.

	All Income			**Low Income**			**High Income**		
	1	2	3	1	2	3	1	2	3
GDP	**0.915*** **	**0.920*** **	**0.801*** **	**1.107*** **	**1.125*** **	**0.600*** **	**0.805*** **	**0.738*** **	**0.716*** **
	(6.17)	(5.28)	(5.48)	(5.52)	(5.57)	(3.16)	(5.25)	(4.58)	(4.33)
GDP Per Capita	**-0.775*** **	**-1.077*** **	**-0.996*** **	**-1.714** **	**-2.341*** **	**-1.618** **	**-0.882*** **	**-0.917*** **	**-0.921*** **
	(-2.64)	(-3.73)	(-3.68)	(-2.02)	(-3.28)	(-2.47)	(-2.96)	(-2.62)	(-2.80)
Trade	0.120	0.0547	-0.315	**2.766*** **	**2.661*** **	**2.493*** **	-0.628	**-1.121** **	**-1.140** **
	(0.28)	(0.11)	(-0.71)	(3.82)	(2.96)	(4.23)	(-1.10)	(-2.35)	(-2.30)
Democracy	**1.168*** **	**1.396*** **	**1.473*** **	0.867	0.882	**1.802*** **	**1.444*** **	**1.540*** **	**1.641*** **
	(2.70)	(3.16)	(3.20)	(0.76)	(0.87)	(3.19)	(4.27)	(3.84)	(3.91)
Literacy Rate		1.977	1.791		2.299	-0.232		3.806	3.608
		(0.99)	(1.04)		(1.22)	(-0.23)		(1.56)	(1.33)
Lang		0.116	0.673		0.763	1.412		1.679	1.644
		(0.14)	(0.73)		(0.77)	(1.41)		(1.54)	(1.41)
Religion		-0.781	-0.248		-1.408	**2.820***		-1.004	-0.902
		(-1.04)	(-0.30)		(-1.42)	(1.89)		(-1.04)	(-0.86)
Asia			0.472			**17.71*** **			0.393
			(1.20)			(12.79)			(0.86)
Africa			-0.967			**14.90*** **			-0.125
			(-1.14)			(11.85)			(-0.16)
Constant	**-17.63*** **	**-16.32*** **	**-12.80*** **	**-26.73*** **	**-23.51*** **	**-32.53*** **	**-10.77***	**-10.34** **	**-9.641***
	(-5.09)	(-4.22)	(-3.16)	(-3.95)	(-3.36)	(-5.59)	(-1.95)	(-2.07)	(-1.74)
N	175	164	164	64	62	62	111	102	102
LL	-153.6	-149.5	-147.1	-43.39	-42.15	-36.46	-101.9	-97.96	-97.58
LL(Null)	-191.0	-185.6	-185.6	-56.42	-55.92	-55.92	-132.8	-127.9	-127.9
Alpha	1.786	1.734	1.661	0.818	0.832	2.26e-22	1.196	1.068	1.038

The results echo many of the findings from the negative binomial regression findings from the Monterey Institute Data. National GDP, GDP per capita and democracy all show similar significance and relationship with CBRN terrorism. Trade openness is also positive and significant in both models, yet the GTD results show trade openness in higher income countries to actually deter CBRN terrorism. Additionally literacy rate is not found to be significant in the GTD results. Once again neither language nor religious fractionalization was found to be a significant indicator of CBRN terrorism.

Panel data from the Monterey Database was also analyzed with results shown below in table 5. Results are in line with results from the cross sectional models.

Table 5: Econ development model: negative binomial panel results.

	All Income			Low Income			High income		
	1	2	3	1	2	3	1	2	3
GDP	**0.916*** **	**0.987*** **	**0.859*** **	**0.848*** **	**0.933*** **	**0.519** **	**1.086*** **	**1.186*** **	**1.139*** **
	(6.91)	(5.70)	(4.99)	(5.07)	(4.44)	(2.06)	(4.48)	(4.45)	(4.53)
GDP/Cap	**-0.553* **	**-1.309** **	**-1.046** **	-1.258	**-1.873** **	**-1.504** **	-0.286	-0.974	-0.897
	(-1.87)	(-2.57)	(-2.41)	(-1.35)	(-2.37)	(-2.15)	(-0.61)	(-1.58)	(-1.56)
Trade	0.216	0.203	0.134	**1.490*** **	**1.066** **	**1.083* **	0.0747	-0.155	-0.0350
	(0.56)	(0.54)	(0.33)	(2.64)	(2.23)	(1.83)	(0.14)	(-0.34)	(-0.08)
Democracy	**0.312** **	**1.554** **	**2.157*** **	0.138	0.0993	0.936	**0.371*** **	**1.509** **	**2.235*** **
	(1.99)	(2.50)	(3.36)	(0.20)	(0.11)	(1.07)	(3.12)	(2.29)	(3.22)
Literacy Rate		**3.918*** **	**3.219** **		**3.812** **	1.542		**5.594* **	**5.865* **
		(2.66)	(2.36)		(2.34)	(1.09)		(1.69)	(1.91)
Lang		0.194	-0.00139		0.139	-0.0219		1.921	1.160
		(0.21)	(-0.00)		(0.13)	(-0.02)		(1.62)	(1.08)
Religion		-1.209	-0.458		-3.689**	-0.493		-1.631	-1.456
		(-1.24)	(-0.48)		(-2.43)	(-0.27)		(-1.52)	(-1.18)
Asia			0.352			**14.61*** **			1.413
			(0.52)			(13.40)			(1.35)
Africa			**1.654*** **			**16.84*** **			**1.604*** **
			(4.25)			(13.23)			(3.11)
Constant	**-22.29*** **	**-20.84*** **	**-20.21*** **	**-20.61*** **	**-17.67*** **	**-26.11*** **	**-28.95*** **	**-29.88*** **	**-30.98*** **
	(-5.85)	(-5.12)	(-4.48)	(-4.87)	(-3.06)	(-4.09)	(-4.38)	(-4.41)	(-4.07)
N	4153	3892	3892	1522	1477	1477	2631	2415	2415
LL	-742.6	-721.8	-703.0	-219.3	-205.2	-198.1	-500.7	-486.0	-472.3
LL(Null)	-871.6	-861.7	-861.7	-238.8	-237.5	-237.5	-627.0	-617.6	-617.6
Alpha	10.80	10.11	8.971	18.21	13.09	9.574	6.991	5.961	5.096

Political Risk Model

Results from the political risk model are shown below in table 6. Regression analysis for the political risk model was run as a panel regression since yearly data was available for all independent variables.

Table 6: Political risk model : negative binomial panel regression.

	All Income			**Low Income**			**High Income**		
	1	2	3	1	2	3	1	2	3
Democracy	**0.217*****	**0.154*****	**0.176*****	**0.181*****	**0.149*****	0.164	**0.239*****	0.0605	0.0280
	(4.71)	(2.65)	(3.19)	(3.45)	(2.59)	(1.59)	(3.28)	(0.49)	(0.28)
Rule of Law	0.209	0.126	**0.487*****	0.158	0.177	0.250	0.216	-0.158	0.159
	(1.26)	(0.74)	(2.84)	(0.69)	(0.75)	(0.96)	(1.01)	(-0.70)	(0.76)
Corruption	**-0.325****	**-0.367****	-0.200	-0.158	-0.164	-0.287	**-0.373****	**-0.383****	-0.151
	(-2.13)	(-2.30)	(-1.37)	(-0.62)	(-0.62)	(-0.80)	(-2.10)	(-2.27)	(-0.96)
GDP/Cap		0.375	**0.446***		0.667	0.516		**1.562*****	**2.005*****
		(1.42)	(1.73)		(1.64)	(1.02)		(2.98)	(4.09)
Socio-economic Cond.			**-0.231*****			0.0979			**-0.392*****
			(-2.94)			(0.92)			(-5.33)
Ethnic Tensions			-0.133			-0.186			-0.161
			(-0.69)			(-1.11)			(-0.68)
Gov. Stability			**0.158****			**0.352****			**0.144***
			(2.05)			(2.35)			(1.82)
Internal Conflict			-0.156			**-0.219****			-0.153
			(-1.48)			(-2.11)			(-1.24)
External Conflict			-0.183			-0.0766			-0.208
			(-1.57)			(-0.81)			(-1.40)
Military Involvement			-0.0352			0.134			0.0125
			(-0.24)			(0.56)			(0.05)
Religious Tensions			0.226			0.0682			**0.509*****
			(1.57)			(0.20)			(2.58)
Constant	**-2.901*****	**-5.413*****	**-5.317*****	**-2.988*****	**-7.821*****	**-7.875*****	**-2.927*****	**-14.92*****	**-18.22*****
	(-4.29)	(-3.10)	(-3.09)	(-6.97)	(-3.04)	(-2.69)	(-2.76)	(-3.67)	(-4.44)
N	1493	1423	1423	407	350	350	1086	1073	1073
LL	-653.8	-638.0	-622.3	-135.5	-125.3	-120.3	-516.6	-504.5	-486.9
LL(Null)	-674.3	-658.5	-658.5	-140.8	-130.4	-130.4	-528.6	-524.2	-524.2
Alpha	12.10	11.77	9.820	6.942	6.831	5.363	13.22	11.91	9.211

Results from the political risk model are not as consistent as results from the economic development models. Democracy level for the all income countries was significant and positive. A lack of corruption also showed signs of a reduction effect in both high-income and all income groups. Per capita GDP was significant in high-income models with a positive coefficient sign. A positive coefficient sign differs from the negative sign found in the economic development model, probably due to the lack of national GDP included in the political risk model. Improved socio-economic conditions show a significant negative coefficient in both high-income and all-income models. Government stability was positive and significant across all income levels. A negative coefficient can be seen for a lack of internal conflict in low income countries. Finally increasing religious tensions in middle/high-income countries increases the probability of a CBRN terrorism event. Significance was not found for rule of law, ethnic tensions, external conflict, or military involvement in government.

CHAPTER 6

NON-PARAMETRIC RESULTS

This section of the results looks at the non-parametric simulation of CBRN incidents based upon statistical replication of historical data. Yearly and quarterly CBRN counts from 1980-2009 from the START GTD are used as the historical representation. Initially a series of 30 years or 120 quarters of data is simulated entirely and compared with historical values. Figure 3 below shows the frequencies of historical and simulated counts respectively. The simulated series captures the increased frequency of the zero counts and mid-level counts.

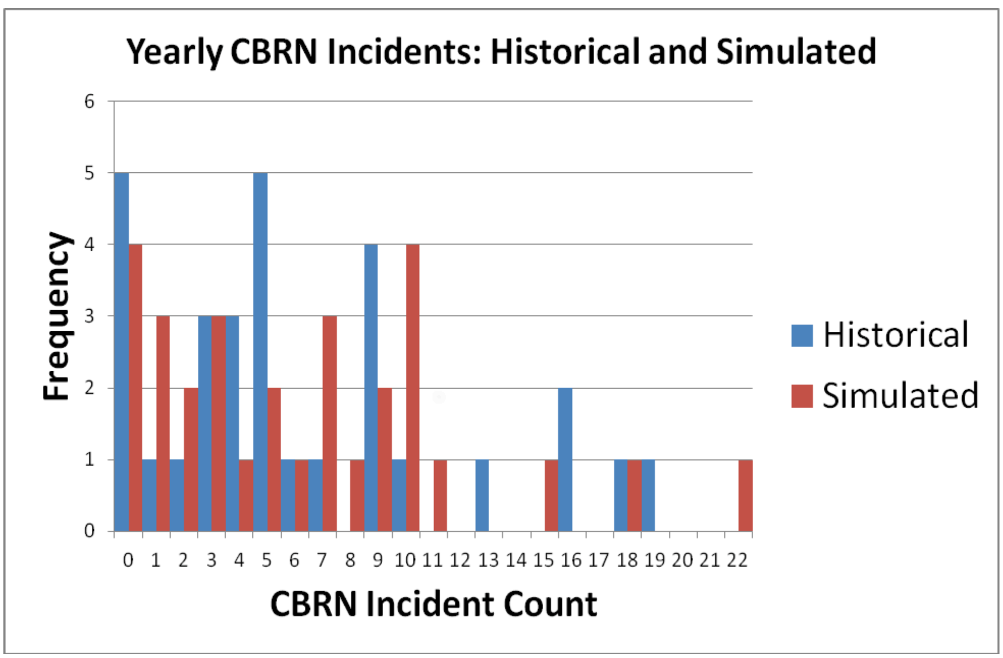

Figure 3: Histogram of historical and simulated yearly CBRN incidents.

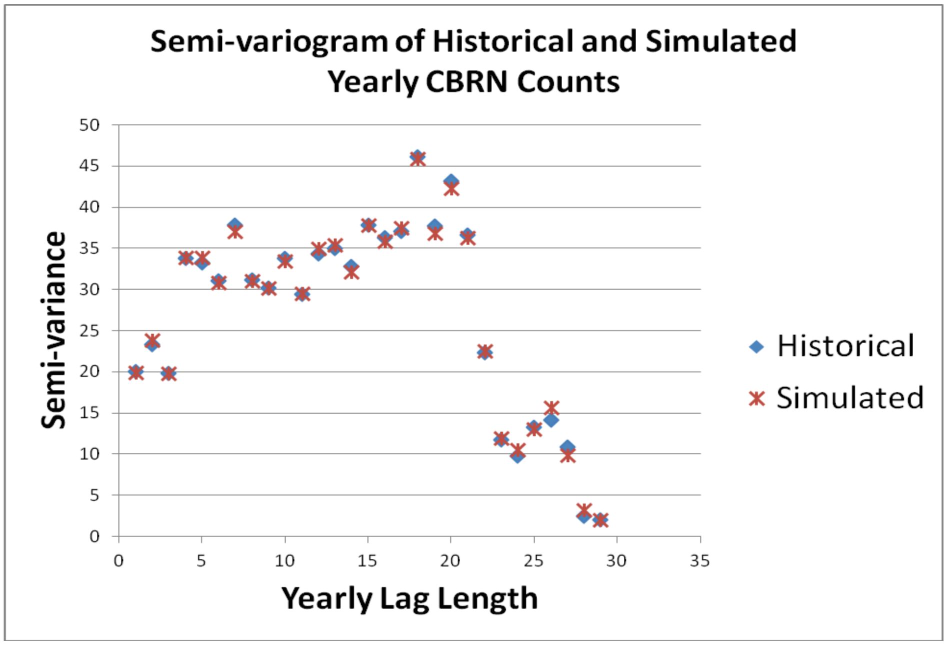

Figure 4: Variogram of historical and simulated yearly CBRN data.

The semi-variogram in figure 4 shows an excellent match between historical and simulated datasets. The simulated data closely matches the spatial properties of the historical series. Both the historical and simulated series are displayed below in figure 5. The series do not necessarily match up exactly however general timing trends agree well.

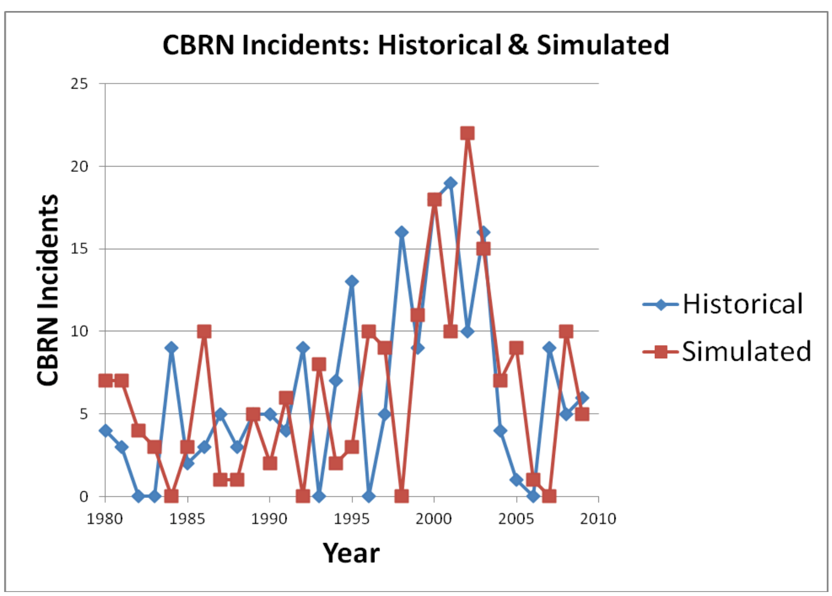

Figure 5: Historical and simulated yearly CBRN incidents

In figure 6, histograms for historical and simulated quarterly CBRN data are shown. Again the simulated frequency trends match the historical frequency trends fairly well. The zero counts are under predicted in the simulated series and in exchange over predicting counts of 2.

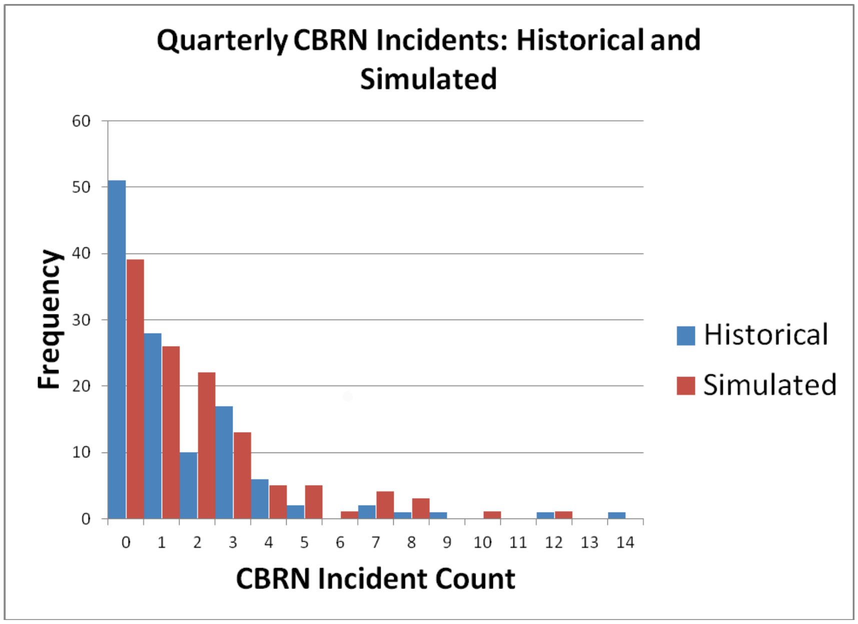

Figure 6: Histogram of historical and simulated Quarterly CBRN incidents

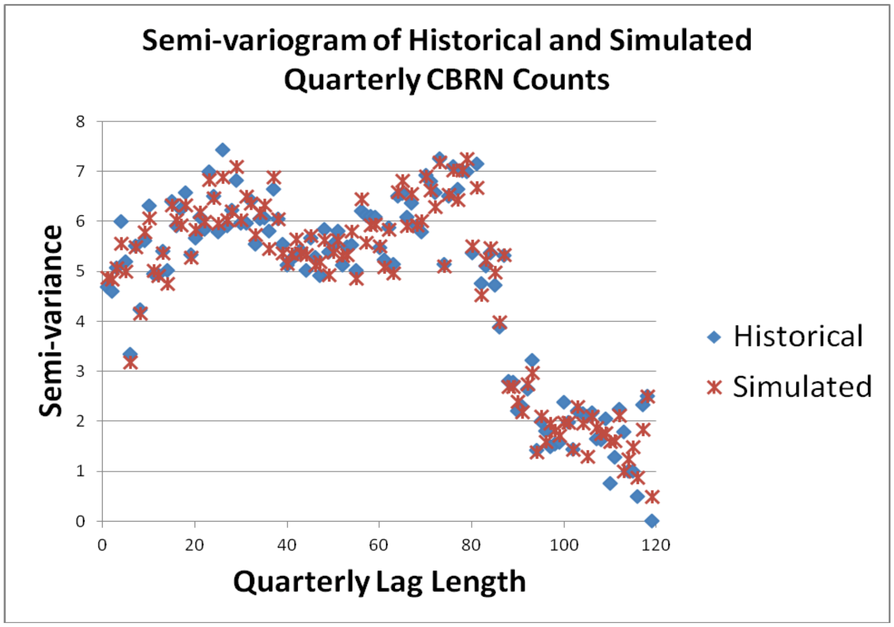

Figure 7: Variogram of historical and simulated quarterly CBRN data

Figure 7 shows the semi-variograms between historical and simulated data match quite well. Figure 8 below shows the historical and simulated series over time.

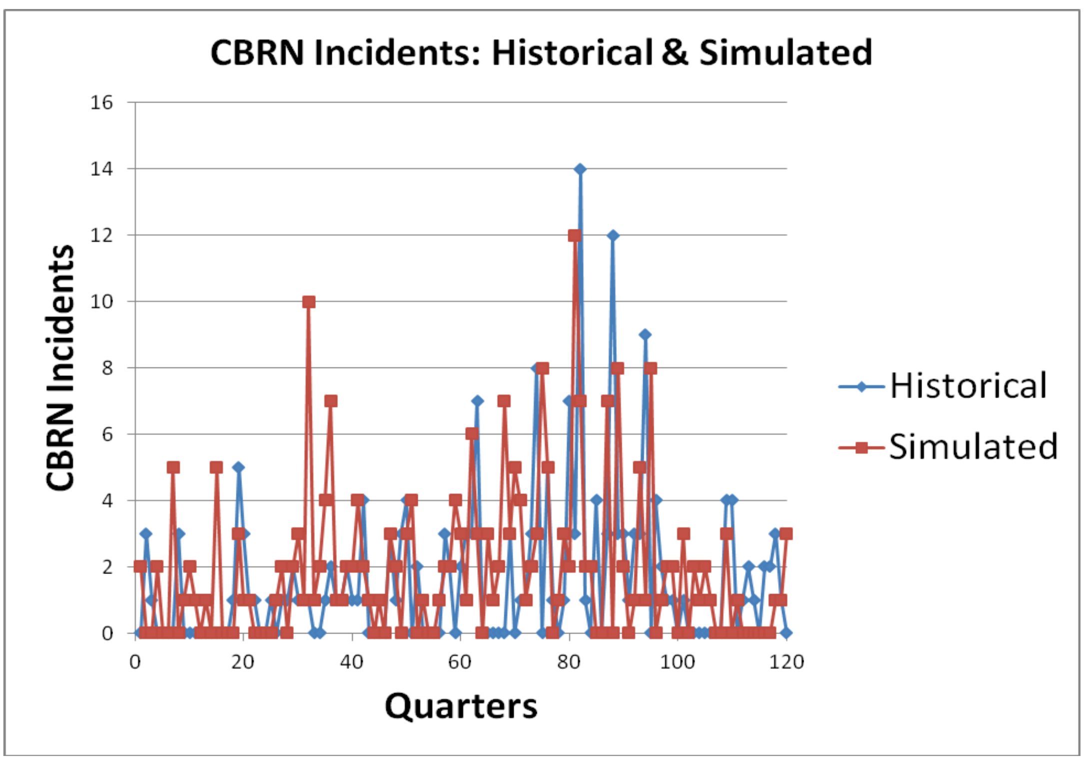

Figure 8: Historical and simulated quarterly CBRN incidents.

Additionally, a 60 year series is generated this time keeping the first 30 years equal to the historical data. This generates a future simulation of 30 years while matching exactly the first 30 years to the historical data. Figure 9 below shows the extrapolated simulated series for yearly data. The future simulation predicts 8 years of 2 or less incidents during the next 30. It also predicts 8 years of more than 10 incidents per year. The max number of incidents in any year in the predicted series is 19.

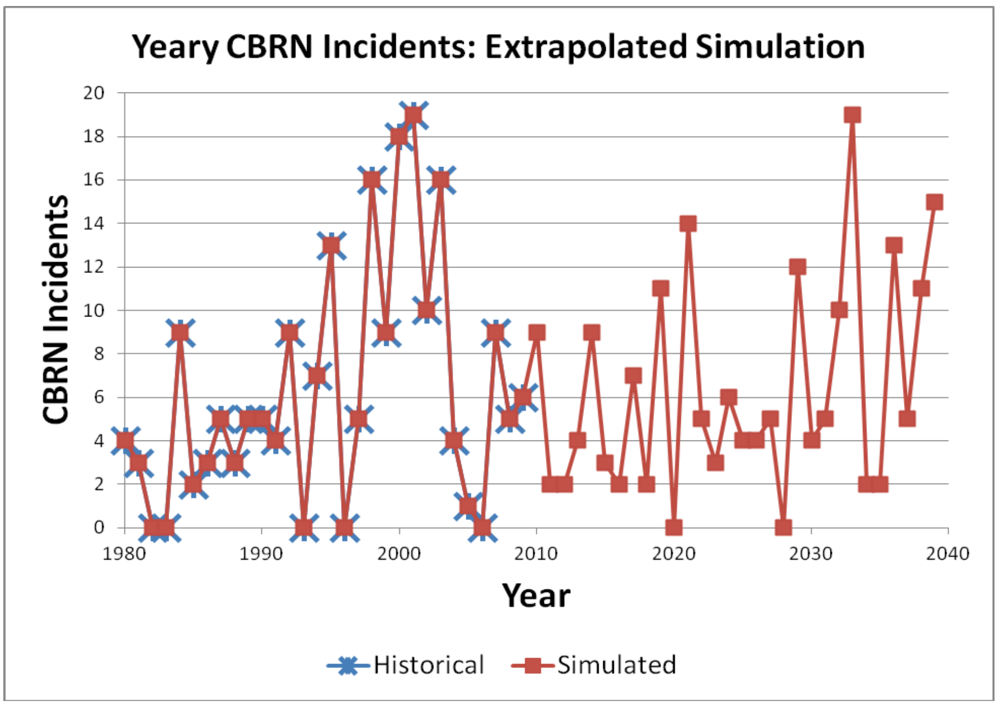

Figure 9: Extrapolated yearly CBRN incidents.

The frequencies of the 30 year extrapolated simulation can be seen below in figure 10.

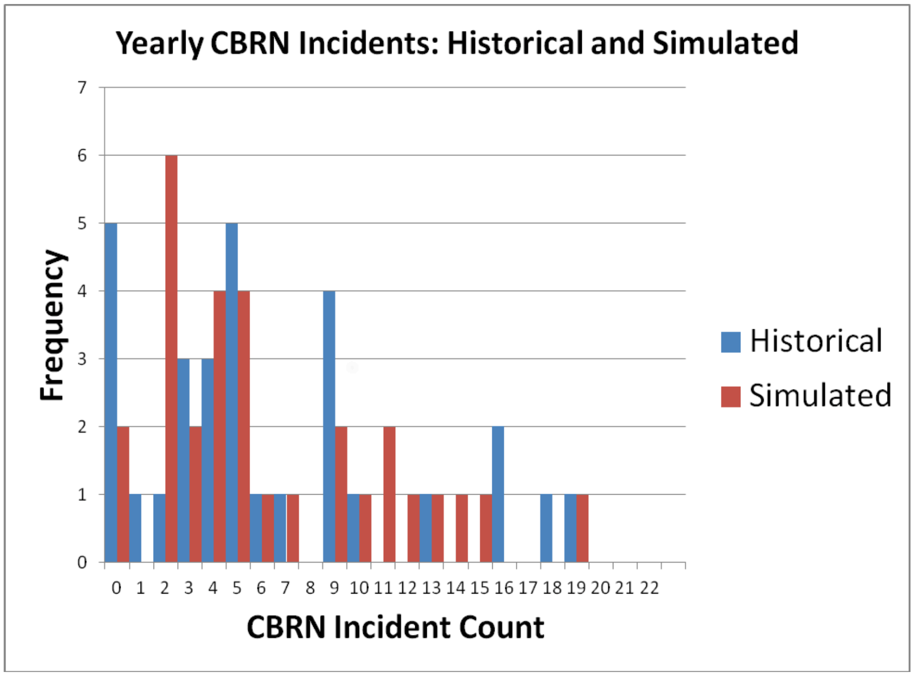

Figure 10: Histogram of extrapolated yearly CBRN incidents.

The simulated configuration predicts a high frequency of 2 counts compared with the historical series. Figure 11 below shows 30 years of simulated extrapolated quarterly CBRN data from the original 30 years

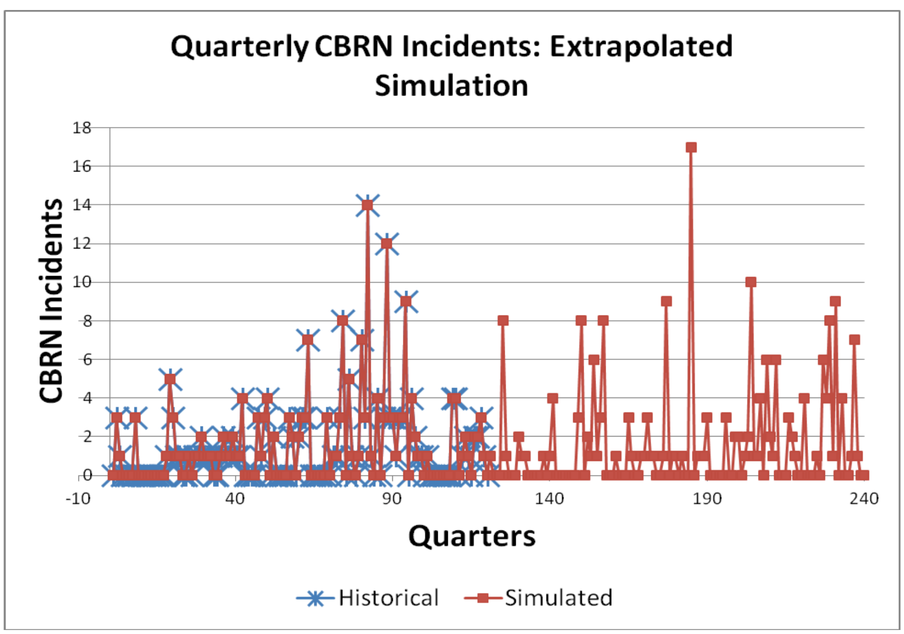

Figure 11: Extrapolated quarterly CBRN incidents.

Frequencies from the quarterly extrapolation are provided in the histogram in figure 12 below. The frequencies from the quarterly extrapolation are better matched with their historical data compared with yearly data.

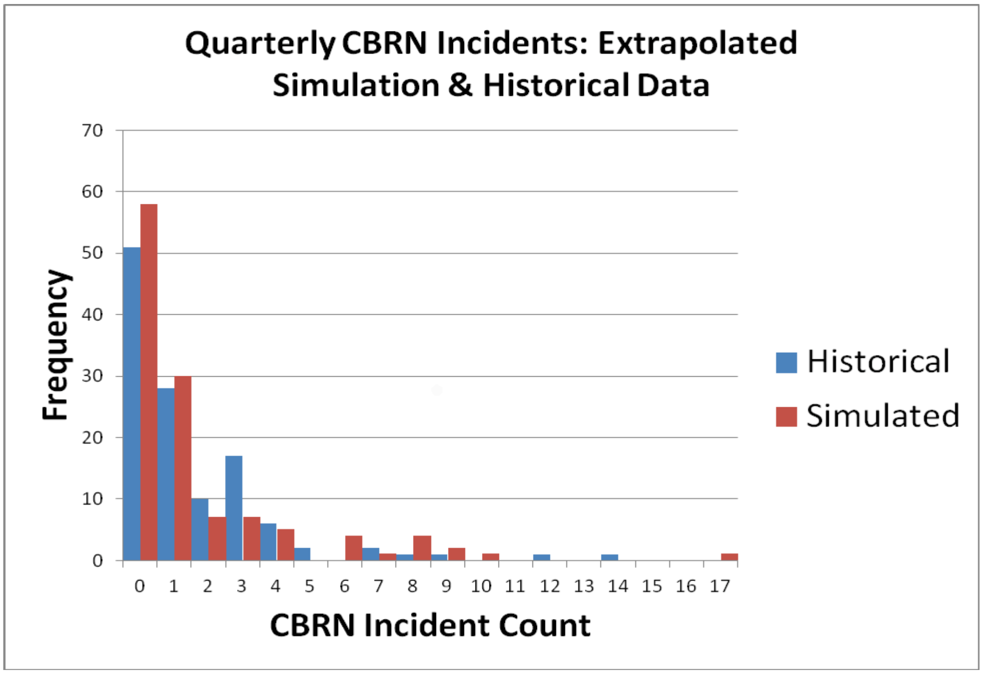

Figure 12: Histogram of extrapolated quarterly CBRN incidents.

CHAPTER 7

DISCUSSION

Economic Development Model

From the economic development model we find similarities with the Blomberg & Hess work. National GDP is found to be positive and significant in all models for CBRN terrorism, while conventional terrorism results from Blomberg & Hess show GDP positive and significant for all income and low income groups. This confirms our hypothesis that countries with higher national GDP levels tend to be targets of CBRN terrorism.

Blomberg and Hess find individual wealth to reduce terrorism likelihood in low-income countries only. They find the opposite effect in middle/high and all-income countries. From our CBRN results, we find similar results for the low-income countries, however we find the coefficients for individual wealth to be negative across all models, including high and all-income countries.

Openness to trade was found most significant in low income countries, having a positive correlation. This disagrees with the initial hypothesis that nations more open to trade would be less at risk of a CBRN event. This positive coefficient is in agreement with findings from Blomberg and Hess. We did not find trade openness to have an effect strictly concerning wealthy nations, while Blomberg and Hess find increasing trade openness to reduce conventional terror.

Democracy is positively associated with increased CBRN terrorism in developed and all country models, opposite to findings from Blomberg and Hess, but in agreement with many results found in the discussed literature. This is also in agreement with the initial hypothesis that democratic states are more likely to experience CBRN terrorism than states with non-democratic regimes.

Literacy rate had a positive correlation in the developed country and all country models in results from the Monterey Database, and insignificant in results from the START database. The literacy rate coefficient was negative for conventional terrorism, but only showed significance in developing countries. This disagreement between results hinders a concrete conclusion to be drawn about literacy rate and CBRN terrorism. Literacy rate is may be of more interest when looking at the origins of CBRN terrorism, rather than targets.

As predicted, neither linguistic nor religious fractionalization was predictive of CBRN terrorism venues. This also agrees with the findings from Blomberg and Hess' analysis of conventional terrorism. Neither linguistic nor religious fractionalization is consistently found to significant predictors of conventional terrorism in any of the reviewed literature.

Political Risk Model

Results from the political risk models show in general increasing democracy level is positively correlated with CBRN terrorism. This falls in line with our initial prediction and is in agreement with the binary predictor from the economic development model. Democracy level change was also looked into but found a lack of significance. Changes in democracy level were cited in the literature as having more predictive value for conventional terrorism but this is not found to be true for CBRN terrorism.

Lack of corruption is also shows a tendency to reduce CBRN incidents, at least in middle/high income and all income groups. This agrees with our initial prediction that honest regimes attract less CBRN terrorism than corrupt regimes.

GDP per capita was significant and positive in the middle/high income country group, in line with Ivanova and Sandler's findings of per capita GDP positive and significant in their analysis of CBRN terrorism. The lack of national GDP's inclusion in the political risk model might be an explanation as to why the sign of the coefficient is positive in this model and negative in the economic development model.

Improved socio economic conditions reduce CBRN incidence as predicted. Improved socio-economic conditions reduce the overall level of discontent within a society and minimize potential for a culture of violence.

Government stability shows a tendency to encourage CBRN terrorism and is significant in all models. In agreement with the hypothesis, it seems that stable governments can alienate fringe groups that seek change, when the overall majority is satisfied with the status quo.

Internal conflict was significant for the low income countries, suggesting that perhaps governmental response to civil unrest in low-income countries could motivate terrorist activities.

Religious tensions were found significant high income countries respectively. Strong religious influence on government in high income countries may provoke violence from opposing religious sects.

From the economic development models we find on the whole that wealthy, populous, democratic states are more likely to experience CBRN terrorism than their small, poor, non democratic counterparts. The political risk model additionally suggests that high level democracies are more at risk than low level ones. Stable, corrupt regimes governing in times of poor socio-economic conditions are also exposed to higher risk.

Simulations

The simulated annealing simulations present future extrapolated series of both yearly and quarterly CBRN incidents. Both results show possible future incidence counts based off of 30 years of historical data. Extrapolated predictions are the best results of few trial runs each for both yearly and quarterly data. Ideally, numerous simulations would be performed to present a predictive range for both frequency and time series data. Finding the correct cooling schedule for the simulated annealing optimizations is a difficult task and could likely be improved to yield more accurate predictions.

Future Work

The results provided in this paper provide a basic overview of the predictive effects of some commonly used economic development and political risk indicator variables. A more in depth regression methodology could be developed to build off of results found here. Instead of focusing on CBRN terrorism venues, one could employ regression methodology to look at the origins of CBRN terrorism. Target types and casualty counts could also be examined, yet due to limited data on CBRN events this could be difficult.

As mentioned above, improving the simulated annealing cooling schedule and performing numerous trials is an area of opportunity. The objective function used to score the simulated configuration could be modified to examine additional statistical properties of the original series.

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