AGENTS, NETWORKS AND EMPIRICAL DATA: AGENT-BASED MODELING FOR UNDERSTANDING INTER-COUNTRY AND INTRA-COUNTRY DYNAMICS

by

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DEDICATION

I would like to thank my parents, who were my first teachers and have always been my biggest support. I’m so thankful for you both. I love you Mom and Dad.

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LIST OF ABBREVIATIONS

Agent-Based Model .... ABM
Comprehensive R Archive Network .... CRAN
Computational Social Science .... CSS
Correlates of War .... CoW
European Union .... EU
Geographic Information System .... GIS
Militarized Interstate Disputes .... MID
National Material Capabilities .... NMC
Principal Components Analysis .... PCA
Three Dimensional 3D
Two Dimensional 2D

ABSTRACT

AGENTS, NETWORKS AND EMPIRICAL DATA: AGENT-BASED MODELING FOR UNDERSTANDING INTER-COUNTRY AND INTRA-COUNTRY DYNAMICS

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Understanding the systems and processes that make up international relations and politics is difficult. Outcomes may appear unpredictable and the processes by which decisions get made may seem too complicated to understand or model. Decisions about complex issues like the decision to go to war or what type of government to establish involve many different interconnected parts interacting with one another and leading to emergent outcomes that have great consequences for countries, governments, and individuals. This dissertation uses agent-based modeling to investigate the ramifications of international alliances, on one hand, and the behavior and interaction of competing political parties and voters on the other, using empirical data and existing theoretical frameworks.

I extended a well-known model for understanding emerging political actors using historical data on the network of formal defense alliances across the world. Based on a country's status and network position, individual countries target one another, each

utilizing plausible decision rules to decide whether to pay tribute or go to war. The resulting positions of countries in the international system, produced by the Global Tribute model, show broad qualitative agreement with the international system of the late 20th century. This work demonstrates that an agent-based model with simple decision rules can yield historically relevant results.

To investigate election behavior within a country I modify and extend, in various ways, a party competition model. Using empirical data comparing political parties I show that a three-dimensional policy space is sufficient to characterize much of the heterogeneity in ideological positions, and I extend the model from two to three dimensions. Then, based on the movement of parties in the ideological space, I incorporate voter decision rules for assessing which party they will support and if they will choose to vote. The results of this Voter and Election model show plausible results for voter behavior and are another example of how agent-based models with simple rules can be used in concert with empirical data.

This dissertation shows a useful methodological framework to understand how complex systems with many interdependencies work by connecting empirical data to relatively simple models. It demonstrates how abstracting these systems and focusing on their constituent components can help to understand systems' outcomes and emergent properties.

1. INTRODUCTION AND MOTIVATION

1.1 Computational Social Science Methods and Research Contribution

Understanding how individuals and countries make decisions about complex things like going to war or electing a new leader is important to help ensure peace and stability in society. These are complex issues that are not easily studied. While this is a dissertation in Computational Social Science (CSS), the questions asked are motived by topics in the areas of political science and international relations. There are many opportunities to adopt a computational approach to examine complex issues in the political, social science, and international relations arena (Troitzsch, 2021; Deutschmann et al., 2020; Maoz, 2017; Ruths, 2017; Victor et al., 2017) including incorporating things like "big data," statistical analysis, social and economic networks, and network effects (Cranmer & Desmarais, 2011). This dissertation uses tools for modeling complex adaptive systems from CSS to extend and enhance two existing models looking at inter-country dynamics (the decision for war and the emergence of powerful actors) and intra-country dynamics (candidates, voters, and elections). While these are two different topics, they share some commonalities that make them both attractive subjects for study using agent-based models (ABM). Agent-based modeling is a tool used to understand complex systems where there may be many different actors with unique characteristics (Epstein & Axtell, 1996). Both international relations between countries and elections held within one country are complex social phenomena where decisions made by individual entities (whether those individuals be nation-states or voters) lead to emergent macro-level outcomes in the system (examples: war, peace, new leadership, change in policy).

I do not try to coerce an arbitrary commonality between these two types of complex systems but instead focus this dissertation more on the methodological contribution it makes to Computational Social Science. While both cases share the fact that they are complex systems, international conflict and elections are indeed two different subjects and will be explored more fully in the text. Each of these systems have an academic and theoretical history behind them; however, these approaches do not adequately take into account the complexity inherent in the systems. By taking a computational approach that allows for a more complex treatment of these issues using simulation and agent-based modeling, I am able to more fully show the processes that lead to emergent outcomes in each system. The main contribution of this dissertation, then, is to show a useful methodological approach to learn and understand how systems with many interdependencies work, and how abstracting these systems and focusing on their constituent components can help to understand systems' outcomes and emergent properties.

Both subjects (a country's decision to go to war and a country's election) involve complex situations where multiple actors make decisions that lead to emergent outcomes for the system as a whole. In the case of formal defense agreements, a country could make a decision about whether or not to sign on to a defense agreement or whether or not to come to the aid of another country when called upon by a defense agreement. In the case of elections, candidates can choose where to position themselves with respect to ideology and specific policy positions while voters can decide whether or not to vote and whom to cast their vote for. These are both complex adaptive systems where individual actors (countries, candidates, or voters) interact, and the outcomes that emerge from these interactions lead to emergent system-level outcomes.

Countries may engage in a variety of international networks or agreements such as trade networks, peace treaties, and formal defense agreements (e.g., the North American Free Trade Agreement (NAFTA); the North Atlantic Treaty Organization (NATO)). These networks could be used to try to secure peace, increase economic activity, or prevent war. These networks also have ties connecting country to country that may be different in the level of commitment they represent and the obligations they entail. International relations between countries is a complex system where individual nation-states will have attributes that may or may not be unique to them, such as their natural resources, defense agreements, or system of government. Formal defense agreements represent a relatively high level of commitment between countries and because of this provide a rich avenue for analysis and modeling; as such they will be the focus of the chapters dealing with inter-country dynamics. These defense agreements could be with other countries that are similar to them or different with respect to their system of government (e.g., United States and Venezuela; Russia and China). While factors like a country’s system of government can also have an impact on a country’s decision to go to war (Doyle, 2012; Kant, 1991), which will be reviewed later in this dissertation (see Section 3.1.2), they are not the focus of this dissertation or the models' extensions.

Elections are a tool that countries can use to make collective decisions about leadership and policy. People generally participate in elections as either candidates (those running for an office) or voters (those casting a vote for a candidate). There may be more than one candidate in an election and there actually may be many candidates running for a public office under a variety of banners. Voters can decide whether or not to vote and, if they decide to vote, whom to vote for—the subject of much debate (Berelson et al., 1986; Conover and Feldman, 1981; Holbrook et al., 2001; Miller et al., 2017; Smith, 1980). We do know that these decisions are made by individuals who can hold a variety of different policy positions or opinions at one time (Converse, 1964/2006; Zaller, 1992). How candidates decide to position themselves in order to attract voters within the framework of a spatial voting model is the main focus of the chapter focused on elections.

Scholarship about complexity in the social sciences has been around for hundreds of years. Although these ideas about complexity and tools for dealing with it have been developing for a long time, computers have now reached a point where new lines of inquiry into complex adaptive systems can be undertaken. In the past a social scientist would have to deal mostly in nondynamic models without heterogeneity that did not take into account interactions and environments. Computation and agent-based modeling give us a set of tools that allow us to deal with heterogeneous agents interacting in a changing environment and connected to each other in a variety of ways (Miller & Page, 2007).

This allows us to abstract less from the real world in our attempts to model and understand it.

There are two agent-based models that this dissertation modifies and extends in different ways. Both models take advantage of the benefits of using agent-based modeling by generating emergent phenomena using behavior that is endogenous to the model and taking place within a specific environment and rule set. Using agent-based modeling can be especially helpful if the system under study is marked by nonlinearities and contains many individual agents (Bonabeau, 2002). Both models are still simplifications of the systems they are trying to represent and are not created for specific prediction of future outcomes. They both model the endogenous birth and death of political actors: powerful countries (Axelrod, 1995) and political party leaders (Laver & Sergenti, 2012).

1.1.1 Countries as Agents

The first model I extend is a model of the emergence of political actors put forth by Robert Axelrod in "A Model of the Emergence of New Political Actors" (1995). This model showed that it is possible to use individual agents along with basic rules for their interaction to create levels of organization that were at higher levels than the basic agents in the model. His simulation uses a bottom-up process where 10 individual units (thought of as individual political entities such as nation-states) in the simulation are arranged on a line whose ends meet to form a circle. This gives each actor one neighbor on each side. Each country has a variable called Wealth that is randomly distributed at the beginning of the simulation and is the currency of the simulation. Wealth can either be transferred or destroyed as the simulation progresses. Political power would grow and diminish as the neighbors next to each actor interacted according to the rules of a tribute model where agents engage in a cost-benefit analysis about a decision to go to war. These interactions lead to tribute payments or war between countries, which either increase commitment and wealth in this simple network of countries or decrease commitment between countries and destroy wealth. Axelrod notes that his model has some interesting characteristics that I look for in my extension of the model. These include the fact that things in the model usually do not settle down (there is no equilibrium), the model history can show a considerable amount of volatility, and a country's initial wealth is not a guarantee of success (Axelrod, 1995).

This dissertation extends Axelrod's (1995) model by moving beyond trying to understand the emergence of higher level coordination from the elementary interactions of the lower level agents and treating the existing networks and wealth of countries as having already emerged. This is done by using data from multiple datasets in the Correlates of War (CoW) ecosystem of data to provide empirical instantiations of agent initial conditions. In the framework of the tribute mode, this empirical network and wealth information is used to simulate interactions between countries. This is in the tradition of moving away from purely theoretical specifications of models to more empirically based models (Taghikhah et al., 2021).

While scholarship about international relations has existed for a long time (e.g., Holsti, 1989; Machiavelli, 1981), large-scale computational modeling of international relations is a relatively new phenomenon enabled by more powerful computers.

Statistical and game theory models of international relations and war are not the focus of this research. Agent-based modeling is the methodological focus of this dissertation; again, with the advent of more powerful computers, agent-based modeling has previously been used for this type of alliance examination (e.g., Cederman, 2003). This model builds upon this literature, and Kennedy's (1989) work on the capacity of countries to sustain war, by taking the empirical Correlates of War data as the initial conditions of defense agreements, running the model forward, and examining which countries become dominant through their ability to produce and extract wealth. The model employs historical data to simulate similar decision-making conditions. Girardin and Cederman (2007) employ geographic data to analyze local conflicts, integrating this geographic information system (GIS) data with computational models to analyze civil wars. My model makes a similar contribution on an international level to the conflict dynamics and resolution literature by using a methodology that is informed by agent-based modeling, networks, and the economic analysis of conflict.

The research using ABM and international relations generally falls into two main categories based on the level of realism that is programmed into the model. Some models are more abstract like the Axelrod tribute model (1995), use simpler decision rules, and aim to be analytically tractable. These more abstract models use simpler decision rules and return less specific and more general results. Other models rely more on empirical data to inform model behavior and can use thousands of data points (e.g., Bremer, 2019) and more complicated decision rules and assumptions. These more empirical agent-based models of international behavior tend to be relegated to development by commercially focused entities and government groups (Masad, 2016). Examples of these types of highly empirical ABMs created by government/industry include work done for the United States Defense Advanced Research Projects Agency (DARPA) (Taylor et al., 2006) and the United States National Defense University (NDU) (Abdollahian et al., 2006). My contribution in this dissertation falls somewhere in between a purely abstract model and a highly parameterized model, probably closer to the more abstract side of this spectrum.

1.1.2 Candidates and Voters as Agents

The second ABM I extend is a model of political party competition that simulates the interactions of voters and party leaders (what I refer to as candidates) in a two-dimensional (2D) policy space (Laver & Sergenti, 2012). Laver and Sergenti make the case that politics is a complex adaptive system that is always in a state of change and evolution that will not arrive at an equilibrium, and that this makes party competition a subject that can be studied using ABMs. They take a spatial approach to understanding voter support for a given candidate in the tradition of Hotelling (1929), Black (1948), and Downs (1957). Agents representing both candidates and voters exist in a 2D policy space where they assume that the candidate who is closest to a given voter will be the candidate the voter supports. Voters' positions in this space are assumed to be the voters' ideal policy points and Laver and Sergenti assume that voters in this space are distributed according to a normal distribution. They acknowledge that voters' actual decision-making processes will be much different than simple spatial distance rules. While they do acknowledge that voter behavior and decision making is a complex process, Laver and Sergenti mostly ignore voter behavior and focus on candidate behavior.

The key ways I extend this model are by giving voters a more expansive data landscape in which to make decisions about which candidate to support. I also take the simulation from Laver and Sergenti's (2012) 2D space to a three-dimensional (3D) space. Lastly, I do not use the assumption of normal distributions for the voters' ideal points; I use an analysis of available data on party competition to instantiate the initial conditions of voter ideal points. This will all be discussed more in Chapter 4.

The use of ABM allows for politically complex situations to be modeled from the ground up (Qiu & Phang, 2020). Previous research done at the intersection of complexity, voting, and elections includes work done to understand voter turnout and how social interaction via mobilization (Fieldhouse et al., 2016) and networks (Fowler & Smirnov, 2005) effect voter participation. Singh et al. (2011) integrate social influence theory with an ABM to look at how voter preferences emerge and how this emergence changes voting patterns. An ABM called VODYS (short for Voter Dynamics Simulator) was built using NetLogo (Wilensky, 1999) and made publicly available by Gulati et al. (2011). Their model incorporates factors theorized to affect voter behavior like income, race, education, partisanship, and media exposure. Madsen and Pilditch (2018) take ideas from psychology and cognitive models of persuasion and connect them to ABM to explore campaigning strategies and how they work to move voters in different ways. Other research uses empirical data from different countries to help verify (either quantitatively or qualitatively) results coming from an ABM. Kononovicius (2017) does this with data from Lithuania's parliamentary elections and Palombi and Toti (2015) use data from Brazil.

1.2 Organization of Dissertation

This introductory chapter (Chapter 1) discusses why someone would want to use a Computational Social Science approach along with agent-based modeling (ABM) to understand complex social phenomena. It reviews the two different models that I extend in this dissertation and how I will extend them, and highlights what they contribute to our understanding of the complex subjects of inter-country and intra-country dynamics. Finally, this chapter places these models and research within the larger context of other ABM and computational modeling projects.

Chapter 2 was published in the *Journal of Artificial Societies and Social Simulation* (JASSS) and began as a class project with two others in Robert Axtell's graduate class CSS 610: Agent-Based Modeling and Simulation. Except for small changes to accommodate the dissertation format and to make the text flow better, the article is presented here as it appears in JASSS. This chapter introduces an agent-based model, the Global Tribute model, that examines the ramifications of formal defense agreements between countries. It builds on previous work and creates an empirically based version of a tribute model in which actors within existing real-world networks demand tribute from one another. If the threatened actor does not pay the tribute, the aggressing actor will engage in a decision to start a war. Tribute and war payments are based on a measure of the country's wealth.

In Chapter 3 I build on ideas and data introduced in Chapter 2 and focus on countries, international networks, and the decision to go to war. Section 3.1 reviews the literature of different types of international agreements and how they are related to war (Section 3.1.1) as well as how the type of government a country has may affect its decision to go to war (Section 3.1.2). Section 3.2 is an overview of the Correlates of War (CoW) dataset, one of the core datasets I use in my modeling, and brings together several disconnected datasets from the CoW ecosystem of data to understand and visualize the network structure of different types of international networks over time (Section 3.2.1). I then address the question of whether historically we see countries following through on commitments made in their formal defense agreements (Section 3.2.2) and present the results from this analysis (Section 3.2.3). The final section of Chapter 3 presents additional experiments on the ABM of countries as agents in the Global Ttribute model that was laid out in Chapter 2. These experiments focus on the varied and alternative histories that emerge from the model.

Chapter 4 focuses on candidates and voters in a simulated election. This chapter starts with a literature review focused around the spatial model of voting and also reviews other research around voting and how voters make decisions. Section 4.2 analyzes the Comparative Parties dataset (Swank, 2018) which gives us information about voting and representation across multiple years and multiple countries. This analysis is used to inform Section 4.3 which presents an ABM of candidates and voters interacting in a multidimensional ideology space.

This dissertation concludes with Chapter 5 with ideas for extensions of the models and future work. It also speaks to verifying and validating the agent-based models. Section 5.3 discusses the technical aspects of this project and reviews the programs and methods used to make and share this analysis.

2. COUNTRIES AS AGENTS IN A GLOBAL-SCALE COMPUTATIONAL MODEL

Our agent-based model examines the ramifications of formal defense agreements between countries.[*] Our model builds on previous work and creates an empirically based version of a tribute model in which actors within existing real-world networks demand tribute from one another. If the threatened actor does not pay the tribute, the aggressing actor will engage in a decision to start a war. Tribute and war payments are based on a measure of the country's wealth. We utilize the Correlates of War dataset to provide us with worldwide historical defense alliance information. Using these networks as our initial conditions, we run the model forward from four prominent historical years and simulate the interactions that take place as well as the changes in overall wealth. Agents in the model employ a cost-benefit analysis in their decision of whether or not to go to war. This model provides results that are in qualitative agreement with historically emergent macro outcomes seen over time.

[*] This chapter was published in the *Journal of Artificial Societies and Social Simulation* (JASSS) and began as a class project with two others in Robert Axtell's graduate class CSS 610: Agent-Based Modeling and Simulation. Except for small changes to accommodate the dissertation format and make the text flow better, the article is presented here as it appears in JASSS. I originated the idea for the model for this paper and was also responsible for data gathering, data cleaning, coding the ABM, integrating empirical data in the ABM, and writing the technical description of the model (Walbert, H. J., Caton, J. L., & Norgaard, J. R., 2018, "Countries as Agents in a Global-Scale Computational Model," *Journal of Artificial Societies and Social Simulation, 21*(3), 4, https://doi.org/10.18564/jasss.3717).

2.1 Introduction

Powerful nations rise and fall; many nations today did not exist 75 years ago. What allows a nation or empire to rise to power? We build upon Kennedy's (1989) analysis of this question by empirically modeling the link between political agreements, wealth, and war. A nation, through networks of political affiliation or lack thereof, can secure its position in the world as a superpower or fall into chaos and collapse. Most and Starr (1984) argue that countries can select and utilize various policy options to their advantage, depending on the problems they face. In this paper, we examine outcomes that arise from the networks of formal defense agreements. These agreements are one type of foreign policy option that countries often use to gain prominence and protection on the global scene.

In this paper, we focus specifically on how defense agreements serve as a foreign policy tool to garner protection and tribute. We employ the Correlates of War (CoW) dataset to provide historical data of formal defense agreements since 1945 (Gibler, 2009). In the tradition of Cusack and Stoll (1990), we use computer simulation to investigate outcomes of international systems, specifically agreements and conflict. By constructing an agent-based model that builds upon Axelrod's tribute model (1995), we examine how formal defense agreements and alliances shape the success and failure of various countries. This analysis is based on Schelling's (1960) foundational work that finds that the threat of retaliation can be more effective than a single country's defense capabilities. We investigate how much defense alliances play into this retaliation threat dynamic.

Axelrod's original model began with 10 actors arranged on a line whose ends meet to form a circle so each actor would only have one neighbor on each side. Political power would grow and diminish as the neighbors next to each actor interacted. Our network model moves beyond simply trying to understand the emergence of higher level coordination from the elementary interactions of the lower level agents. We take the existing networks and wealth of countries and treat them as having already emerged. In the framework of our tribute model, we use this information to simulate interactions between countries.

Agent-based modeling has previously been used for this type of alliance examination (Bennett & Stam, 2000; Cederman, 2003; Cederman & Girardin, 2007). We build upon this literature, and Kennedy's (1989) work on the capacity of countries to sustain war, by taking the empirical Correlates of War data as the initial conditions of defense agreements, running our model forward, and examining which countries become dominant through their ability to produce and extract wealth. We set four years as initial conditions, 1945, 1960, 1980, and 2007. Our model employs historical data to simulate similar decision-making conditions. Cederman and Girardin (2007) employ empirical data to simulate local conflicts. They integrate GIS data with computational models to analyze civil wars. Our model makes a similar contribution on an international level. We identify the emergence of patterns of international conflicts and distributions of power. Our paper makes a contribution to the conflict dynamics and resolution literature using a methodology informed by agent-based modeling[1] and the economic analysis of conflict.[2]

[1] As in Axelrod (2006) and Bhavnani and Miodownik (2009).

Section 2 provides the theoretical basis on which our model stands. Our model, methods, and data are laid out in Section 3. The results and conclusions from our agent-based model are shown and discussed in Section 4.

2.2 Theory

Jouvenel (1963), in *Pure Theory of Politics*, introduces the problem of political exchange and reciprocation. At its root, politics is the art of moving "other men in pursuit of some design cherished by the mover" (Jouvenel, 1963, p. 38). Agent A suggests some action H by agent B. Agent A may promise agent B gain for cooperation, penalty for defiance, or both. The principle extends to foreign policy where state power is exercised against other states through various channels. Morgan and Palmer (2003) show that foreign policy is goal directed, either to accomplish a certain task or destroy a particular state. Alliances involve "both costs and benefits, and the only alliances we observe are those in which the benefits outweigh the costs" (Morgan & Palmer, 2003, p. 200). Costs and benefits that govern diplomatic outcomes are those born and received by political decision-makers: those who have influence over the evolution of society's power structure (Salter & Wagner, 2018; Wagner, 2016). Depending on a nation's institutional arrangement, political decisions may or may not lead to desirable outcomes for the public. We integrate this understanding at a high level, considering states to make decisions in light of costs and benefits of war. While tension of internal social and institutional dynamics may not always lead to the welfare maximizing outcome (Arrow, 1950; Boettke & Leeson, 2002; Buchanan, 1954; Caplan, 2008/2011; DeCanio, 2014),

[2] See for example Sandler (2000), Wittman (2000), Hirshleifer (1995), and Garfinkel and Skaperdas (2007).

deal-making within democracy can move society closer to this outcome (Buchanan & Tullock, 1962; Wittman, 1989, 1995). To account for generally imperfect rationality among actors, we include a random parameter that influences the efficiency of democratic decision making in its decision to go to war.

In economic interactions two agents engage in exchange because both parties expect to realize a state superior to the one that would arise absent exchange (Menger, 1963/1985). This requires that agents, as legal persons, are not so inequitable that one can, owing to a privileged position, use force or the institutions of force to manipulate the terms of exchange to benefit himself at the cost of another agent. This is not the historical norm. For most of human history, the Hobbesian "natural state" embodied the dominant form of political relationships.[3] Even when the "natural state" is superseded by robust institutions of governance, relationships between agents of different states are prima facie exposed to the risk of poorly constrained violence. In the "natural state," whether domestic or international, asymmetries in power allow a stronger agent to employ force or the threat of force as a tool to transform his relationships with other agents. The weaker agent, sensing a threat, may choose to cooperate under such circumstances (Buchanan, 1985, pp. 68-69). Alliances that embody substantial political inequity are the fruit of this type of power relationship. They can breed the discontent that gives rise to future conflicts (Benson, 2011). In this anarchic world, peace and security are especially rare.

[3] This is in no way to deny the existence of voluntary institutions such as religion (in some cases), civil societies, and those institutions used to manage common areas during that are endowed with sovereignty within a given domain (Ostrom, 1990).

We generalize this sort of behavior with a derivation of a game of war. Table 1 demonstrates the payoffs for this scenario. Given the payouts in Table 1, both agents will typically be incentivized to avoid conflict. There are cases where either agent might not avoid conflict; these include games where payouts for engaging in conflict differ between agents. Imagine that agent A is substantially stronger than agent B and that the rule of law is not firmly established. Agent A might destroy agent B. More likely agent A will promise not to harm agent B. Instead, agent A proposes to agent B "something similar to the slave contract, in which the 'weak' agree to produce goods for the 'strong' in exchange for being allowed to retain something over and above bare subsistence" (Buchanan, 1975, p. 78). Agent A may offer to agent B the opportunity to keep a portion of his income by a formal agreement.

Table 1: Game Theoretic Payoffs for Agents of Equal Strength

		B	
		Altruism	Fight
A	Altruism	a, a	-b, b
	Fight	b, -b	-c, -c

In their analysis of the development and constraint of state power, North et al. (2009) describe the emergence of early forms of political organization. Development begins from "the natural state."

> The natural state reduces the problem of endemic violence through the formation of a dominant coalition whose members possess special privileges. The logic of

> the natural state follows from how it solves the problem of violence. Elites—members of the dominant coalition—agree to respect each other's privileges, including property rights and access to resources and activities. By limiting access to these privileges to members of the dominant coalition, elites create credible incentives to cooperate rather than fight among themselves. Because elites know that violence will reduce their own rents, they have incentives not to fight. Furthermore, each elite understands that other elites face similar incentives. In this way, the political system of a natural state manipulates the economic system to produce rents that then secure political order. (North et al., 2009, p. 18)

From this process arises a system of government that maintains a monopoly on the use of force. This logic can be extended to the formation of international order. Agents on both sides who influence government recognize that they will be better off if both governments reach an agreement with one another, which will constrain the use of force in their interactions (Olson, 1965).

The scenario we have described is the starting point from which agreements between governments must emerge. Interaction between agents from different nations includes a peculiar problem that is not present among interactions within a nation. Besley and Persson (2008) find that external war typically leads to much larger investments in fiscal capacity than do civil wars. In nations where the rule of law has reached an appreciable level of maturity, the position of any two agents in the legal system is much closer to equality than in a system where the rule of law is absent, thus reducing costs that arise due to legal uncertainty (Hayek, 1960/2010). The formation of legal equality promotes predictability within the system as agents can not only form expectations about the governing system's response to their own actions, but also its response to the actions of other agents (Koppl, 2002). Under the rule of law, an agent can expect that the legal system will respond symmetrically and, by implication, predictably to his own action as it would to the same action taken by any other agent (Hayek, 1982/1993, p. 112-113).

In order for the rule of law to extend beyond a single nation, whether in piecemeal or in whole, different nations must form enforceable agreements with one another. These agreements can also manifest themselves in common institutions as the "institutional arrangements of political systems influence the incentives of leaders to provide different kinds of policies" (de Mesquita et al., 1999, p. 41). Countries with similar institutions, democracies for example, interact differently and often times more cordially with each other than they do with autocracies. Discrepancies in the power of nations will play a significant role in determining the extent to which the rule of law plays a role in international relations. Alliances may also be used as a tool of increased control for the stronger party. Given power asymmetries between nations, Benson's (2011) findings that alliance formation can even create incentives for alliance members to initiate and perpetuate conflict are unsurprising. Our model integrates these attributes of alliances in their willingness to respond to conflict.

This section provides a description of our Global Tribute model as well as a background on the data and methods used to conduct our analysis. We identify our agent as the nation-state. In doing this, we assume an equilibrium condition within political markets in each state. Each agent involved in enacting state policy knows the expected costs and benefits of the potential action and chooses their most preferred option. We allow for inefficiencies in collective decision making to arise and test the effects of such a systematic deficiency (Arrow, 1950).

The process of becoming an active agent who has the potential to go to war is random. At the core of the model, the decision of whether to attack or not and the decision to attack certain countries or not, however, is strategically calculated. Activated agents make their decisions whether or not to threaten another country by the potential amount of tribute they can garner from their threat. Countries do not threaten their allies. They engage in a cost-benefit analysis for each decision. These decisions are much like the decisions modeled in Cederman's model (2003). He poses that due to increased globalization and technological advancements, stochastic decisions to wage war are based on the specific contexts, costs, and benefits. Agent utility is based on accumulated wealth, and their foreign policy decisions are based upon future expected utility (Bennett & Stam, 2000). Deviations from this norm are dependent upon the efficiency of collective decision making.

As the model runs, agreements between countries are created and are strengthened or weakened based upon the interactions of the actors. In our model, agents are nodes that comprise an existing network of countries. These actors may or may not have connections to other countries. Although this model can be run on any variety of simulated networks, the analysis of this paper is concerned with the dynamics of specific real-world networks drawn from certain points in time.

The data used for our global network model experiments come from the Correlates of War Project. The networks for the countries are created using data on formal defense alliances, where one state has signed a defense pact to protect another (Gibler, 2009). These defense networks convey information about the structure of global relationships as they represent a high level of commitment to another country. They are directed connections that represent an explicit public promise that one country will commit some level of resources to another country should they come under attack. The Global Tribute model takes the formal defense alliance networks of years 1945, 1960, 1980, and 2007 and treats them as having already emerged from the previous interactions of the individual countries. These years were chosen because they allow us to compare model results from time periods before during and after the Cold War, a time of international tumult. In the model, alliances are preexisting conditions that are taken as given and are fixed as the simulation is run forward each time.

New links between previously unlinked countries arise when one country pays tribute to another country. These new links do not represent formal defense agreements. They represent a "non-aggression" agreement between the two countries. They signify that neither country, should they become active again, will target the other in the future. They do not represent a promise to commit any resources to another county in the future.

The CoW project has detailed data on the national material capabilities of countries throughout much of the 20th century. In the globalized model, each country is instantiated with a proxy for wealth that is based on data for that country in that year. We use CoW data on yearly steel production as a proxy for wealth. One might argue that certain countries, Japan in particular, did not have adequate steel production of their own to sustain their growing army in the 1920s-1940s. Although this is true, Japan did have three principal mines in the early 1900s that provided an ample amount of iron and steel to the country ("Japanese Iron and Steel Production," *Journal of the Royal Society of Arts*, 1908). As Berglund (1922) states,

> the iron and steel industry of Japan is closely bound up with that country's continental policies. Military power is dependent upon this industry, the political situation in the Orient will be better appreciated as the conditions governing Japan's iron and steel industry are understood. (p. 623)

Iron and steel production is closely linked with levels of industrial activity. This measure provides a valuable proxy for military potential (Inwood & Keay, 2013, p. 1265; Rodgers, 1948, p. 41; Shone & Fisher, 1958; Wayman et al., 1983).[4] Production of steel is required to fight wars and sustain infrastructure for a modern society. Trade during, before, and after war is crucial to military success, however a country's own iron and steel production indicates its ability to acquire this significant input independently during a time of war (Birkett, 1920, p. 353; Zimmern, 1918, pp. 7-10).

Previous models have used arbitrary thresholds for when actors are to become active during a simulation. Some literature suggests that the frequency of wars worldwide has been increasing since 1870, due to economic globalization and democratization (Harrison & Wolf, 2012, p. 1055). In order to define a year in our model we look to the

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[4] According to Wayman et al. (1983), "examining these statistics and the frequencies of victory, we see that industrial strength as reflected in iron and steel output is the most critical of those factors examined, and that armed force size and military expenditure are fairly important elements, followed by total population, which has an effect in the predicted direction but which, unlike the others, is too weak to be statistically significant" (p. ?).

CoW Militarized Interstate Dispute data (Palmer et al., 2015). The average number of disputes in the four years considered in this model was calculated at 23.25 disputes; Table 2 shows the number of disputes each year. Therefore, in our globalized model, 23 countries are asked to become active each year. These active agents could potentially enter into a conflict. The selection of the countries to become active is random.

Table 2: Number of Global Disputes Each Selected Year

Year	Number of Disputes
1945	14
1960	30
1980	30
2007	19
Average	23.25

In our model, there are two parameters that may be chosen by the modeler. The experiments for our model include a parameter sweep of the tribute rate as well as the cost efficiency of democratic decision making. The tribute payment is a parameter that can be modified to see the effect that various levels of tribute have on the outcome of the model. The democratic efficiency parameter adds the notion of irrationality to the model.

2.3 Agent Decision Making and Interaction

An active country must decide whom to target and it does this by assessing a possible target's vulnerability and multiplying it by their possible tribute payment. The greater the costs of tribute, the more likely a threatened country will choose to fight. Vulnerability is defined by Axelrod (1995) according to the following formula:

Equation 1: Vulnerability of a Possible Target (with no allies)

$$\frac{W_A - W_T}{W_A}$$

In Equation 1 W_A and W_T are the wealth of the active actor and the target, respectively. In order to take into account the networks of targeted countries we need to add a term to this formula that will allow the Active Country to incorporate this information. This term is called AC_T and it represents the weighted wealth contribution of all countries that have a link to the targeted country. Only countries that have a network will calculate the modified vulnerability calculation:

Equation 2: Vulnerability of a Possible Target (with allies)

$$\frac{W_A - (W_T - AC_T)}{W_A}$$

The AC_T term is calculated by each actor in the defense network of a targeted country. Each country in the defense network multiplies the alliance strength it has with the targeted country by its own wealth. This is the amount that each country is willing to contribute to the defense of the targeted country.

When an agent becomes activated, it will look at all the countries that it does not have a link to and from those countries it will find the county that maximizes the product of vulnerability and payment. The country with the maximum attack score becomes the targeted country. At this point the active actor will have made its decision based on the information available to them. Not all decisions to go to war are rational and it is not guaranteed that the active country will carry out its threat to fight. Previous models made unrealistic assumptions about a country's decision to go to war but the democratic efficiency parameter adds this element of irrationality to our model.

The targeted country is faced with two options: they can either choose to pay the tribute to the active country (in which case they transfer a certain percent of their total wealth to the demander) or they can refuse the demand and war will occur. The targeted county will decide to pay tribute if the amount demanded in tribute is less than the cost of going to war. The threatened country engages in a cost minimization calculation in which they calculate whether losing wealth equal to 25% of the attacking country's wealth or losing the amount demanded in tribute is less costly.

Our model uses a proxy for alliance strength that is calculated using data from the CoW dataset. This measure exists for each defense agreement in each year considered. It contains information on the length of time the two countries have had a formal defense agreement with each other as a proxy for the strength of the relationship between the two countries. Alliances can, however, create some unintended consequences themselves. Historically, various alliance groups actually increased the probability of a conflict within the alliance. Because of this fact, many alliance groups started to add caveats to their alliance agreements that countries would only be obliged to come to the aid of another country if they were attacked by a country outside the alliance (Benson et al., 2013, p. 47).

Alliance strength in our model is bounded between 0 and 1 and is used in the calculation of how much assistance a targeted country would receive from each country that has agreed to protect it if attacked. In the globalized model the strength of alliances is thought to have already emerged from real-world processes. These link weights are treated as given and are fixed for the duration of all simulations, therefore, the weights and network connections do not update as the model runs. The new links created in the model are not to be confused with defense agreements. They are created when one county decides to pay tribute to another country. After the tribute is paid and the link is created, those two countries will not target each other (in either direction) again. They do not commit any resources from one country to another. If war occurs and the targeted country has no network, the attacking country has its wealth reduced by 25% of the targeted country's wealth and the targeted country has its wealth reduced by 25% of the attacking country's wealth.

If war occurs and the targeted country has a network, each country in the defense network multiplies the alliance strength it has with the targeted country by its own wealth. The sum of the amount that all countries will contribute is added to the wealth of the targeted country and this sum represents the total alliance contribution to be put toward the defense of the targeted country. Damage is done to the attacking country that is equal to 25% of the sum of the contributed wealth of all countries in the defense network plus the targeted country's own wealth. Damage is done to the targeted country equal to 25% of the wealth of the attacking country. Each country in the defense network of the targeted country has its wealth reduced by the total amount they contributed to the defense of the targeted country.

The code for preparing the data, running the simulation and experiments, and visualizing outcomes is available in a GitHub repository at the following link: https://github.com/hwalbert/Countries-as-Agents-in-a-Global-Scale-Computational-Model. This repository contains a static version of an R package that contains the raw data used for instantiating the model as well as the functions that allow creation of the different empirical instantiations of countries, networks, and attributes. The standard R documentation for this package is also included as a pdf file. The simulation model was created in NetLogo (Wilensky, 1999) and is also available in the repository. The experiments for the model are included in the behavior space tool within NetLogo. Python scripts for analysis and visualization of results are also included.

2.4 Results

We run experiments for the years 1940, 1960, 1980, and 2007. We sweep values from .1 to 1 in increments of .1 for the rate of tribute and democratic efficiency. For all parameter combinations, we run 100 trials. We also sweep values between .01 and 1 in increments of .01 to observe the results with finer texture. For each pair of exogenously determined parameter values we run 20 experiments. We use this set of experiments to generate heatmaps that include the mean values generated for variables for each pair of exogenously determined parameters. In the results we consider the average values generated in each set of runs. We discuss results that are representative of experiments across years.

Results of the experiments share many of the same characteristics of the original model. Axelrod (1995) notes that model runs show significant variation. Each set of parameters is usefully described by the mean values they generate. When agents do not perfectly maximize their expected wealth holdings, conflict can arise late in the model. Across runs, there tends to emerge a dominant player. There also can emerge two powerful, yet opposing players, as is the case between Russia and the United States in many runs. Nations with relatively greater levels of wealth tend to accumulate the greatest levels of wealth, but a nation's initial endowment does not guarantee it success in any given run (Gilbert & Conte, 1995, p. 28).

Axelrod (1995) found that his model could see devastating wars and other large events long into a model run. A typical run of the Global Tribute model will see an initial period of turbulence in which many wars of varying size are fought. This behavior can continue many years into the run of the model but after a time a sort of equilibrium will emerge and wealth will only grow at the rate of wealth increase in the model. This result is unique and different from one of the characteristics of the original Axelrod model where the model never settled down. This difference is probably due to the fact that this model takes the existing network as given, alliance strength is not dynamic in this model, and ties are not broken. Thus, a rigid hierarchy of tribute payments is inevitably formed, and with especial swiftness when tribute rates are relatively high.

We test varying combinations of values for democratic efficiency and tribute rates in the model. We expect to see that higher rates of tribute lead to relative impoverishment of society, including those who are collecting tribute, as defending nations have a significant incentive to go to war to prevent themselves from being subject to high rates of extraction. The democratic efficiency parameter influences the likelihood that an aggressor who would profit from going to war actually follows through. The defending country decides whether to pay tribute or fight. In this case, the democratic efficiency parameter influences whether the defending nation will fight even when it expects that paying tribute would be cheaper. Since the aggressor is the first to act, we expect the effect of democratic efficiency on the frequency of war to be generally positive. We expect that increased democratic efficiency—i.e., only going to war when it is profitable —will tend to have welfare-enhancing effects when tribute rates—that is, the incentive to go to war—are relatively low.

High tribute rates lead to lower levels of welfare across the system. The results show a generally negative correlation between tribute rates and the level of global wealth. The highest levels of wealth, for both the system and for individual states, occurs with the lowest rates of tribute (Figure 1). In cases where there is one agent whose holdings of iron and steel are multiples larger than the next most powerful country, this negative correlation reverses as the rate of tribute approaches 100%. Wars under this scenario are fought early on and lead to complete or nearly complete extraction of a losing nation's resources. Having lost most or all of their resources, these nations are unable to engage in war later in the experiment. This finding is consistent with Kennedy's (1989) work which concludes that a country's economic resources are a prerequisite for sustained conflict. Although the level of wealth that develops at a tribute rate of 100% is relatively high for experiments in 1945 and 2007, this is an artifact of initial conditions where one nation—the United States in 1945 and China in 2007—is much wealthier than all others. In 1945, for example, not much wealth is lost from war since no nation is able to effectively oppose the rule of the United States. This set of experiments exhibit an implicit hierarchy due to these discrepancies. Further, the model's assumption that wealth extracted as tribute is efficiently invested within the recipient nation is independent from the productivity and welfare of other nations. In data from other years, such a discrepancy in power does not exist. High levels of tribute tend to lead to impoverishment across the system.

It is tempting to think of this result as reflecting an upward-sloping supply curve for war. As the expected return to war increases, more wars are fought (Figures 2 and 4). This is true for individual countries in the short run, but the effect is complex. We must also consider that willingness for a nation to defend itself increases as the rate of extraction increases. Thus the cost of war increases significantly and wealth plummets at the beginning of runs where the tribute rate is relatively high (Figures 1 and 3). It takes a significant period of time for wealth to recover in these cases. This suggests a corollary to the Laffer curve, as tribute is essentially tax. Rather than substitute leisure for labor, nations attempt to avoid tribute payment in the model by engaging in war (Laffer, 1981). Nations are more willing to submit to low rates of tribute than high rates. If aggressing nations agree to limit their rates of extraction, the growth rate of the system is improved. This tends to improve the growth of nations across the system, including more powerful nations. Likewise, acts of aggression that might lead to war are limited when the return to war is relatively small.

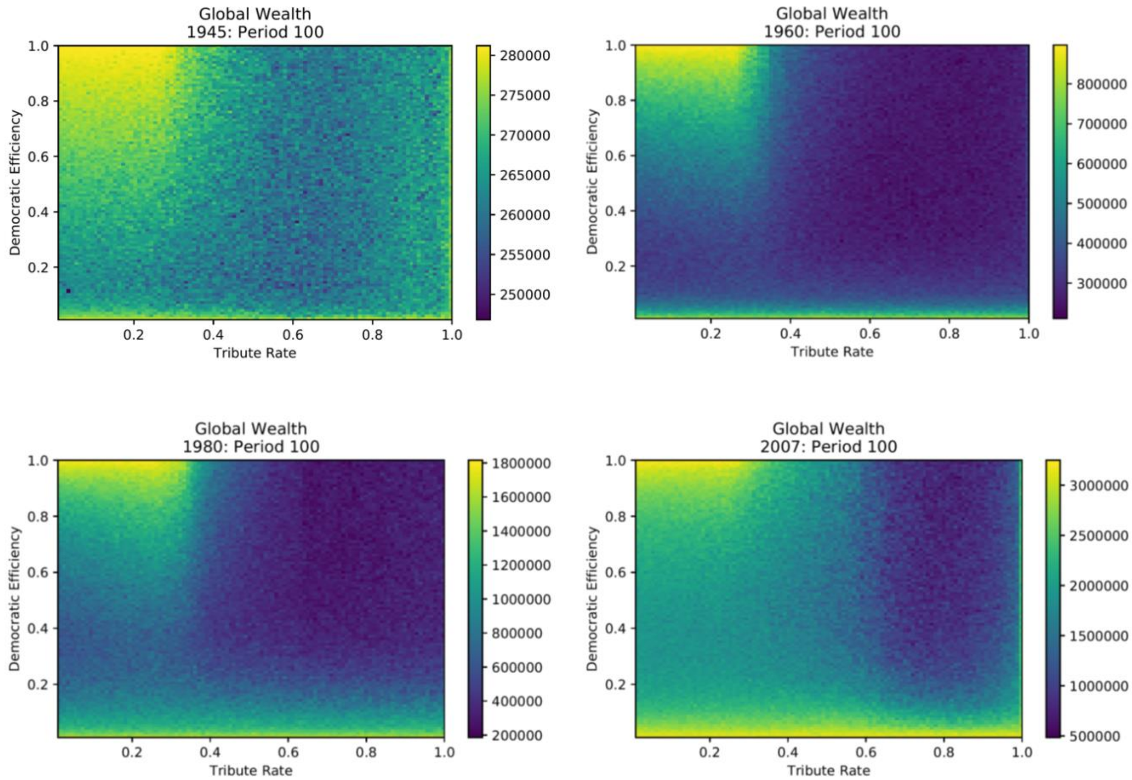

Figure 1: Global Wealth

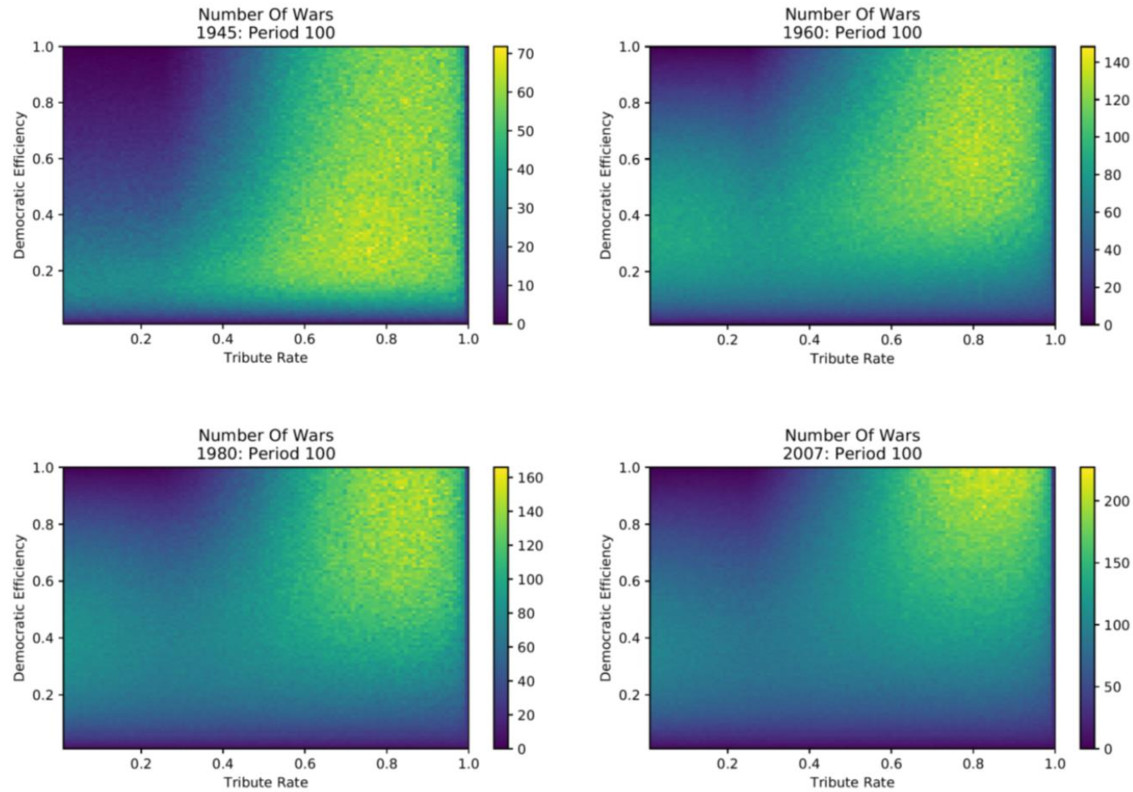

Figure 2: Number of Wars

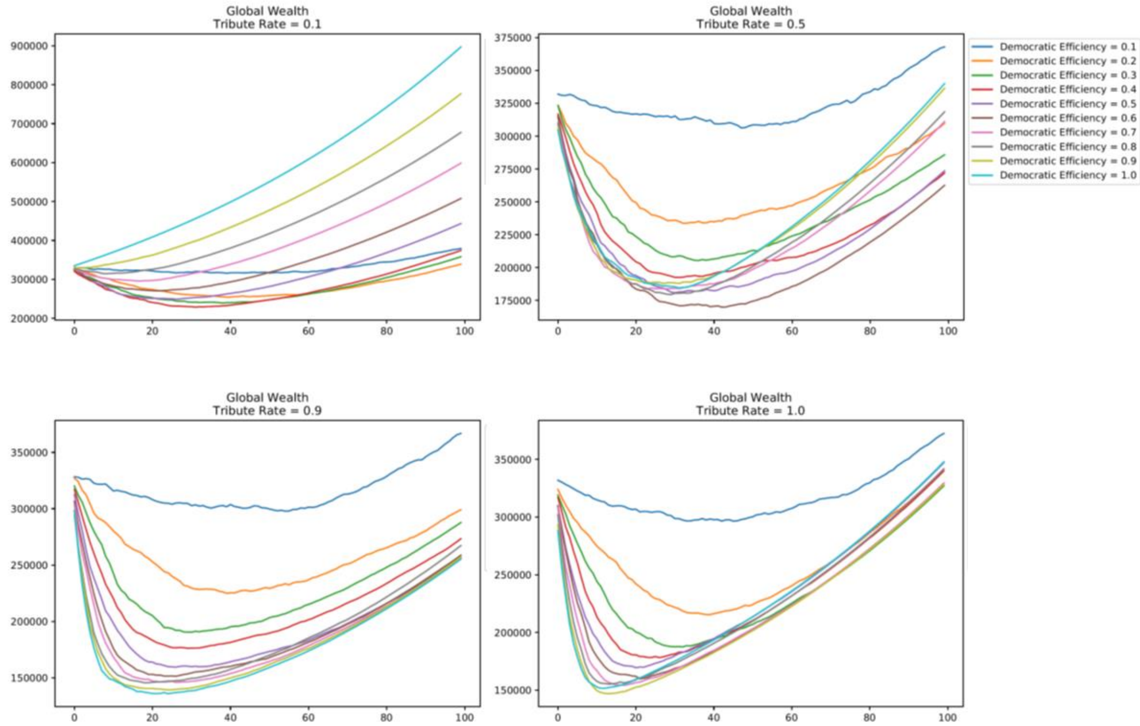

Figure 3: Total Wealth of All Nations (1960)

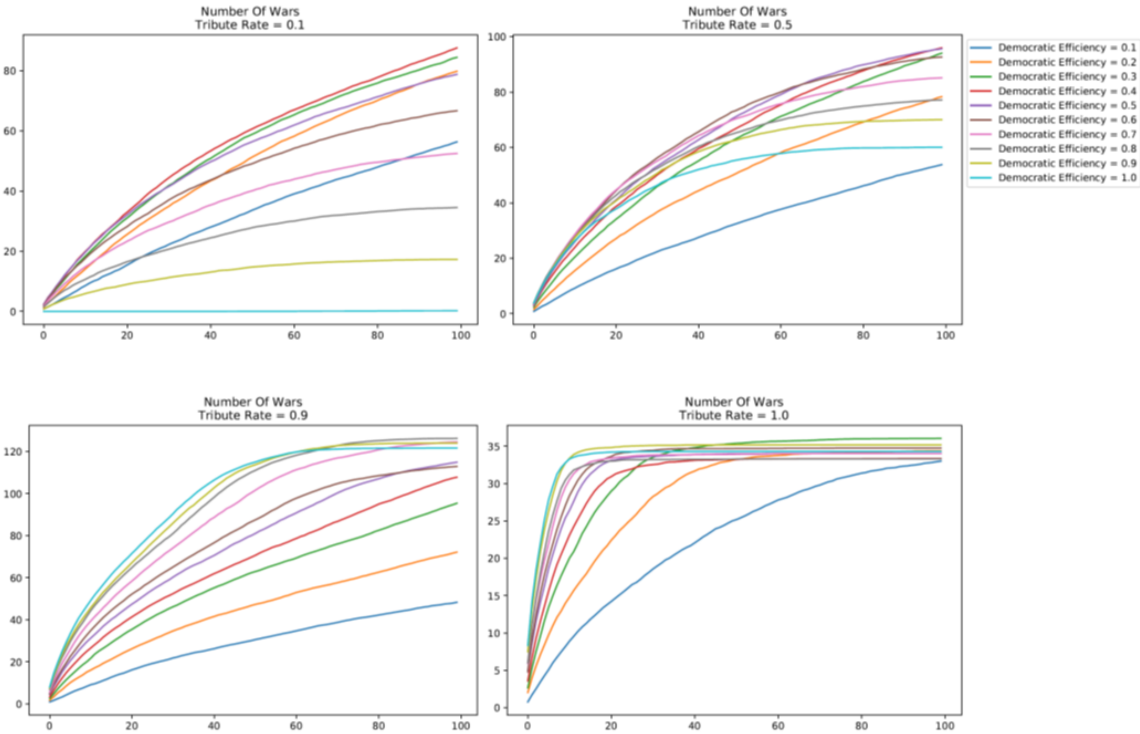

Figure 4: Number of Wars Fought (1960)

In terms of war, the effects of democratic efficiency may be ambiguous. We expect that less efficiency will lead to lower levels of wealth extraction by more powerful countries. This means that poorer countries may perform relatively well in cases of lower levels of democratic efficiency. Since our model shares with Axelrod's model that the country that initiates war is only concerned with its financial ability to wage war, more wars are initiated under the original decision criteria compared to less efficient democratic decision making where aggressive nations avoid war.

The expectation of less war occurring at low rates of democratic efficiency is observed as the rate of democratic efficiency approaches 0. As democratic efficiency falls below a level of .1, the number of wars experienced in the system collapses and the level of wealth in the system quickly rises. This is true even at the highest rates of tribute. At a rate of democratic efficiency of 0, we expect that, according to the model, there would be no wars.

Alliance structure matters. In concordance with Schelling's (1960) work, outcomes in each experiment depend largely upon alliance structure. This alliance structure has direct consequences for a country's retaliatory capacity. A powerful country that attempts to attack a weaker country whose alliance is able to repel the stronger country finds imperial expansion an unviable option. Figures 5 and 6 show cases where the most powerful nation is not opposed by a relatively strong alliance. Under every circumstance, the most powerful nation—the United States—is able to expand. The cost of war for the winning nation is offset by tribute from weaker nations. In the case that the tribute rate is relatively low (.1) and democratic efficiency is relatively high (1), a sustainable structure of tribute is established, allowing all nations to experience a positive, even if negligible, rate of growth.

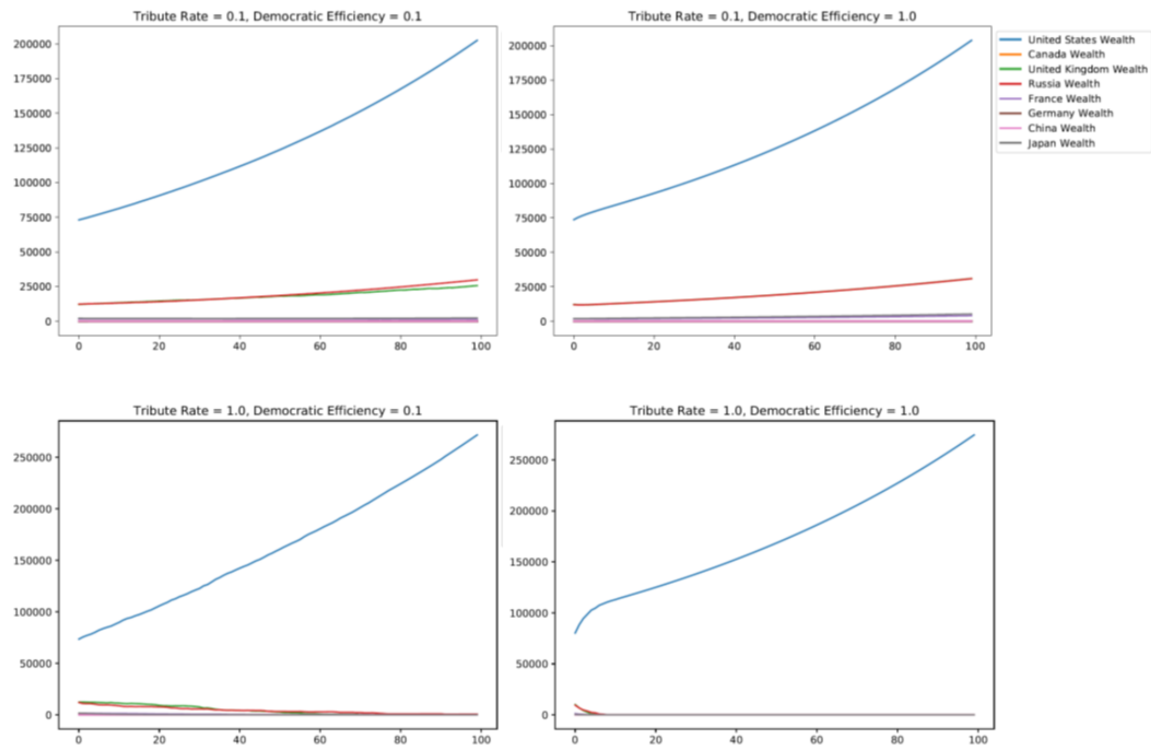

Figure 5: Wealth by State (1945)

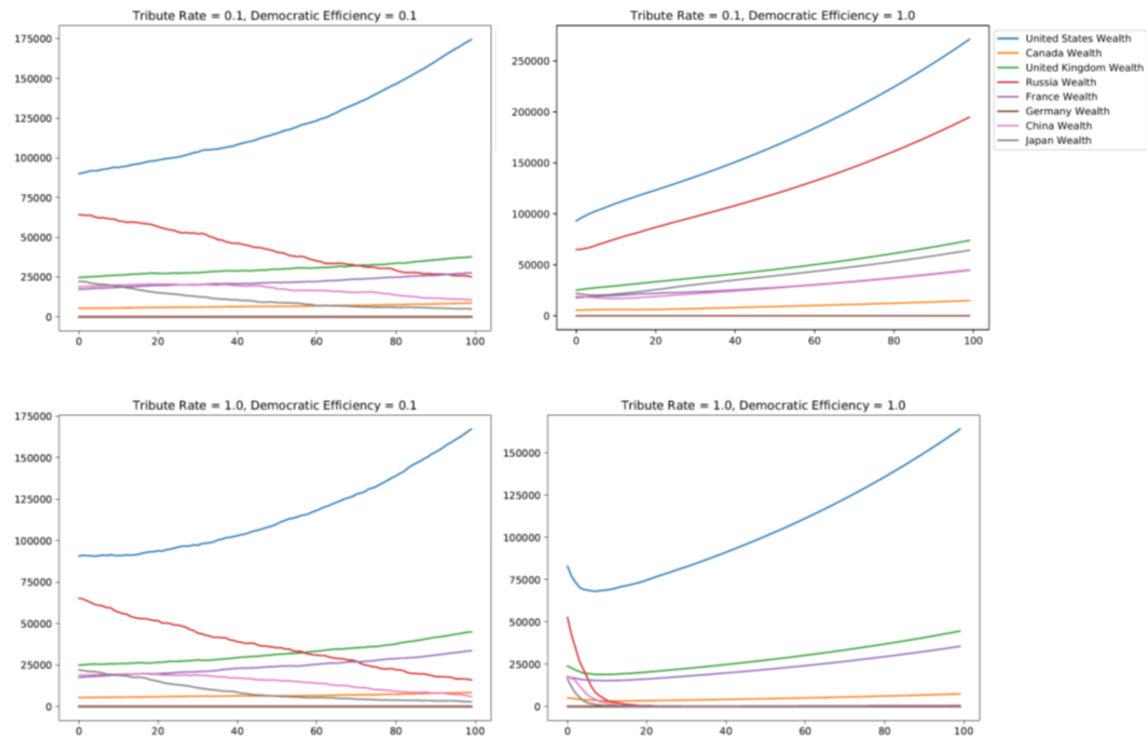

Figure 6: Wealth by State (1960)

Only in the case where the most powerful country can be opposed by a strong alliance do we see that conflict is either abated or that the nation that starts with the greatest resource capacity loses that position (Figures 7 and 8). The finding is consistent with Axelrod's (1995) finding that alliance networks can consist of more than one powerful actor. This is the case in 1980 where the most powerful nation, Russia, is opposed by an alliance between Japan and the United States. If Russia attempts to extract from these nations at a high rate, the United States and Russia respond by entering into conflict with Russia. Since these two, together, have greater resources than Russia, Russia loses these wars. In the case where Russia extracts a low rate of tribute and democratic efficiency is high, a tribute structure is formed early on that allows all nations to experience positive rates of growth.

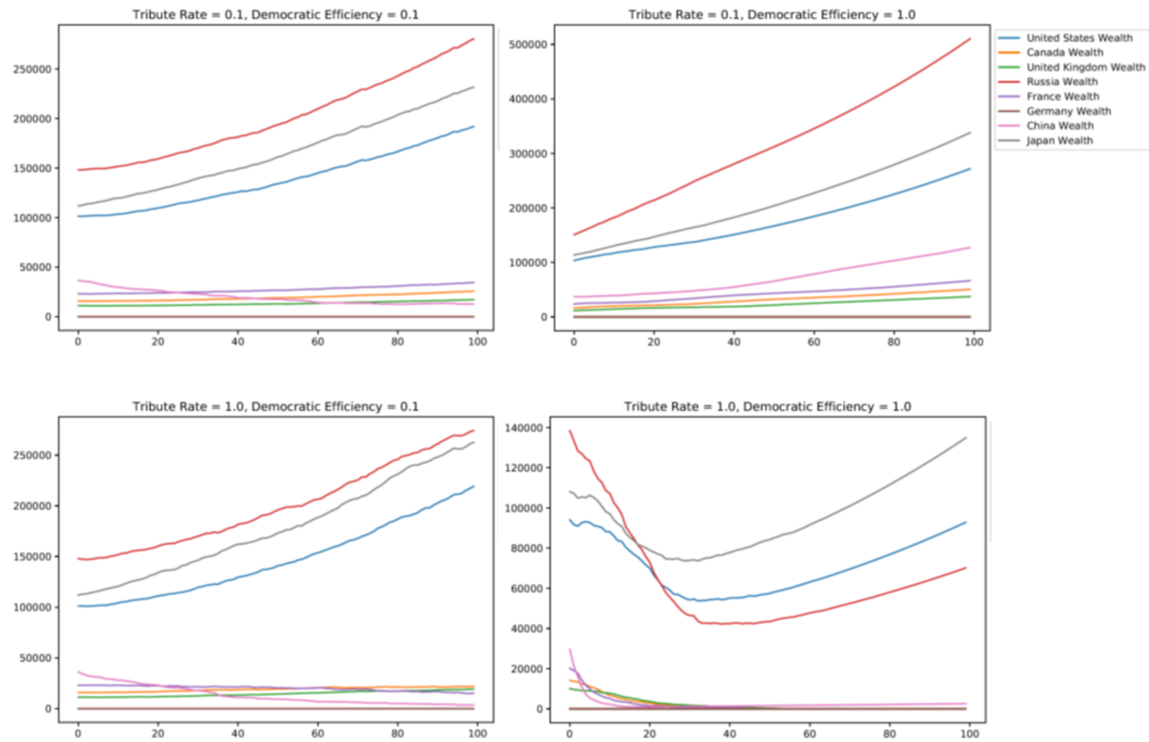

Figure 7: Wealth by State (1980)

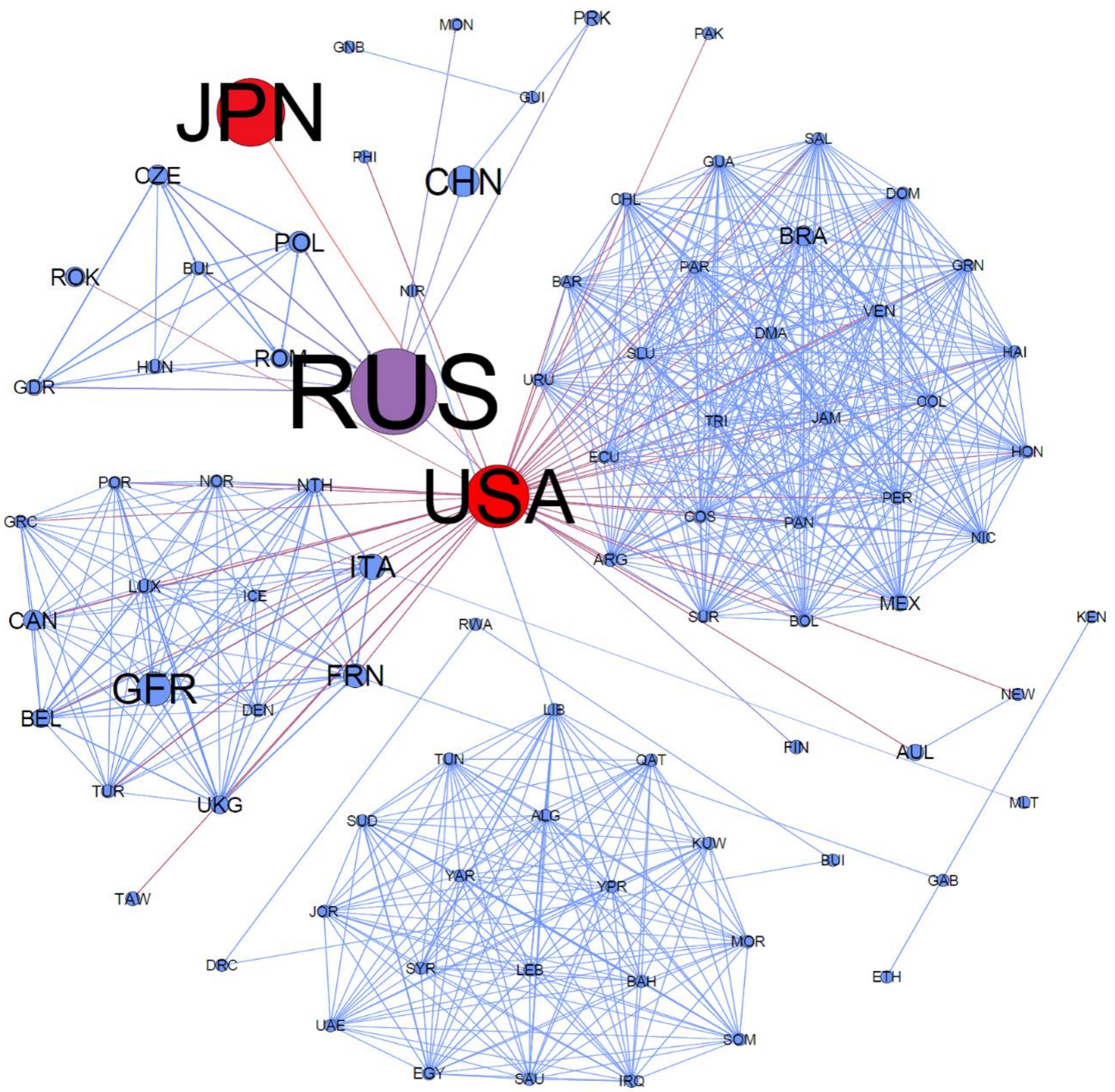

Figure 8: U.S. Defense Agreements
Note. US Defense Agreements and Japan Shown in Red; Russian Defense Agreements Shown in Purple. Defense Network: 1980; Node Size = Wealth.

2.5 Conclusion

Perhaps our main result is not surprising. Societies are best served when the extent to which they extract wealth (i.e., steal) from their neighbors is relatively low. Our model assumes that society experiences an equilibrium level of extraction for those who are successful in such endeavors. This feature allows us to investigate the relationship between rates of extraction of tribute and the predisposition toward war and welfare levels that result. Higher levels of tribute lead to more war, except under the premise that powerful nations are able to extract the entirety of another nation's wealth. Further, we find that large discrepancies in power between the most powerful nations tend to lead to a single dominant player in the network.

We have provided a general model of international conflict and negotiation. Our model is not a predictive model in the sense that it accurately predicts future alliances and levels of wealth in each country. The model shows the relationship between the efficiency of decision-making processes and the incentive to engage in conflict as represented by the tribute rate. It is conceivable, however, that the model could be calibrated to reflect past levels of extraction or integrate other variables of significance that may make it useful for predicting future conflicts.

Extensions for future work include an extension similar to Mearsheimer's (Toft, 2005) work. Just as he focuses on the role of power and geography in world politics in his theory of offensive realism, we wish to expand our model by adding geographical components to the decisions that the agents make when deciding whether or not to go to war. There is also potential to include a more in-depth network-based theory of alliance formation that relies on a more expansive data environment for the country-agents to use in decision making. Networks and structure also exist within a nation-state. Our model does not consider such structure, however, there is no reason why these structures cannot be simulated using voting models and other complex simulations of decision making within government.

3. INTERNATIONAL NETWORKS AND DYNAMICS

Wars devastate people, countries, and economies and in order to avoid these types of disasters, states engage in various types of alliances that bind them in certain ways to other states. Alliances have historically been used with varied success to attempt to bring about international order and peace. Formal defense alliances represent a high level of public commitment that one country will contribute treasure and/or spill blood to defend the other country. Asking if a country will actually live up to a formal defense alliance commitment goes to the core of a country's international credibility. Formal alliances are dynamic and change over time, and in the presence of competing interests, divergent goals, new regimes, and other threats to the status quo, alliances may not be stable and may break down over time. This chapter considers the different types of alliances that countries may enter into and then asks the question, Are countries credible when entering into a formal defense agreement? In Section 3.1 I review and summarize applicable literature around international networks. Section 3.2 introduces CoW more fully and uses it to conduct an analysis of networks over time with a particular focus on defense networks. The last section of this chapter covers additional experiments and analysis of the network model introduced in Chapter 2.

3.1 Literature Review

3.1.1 Networks and War

Formal defense agreements are not the only type of alliance that may exist between countries. Non-aggression pacts, neutrality, entente, and trade relationships are other formal ways a country may enter into an alliance with another country. Other alliances could include trade relationships (a type of economic alliance) which are an economic tool that countries use to facilitate interaction with one another and promote stability with the hope that this will bring economic benefits. Some of these trade relationships could also take the form of international arms trades between countries and could represent a shared desire between nation-states (Masad & Crooks, 2012). Two relatively recent examples of international trade agreements include the European Union (EU)–Korea Free Trade Agreement, which is the first free trade agreement between the EU and an Asian country (Directorate-General for Trade (European Commission), Civic Consulting, & Ifo Institute, 2018) and the U.S.–Mexico–Canada Agreement (USMCA) which was largely an update to the North American Free Trade Agreement (NAFTA) (Villarreal & Fergusson, 2020). Empirical examinations of the relationship between trade and conflict generally fall into two different categories of questions: Do wars disrupt trade? Does trade promote peace?

Wars do, unsurprisingly, devastate economies and trade. Glick and Taylor (2010) attempt to estimate the effects of war on trade and find wars have large and continuing impacts on things like national income, trade, and the welfare of the global economy. They estimate that World War I was responsible for a 95% decline in trade while World

War II was responsible for a 94% decline in trade. Other studies have focused more on the question of whether defense alliances help to promote trade between countries. Mansfield and Bronson (1997) argue that the flow of trade and increased commerce is promoted by both alliances and trading agreements working in tandem, and agrees with the idea that benefits from security externalities make trade among the states a more attractive proposition.

Do alliances or trade agreements (such as the EU–Korea Free Trade Agreement or the USMCA) act as a safeguard against war? Some debate has come out of the question of whether alliances really do mitigate the threat of wars or if trade and alliances are beneficial for international order and peace. One response would be that the aligned incentives arising from alliances and the very high cost of war are the key stabilizers that trade and alliances provide (Jackson & Nei, 2015). Jackson and Nei argue that trade may be more important for preventing conflict than other alliances due to the aligned incentives of trading countries; they find that without a trade network other networks like alliances do not remain stable and at peace. Other studies such as Barbieri (1996) find little support for the idea that trade leads to more peaceful outcomes. Barbieri (1996) acknowledges that trade and economic concerns are powerful incentives in a country's decision to go to war, but notes that trade does not necessarily mean there will be less conflict. In addition, Barbieri (1996) points to the extensive interdependence of countries as the key factor that increases the likelihood of conflict, noting that moderate amounts of connectivity seem to reduce the chances of a dispute between countries, but larger amounts of connectivity could lead to an increased risk of conflict. Empirical answers to the question appear to be sensitive to model specifications. Hegre et al. (2010) make an argument against two previous studies (Keshk et al., 2004; Kim & Rousseau, 2005) that found no pacifying effect of trade in their empirical analysis.

Like research on the implications of trade on conflict, research into formal defense alliances' impact on conflict returns mixed findings on the ability of these alliances to mitigate the outbreak of conflicts. Gibler and Vasquez (1998) argue that alliances can be broken into groups based on the initial conditions that led to the alliance formation. There are situations of alliance formation that are more likely to lead to stability, and there are alliances formed under conditions more likely to lead to conflict in the future. Their analysis is theoretical, but uses data from the time period 1495–1980 to test their arguments, and notes that countries may view other countries as being extremely prone to going to war and so alliances with these countries could be preparations for a coming war.

Alliances can take many forms and different types of alliances can have different effects on country behavior and aggregate outcomes, but seem to have deterrent effects for conflict (Leeds, 2003). Leeds and Johnson (2011) found evidence that defensive alliances help stop disputes from happening, but they did not find evidence suggesting that countries with defensive allies are more prone to starting disputes. They concluded that alliances can lower the chance of a war and are a good option for countries trying to achieve peace. Cranmer et al. (2012) connect ideas about military strength and the type of government a country has (democracy or something else) to the type of alliances that end up being formed between countries. How a network changes over time is dependent on the original structure of the network and how countries view one another as possible allies.

Other studies of alliances and conflict include Smith (1995), who suggests a game theoretic model with interaction between three countries engaging in decisions about alliance formation and the decision to go to war, and where the decisions of individual nations can influence the decisions of other countries in the model. This approach found that alliance formation would have predictable effects on an individual nation's decision to go to war, but the overall effect on a war occurring would be ambiguous. In certain cases alliances could increase the chances of a war, but in others they could decrease the chances. Smith (1995) also explored the effect that an unreliable alliance from a country had on a country's likelihood of being attacked and found that those countries that had untrustworthy alliances were in greater danger of being attacked. If there is uncertainty about whether alliances of any type are beneficial for peace, then there could be underlying uncertainty about the credibility of the states entering into the agreements.

What does the historical data have to say about reliability and a country's track record when it comes to honoring their formal defense commitments? Can nations be believed when they enter into a formal defense alliance? I focus on defense alliances precisely because they represent such a high level of commitment between two countries and the behavior of the individual countries after a war is triggered is relatively easy to observe in the empirical data. The research summarized above makes normative arguments about alliances and their impact on outcomes but the analysis in this chapter aims to be positive in nature and to present a data analysis of existing historical empirical data on what has been observed in country behavior.

3.1.2 Country Attributes and War

Alliances are not the only thing that can have an effect on the decision for war. The way a country orders itself internally through its institutions and form of government can shed light of the likelihood it will be involved in a conflict. The observation that countries with democratic forms of government were less likely to fight each other in wars was first put forward by Kant (1991). This idea of a democratic peace has generated a large amount of scholarship and has been further refined through the years. While still creating debate among academics, the democratic peace theory remains a key insight to understand how countries behave (Kinsella, 2005).

Doyle (1983) agrees with Kant's (1991) idea of a democratic peace and notes that other explanations like geography, national wealth, or alliances cannot explain why we observe a general peace among democratic nations. Cowhey (1993) argues that a country's internal institutions and perceived level of credibility (possibly due to political concerns and considerations at home) could decrease the effectiveness of multilateral agreements. Maoz and Russett (1993) make the point that democracies are not necessarily any less likely to go to war than other non-democratic countries, but they are less likely to go to war with other democracies—especially when accounting for other variables.

The leaders of democracies and non-democracies may view the decision for war very differently and may consider different factors when deciding whether or not to engage in war (de Mesquita et al., 1999). When a conflict happens the leaders of non-democracies may have less to fear if they go to war and lose than leaders of democracies who may fear being voted out of office or losing power. Because of this democracies may be more likely to only engage in wars where they can be victorious, while leaders of non-democracies may go to war even when that war is more high risk.

3.2 Overview and Analysis of Correlates of War Data

Empirical international relations research into conflict, alliances, and country behavior was aided when Singer and Small (1966) introduced a standardized dataset of conflicts and alliances that is a part of the Correlates of War (CoW) collection of datasets. Since 1966, the CoW datasets have been expanded to include additional information on variables such as trade, religion, military capabilities, geographic information, and other data of interest. The core alliance and dispute data from 1966 has been updated and revised over time and has served as the basis for many international relations researchers interested in conducting data analysis or building models informed by empirical data. This chapter builds on the existing body of empirically based research into war and alliances and asks the question: Are countries credible when they enter into a formal defense alliance?

CoW data has been used for decades as a trusted and well-established source of information on countries, international conflict, and alliances (Suzuki et al., 2002). This data has formed the basis for many studies across a range of research areas, specifically: theoretical rationale and research strategy, indicator construction and data generation, model/hypothesis testing and data analysis, and practical implications for policy and teaching (Suzuki et al., 2002). Scholarship using CoW data includes *The Wages of War, 1816-1965* by Singer and Small (1972), which focuses most on the theoretical groundwork of conflict as well as how best to categorize and parameterize international relations and conflict data. Other examples include *Prisoners of War? Nation-States in the Modern Era* (Gochman & Sobrosky, 1990) and *Measuring the Correlates of War* (Singer & Diehl, 1990), which focus mostly on "capability differentials, expected utility, and deterrence attempts as predictors to war and armed conflict short of war, including militarized interstate disputes and crises" (Suzuki et al., 2002, p. 72). In *What Do We Know about War?* Vasquez (2012) provides a deeper look at quantitative approaches to understanding war and conflict and tests hypotheses using models informed by empirical data.

To answer the question of whether countries are credible, we have to connect information on disputes, the countries involved in these disputes, and information about the networks that these countries were a member of during the time of the dispute. The Correlates of War Project (CoW) makes available several datasets that contain the information listed above. The Militarized Interstate Disputes (MID) data (Maoz et al., 2019; Palmer et al., 2015) from the CoW provides two main datasets for understanding MIDs: MIDA, and MIDB. Both MID datasets provide data from 1816–2010, but the MIDA dataset contains dispute-level information with one entry for each dispute, while the MIDB data contains one record for each participant for every dispute. The second important dataset for this analysis is the Formal Alliances (v4.1) data (Gibler, 2009) which gives the directed dyad information at the year level for the following alliances:

defense, non-aggression, entente, and neutrality. International Trade data from 1870–2014 comes from the Trade (v4.0) dataset (Barbieri & Omar, 2016).

3.2.1 Disputes and Networks Over Time

The MID data categorizes all disputes into five levels: 1. No militarized action, 2. Threat to use force, 3. Display of force, 4. Use of force, 5. War. Figure 9 shows a graph of disputes over time where disputes are broken out into the categories listed above. Figure 10 shows the disputes at levels 2 and 3 while Figure 11 shows the disputes at levels 4 and 5. Note that dispute level 1 is not shown because it is essentially a null value in the data (i.e., dispute level 1, defined as no militarized action, could be removed from the data with no repercussions).

The number of level 5 disputes (wars) and level 2 disputes (threats) appears to remain mostly stable for the time period covered by the data. The level 4 disputes (those instances where war is not explicitly declared but force is used) and disputes of level 3 (where a country takes part in a display of force) appear to be increasing during the time period covered by the data. At the beginning and end of World War I there are two spikes in the number of level 4 disputes observed. The two largest spikes in level 4 disputes occurred in 1940 (near the beginning of World War II) and 1987 (near the end of the Cold War) and the general amount of level 4 disputes appears to be at a higher steady state after the end of World War II. It is unclear if this new sustained spike in the number of disputes at level 4 is due to a true increase in the level or if better or more extensive data collection efforts have identified more uses of force around the world. Some events that may appear like wars but are categorized as level 4 disputes may fall into this category because of the legal hurdles a dispute may have to overcome if it is to be legally recognized as an official war (i.e., in some countries a governing body may need to officially designate a dispute as a war by making a declaration of war). This chapter does not go into detail about the number of fatalities observed during a dispute of any level but it should be made clear that the question of whether a dispute rises to level 4 or 5 is mainly an issue of semantics, and legal definitions and disputes at both levels have many fatalities to their name.

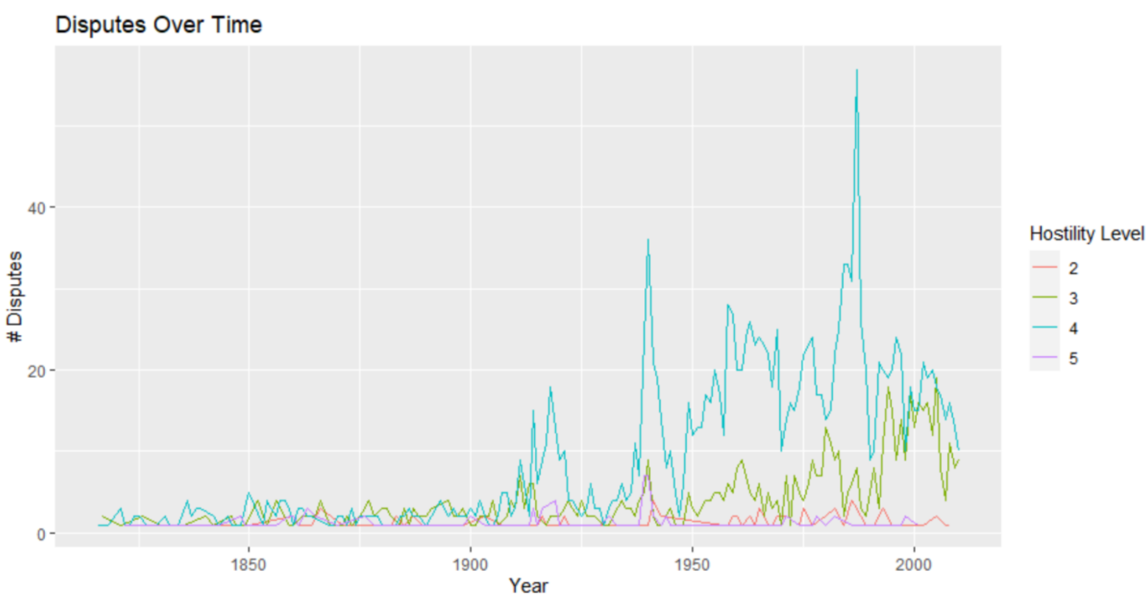

Figure 9: Disputes by Hostility Level Over Time (All Hostility Levels)
Note. Dispute level 1, no militarized action, is not shown because it is essentially a null value in the data.

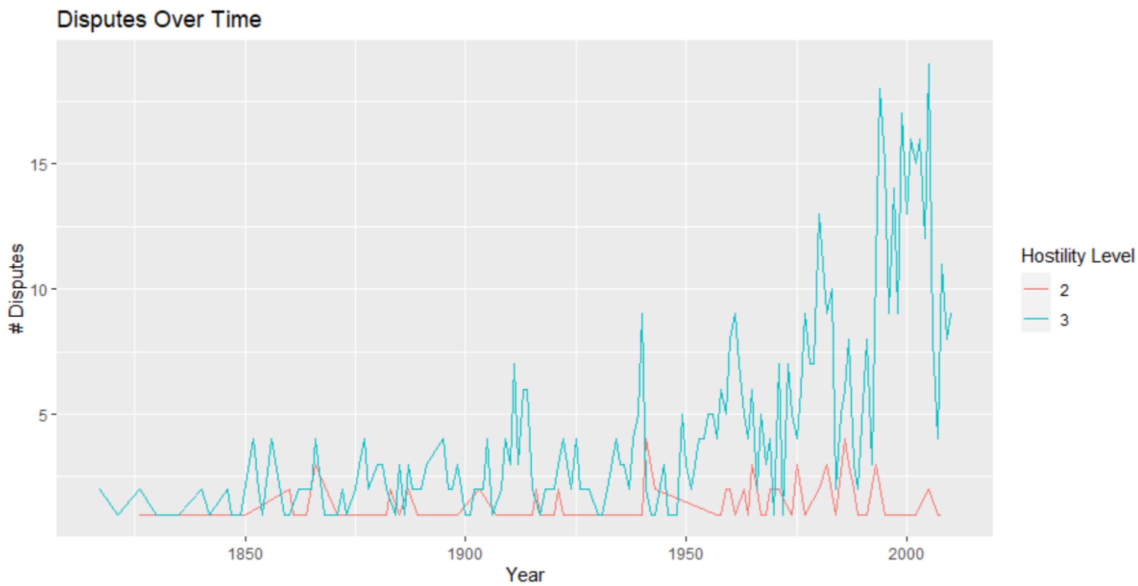

Figure 10: Disputes by Hostility Level Over Time (Low Hostility Levels)

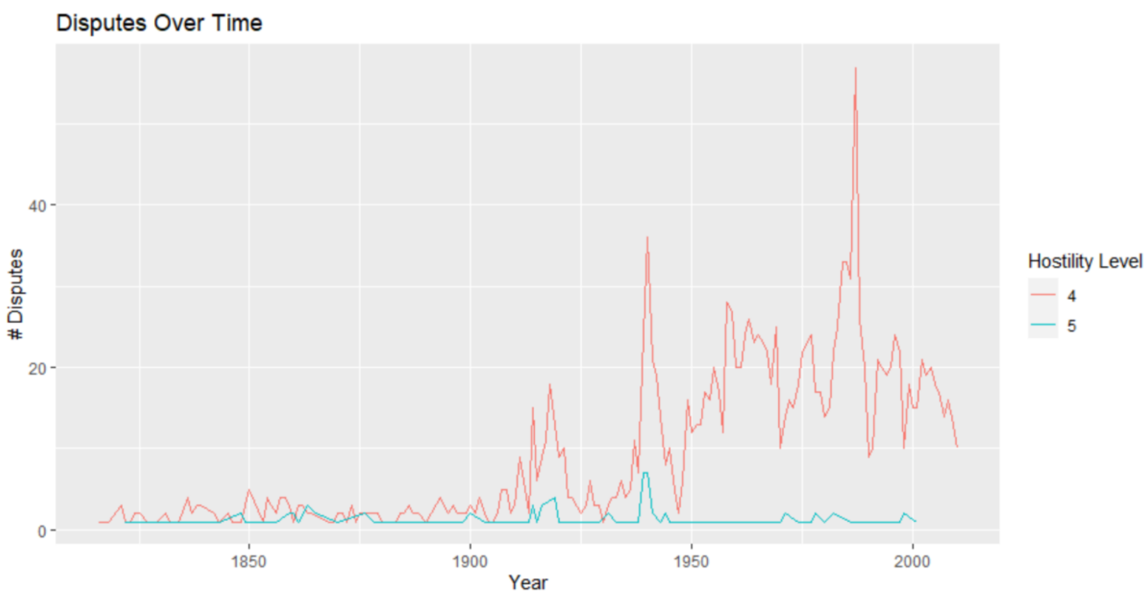

Figure 11: Disputes by Hostility Level Over Time (High Hostility Levels)

Defense networks (formal alliances between countries, e.g. North Atlantic Treaty Organization) as well as other networks like trade (e.g. African Continental Free Trade Area), entente (an informal alliance or agreement, e.g. the Triple Entente between Russia, France, and the United Kingdom]), nonaggression (a promise not to attack, e.g. the Molotov–Ribbentrop Pact between the Soviet Union and Nazi Germany before World War II), or neutrality (a promise to not get involved in a conflict, e.g. the Japanese–Soviet Union neutrality pact during World War II) were created and dissolved during the same time that the disputes above were playing out. Figures 12 through 16 show high-level network measures by year for defense networks, trade networks, neutrality networks, nonaggression networks, and entente networks. The top chart in each figure shows the network density (a network-level measure of the number of actual connections in a network compared to the number of total possible connections in a network), while the bottom chart shows the average degree (degree being a node-level measure that gives the number of connections each node has) for the network in each year.

The defense network shows overall network density measures fluctuating over time with a relatively stable flat history since around 1960. The average degree in defense networks remained relatively stable until after WWII, where we see a clear jump in the average number of alliance partners for each country as countries scrambled to attempt to ensure another catastrophe like WWII could not happen again. It was during this time period from 1944 on that countries developed international organizations like the United Nations, the World Bank, and the Internal Monetary Fund. The trade network shows overall network density measures as well as average degree increasing over time. The only real breaks in this trend occurred during the World War I and World War II time periods where clear dips are evident. This is clear evidence in the data that war disrupts trade and at least temporarily breaks down trade networks.

Neutrality, nonaggression, and entente networks tend to have lower numbers of countries participating in the network and because of this we can see large jumps in network density as the network grows or shrinks. All of these networks have large fluctuations in the network density in the early years of the 1900s due to the relatively low number of countries participating in the network. The entente and nonaggression networks also see a large upward fluctuation in average degree right before and after World War II. The entente networks (the countries with an informal agreement) show a jump up in average degree leading up to 1940 and stay at this level with a trend upward for the rest of the century. The nonaggression network has a similar jump in average degree but this jump occurs right after the end of World War II and stays at this new level with a trend upward for many years after. Of the different types of network alliances discussed above, defense agreements represent the highest level of commitment between countries because they obligate a country to expend resources to help another country. Because of this high bar, defense agreements are the main focus in the rest of this chapter.

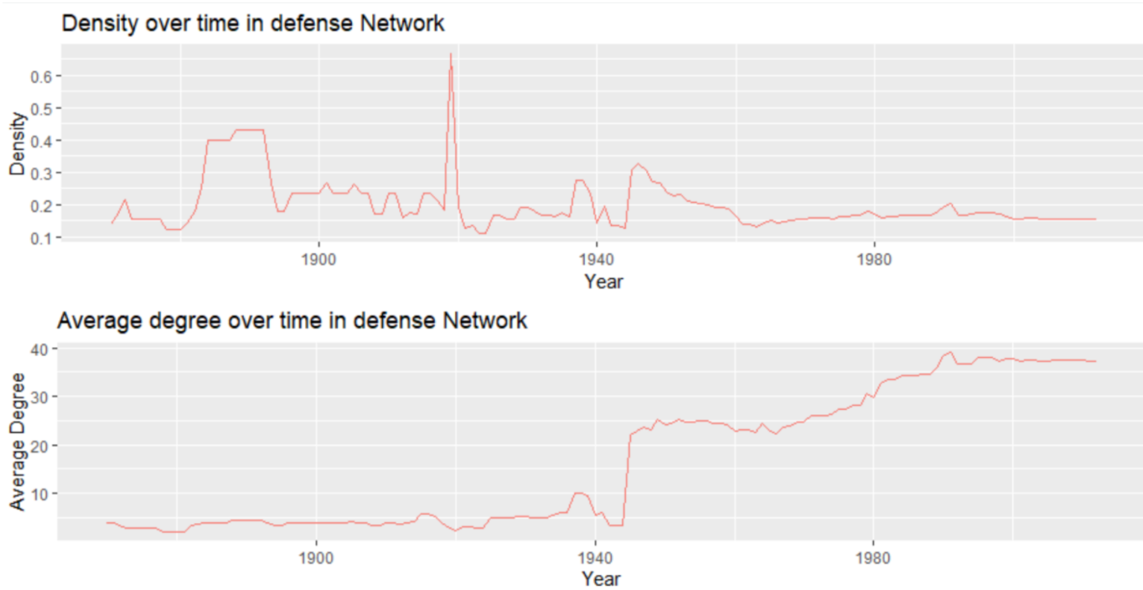

Figure 12: Network Measures Over Time in Defense Network

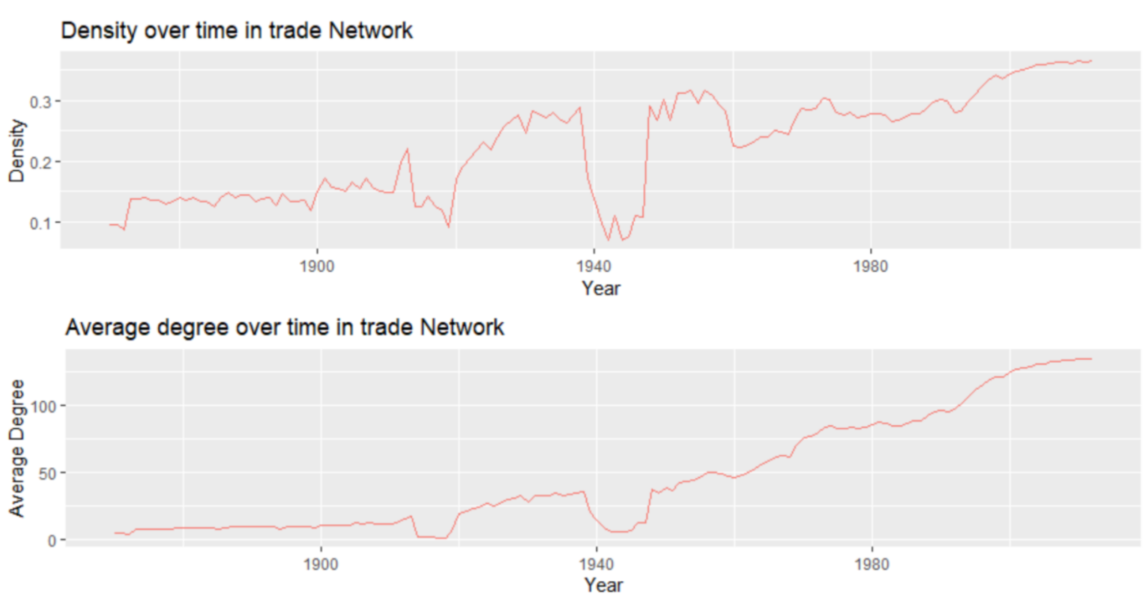

Figure 13: Network Measures Over Time in Trade Network

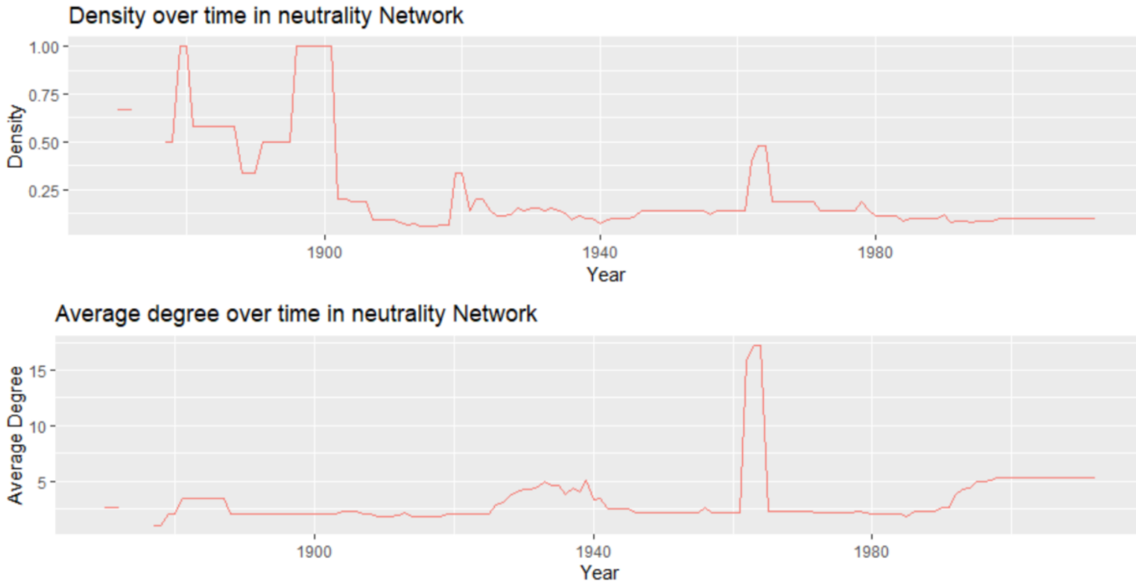

Figure 14: Network Measures Over Time in Neutrality Network

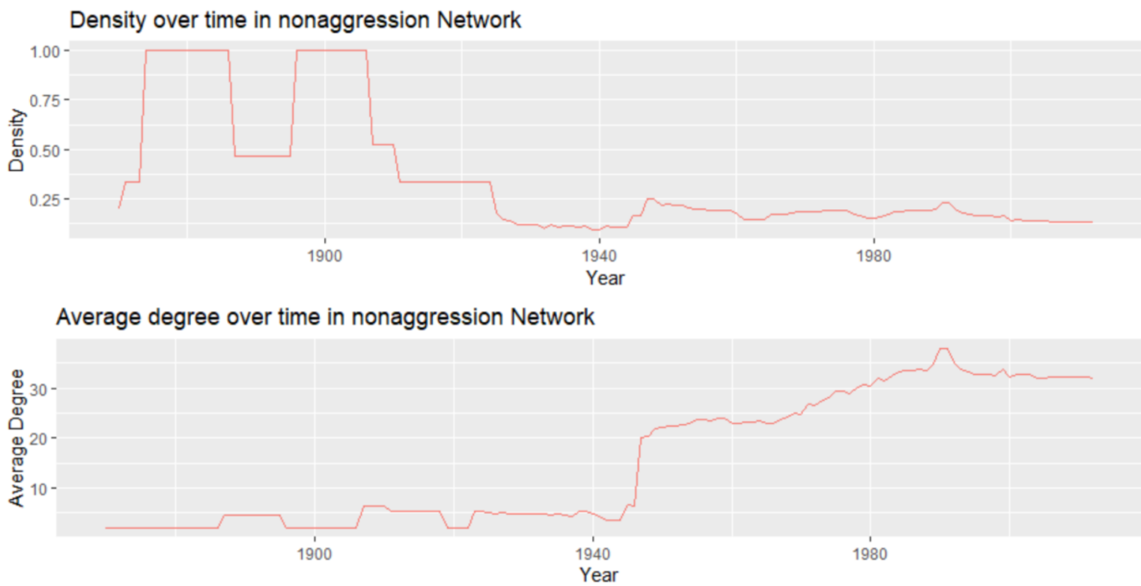

Figure 15: Network Measures Over Time in Nonaggression Network

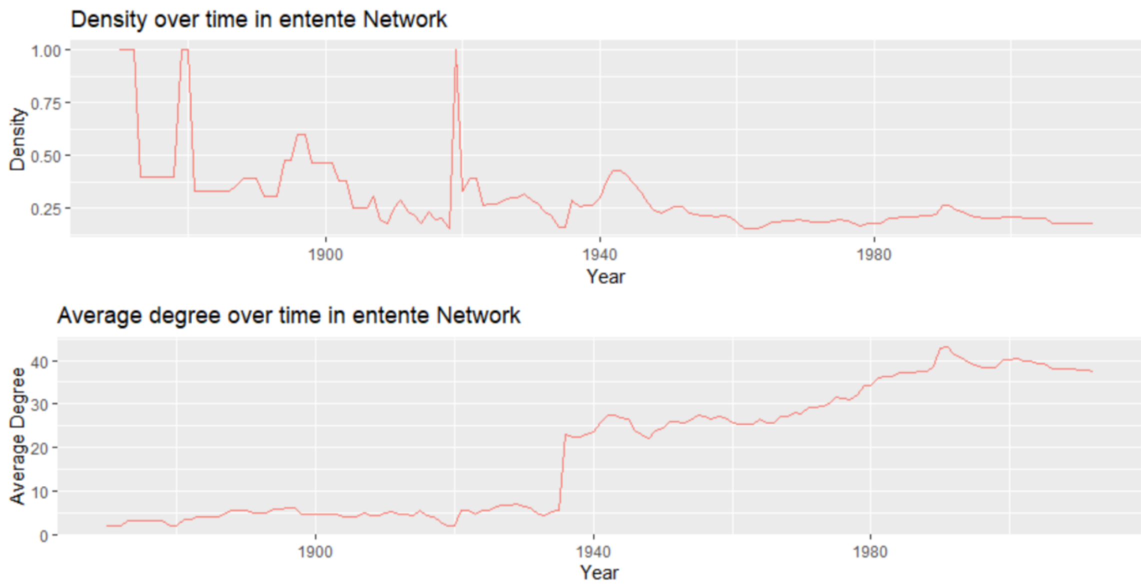

Figure 16: Network Measures Over Time in Entente Network

3.2.2 Analysis of Defense Networks and War

I created an R package to aid the research by connecting the data required for analysis and providing reusable code to recreate analyses. It fulfills a key need in the area of research sharing and reproducibility by using a computational tool that allows standardized and repeatable analysis of datasets (Peng, 2015). Using R and the available packages allows combining specific data with select functions, methods, or routines to use to understand the data. In addition, through the Comprehensive R Archive Network (CRAN) repository, R can access a rich library of packages that allow all types of advanced analysis and visualizations. This package also provides the functionality to understand what is collectively known as the Correlates of War dataset. Many of the graphs and charts in this chapter are supported with this tool.

To begin the analysis I run a function in the package called "CountryCredibilityCalc()" which executes code that does what is outlined in the following paragraphs and summarized in Figure 17. It begins by calling on the MIDA (summary dispute data) and MIDB (detailed dispute data) datasets. To eliminate any discrepancies in the different datasets, I connect the StateAbb and StateNme IDs from the Country Codes dataset to the MIDB detail data. There are differences in the column names and this step is an attempt to address these issues with a common data model implemented across CoW datasets. This step helps to make sure that comparisons across datasets are using a common name.

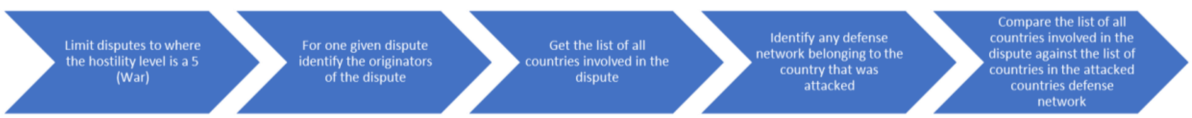

Figure 17: Flow Diagram of Analysis of Countries and Adherence to Formal Defense Agreements

The package contains a function designed to analyze if a country, when allied with another country via a formal defense agreement, becomes involved with a war when its ally comes under attack. The function provides an option to analyze this question for disputes at different levels using the "Analyze4_5" argument in the function. As discussed in section 3.2.1, disputes are categorized at different levels: 1. No militarized action, 2. Threat to use force, 3. Display of force, 4. Use of force, and 5. War. For this analysis I limit consideration to only those disputes rising to the level of war because formal defense alliances represent such a high level of commitment. I do this to remove any doubt about another country's obligation to become involved in the presence of a formal defense agreement. There are 107 instances of disputes that rise to level 5 (war). For each of these disputes gathered from the MIDA dataset, I find the entire list of countries that were involved in the dispute from the MIDB dataset. The MIDB dataset contains information about each country and its relation to the war; from this information I extract the “originators” of the war, referred to hereafter as “Side A” and “Side B.”

At this point I take the year that the dispute started and use the “CreateNetwork()” function to recreate the defense network that would have existed in that year. Using the resulting network graph, I ask the following questions: If Side B has a network and there are not multiple originators on the B side, check to see if the B originator has a defense network. If Side B does have a network, I take the countries in the Side B ego network (the network of connections directly connected by a link) and list them as Side B Allies. If Side B does not have a defense network or there are multiple originators on the B side, then Side B is considered to not have a defense network. If Side A has a network and there are not multiple originators on the A side, check to see if the A originator has a defense network. If Side A does have a network, I take the countries in the Side A ego network and list them as Side A Allies. If Side A does not have a defense network or there are multiple originators on the A side, then Side A is considered to not have a defense network.

Now I can make an exhaustive list of all countries that were involved in the dispute and/or were allied with a country that was an originator. Some countries may be listed only in the MIDB file detailing the countries in the war and may not actually be in a defense alliance with either of the originating countries. Some of the countries may appear in the MIDB listing as well as in one or both of the originators' defense networks. Some of the countries may only appear in a defense network and did not get involved in the dispute. It is at this point that we can start to calculate the distributions of observed country behavior if one of the countries has a defense network. There are four groups that the countries can be sorted into. The first group are countries that are not involved in any other country's defense network but decide to get involved in the dispute (external participating countries). The next group of countries could be considered unreliable in a defense alliance. The third group of countries actually fight against the countries that they are allied with in the defense network. The last group of countries participate in the conflict when called upon by their defense alliance. More in-depth analysis of these outcomes will be discussed in the following section. Overall results for the number of times a country was observed to be in one of these groups for all 107 wars analyzed are shown in Table 3.

Table 3: Alliance Adherence Analysis Results

Result	Freq
Follows Through On Defense Alliance	69
Does Not Follow Through On Defense Alliance	453
Involved in War but Not Part of a Network	131
Does Not Follow Through On Defense Alliance AND Fights on Opposite Site	17

3.2.3 Results and Findings

As discussed in section 3.2.2, a country's results can be broken down into four main categories: countries that follow through on defense alliance commitments, countries that do not follow through on defense alliance commitments, countries that fight against the country they have a defense agreement with, and countries that did not exist in any defense networks but participated in the conflict nevertheless. At different times and in different wars the same countries could be categorized into more than one of these categories. There are 107 disputes in the dataset analyzed which rose to the level of war. There were 670 unique war/country pairings, meaning that each war had an average of 6.3 participants. The war with the earliest start date occurred in 1822 and the war with the most recent start date occurred in 2001. There are 62 instances of a country being aligned to both of the countries in a war. An example of this can be seen in Table 4 where we see Argentina being involved in some capacity with five different wars.

Table 4: Argentina's Alliances During Disputes

Country	Ally to Side B?	Ally to Side A?	Ally To A & B	Participated in Conflict	Side Participated	Defense Agreement Adherence	Dispute Number	Start Year of Conflict
Argentina	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	611	1964
Argentina	Y	Y	TRUE	N	Did Not Participate	Did Not Adhere to Defense Agreement	1206	1969
Argentina	Y	N	FALSE	Y	B	Adhered to Defense Agreement	1590	1863
Argentina	N	N	FALSE	Y	B	Not In Defense Network	3957	1990
Argentina	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	4273	1997

In three out of the five wars Argentina was in a formal defense agreement with either Side A or Side B but chose not to participate in the war. In the war that occurred in 1990 (the Gulf War), it was not in a formal defense network with any of the originator countries, but chose to participate anyway. The one time Argentina was found to follow through on its defense agreement was in 1863 with a dispute that originated with Paraguay (Side A) and Brazil (Side B). Brazil only had one ally in its defense network (Argentina) and Paraguay had no defense network. Brazil went on to win this war.

In some cases countries get involved in wars when they were never a part of the origin of the dispute or a part of a defense network. This can be seen in Table 5. The United Kingdom was not in a defense alliance with either of the originators of the war but still got involved, allying with Side B. Dispute #194 took place from 1863–1864 and involved 9 countries. It originated with Germany (Side_A) and Denmark (Side_B). Germany had a network while Denmark did not, and the war ended with a victory for Germany. Motivations would surely differ, but even countries that do not have formal defense agreements with the originators of a conflict may still have an interest in the outcome of the dispute and therefore be willing to get involved.

Table 5: Dispute Number 194 Participation Summary

Country	Ally to Side B?	Ally to Side A?	Ally To A & B	Participated in Conflict	Side Participated	Defense Agreement Adherence	Dispute Number	Start Year of Conflict
Hanover	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
United Kingdom	N	N	FALSE	Y	B	Not In Defense Network	194	1863
Baden	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
Wuerttemburg	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
Hesse Grand Ducal	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
Saxony	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
Austria-Hungary	N	Y	FALSE	Y	A	Adhered to Defense Agreement	194	1863
Bavaria	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	194	1863
Hesse Electoral	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	194	1863
Mecklenburg Schwerin	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	194	1863
Russia	N	Y	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	194	1863

Other countries are considered to not be adhering to their defense agreements when they are in a defense network with one of the originators and do not participate, or they are in a defense network with both originators of the conflict and do not participate on either side. The countries with defense alliances with both of the originators are in a position where no matter what they do (support Side A, support Side B, or Did Not Participate (DNP)), they will be considered to not be following through by one of the countries; however, for this analysis they are considered to be adhering to their agreement because they come to the aid of one of their alliance partners. An example of this can be seen in Table 6 where Germany is in a defense agreement with both sides.

Table 6: Dispute Number 320 Participation Summary

Country	Ally to Side B?	Ally to Side A?	Ally To A & B	Participated in Conflict	Side Participated	Defense Agreement Adherence	Dispute Number	Start Year of Conflict
Turkey	N	N	FALSE	Y	B	Not In Defense Network	320	1914
Germany	Y	Y	TRUE	Y	B	Adhered to Defense Agreement	320	1914
Bulgaria	Y	N	FALSE	N	DNP	Did Not Adhere to Defense Agreement	320	1914
Romania	Y	Y	TRUE	N	DNP	Did Not Adhere to Defense Agreement	320	1914

The final group of countries are those that are entered into a formal defense agreement with one of the countries, but ended up getting involved in the conflict on the side of the other country. In this analysis these countries would not be credible and actually go one step further to be a kind of turncoat for the country with which they were in a defense agreement. An example of this can be seen in Table 7 for dispute number 111 which took place from 1834–1836. It originated with Ethiopia (Side_A) and Italy (Side_B) and both countries had networks. The dispute ended with a victory for Ethiopia.

Table 7: Dispute Number 111 Participation Summary

Country	Ally to Side B?	Ally to Side A?	Ally To A & B	Participated in Conflict	Side Participated	Defense Agreement Adherence	Dispute Number	Start Year of Conflict
United Kingdom	Y	N	FALSE	Y	A	In Defense Agreement But Fought Against Country	111	1934
Ethiopia	N	N	FALSE	Y	A	Not In Defense Network	111	1934
Italy	N	N	FALSE	Y	B	Not In Defense Network	111	1934
Albania	Y	N	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	111	1934
Belgium	Y	N	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	111	1934
France	Y	N	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	111	1934
Germany	Y	N	FALSE	N	Did Not Participate	Did Not Adhere to Defense Agreement	111	1934

3.3 Alternative Histories: Experimenting with an Agent-Based Model of Countries as Agents in a Global Network

In this section I describe conducting additional experiments on the model and research introduced in Chapter 2. These experiments are not in that chapter's published journal article and focus on the varied histories that characterize the models as well as the emergence of powerful countries. For a full review of the model and how the agents make decisions and interact see Section 2.3 of Chapter 2. The simplified overall process and flow of the model is shown in Figure 18.

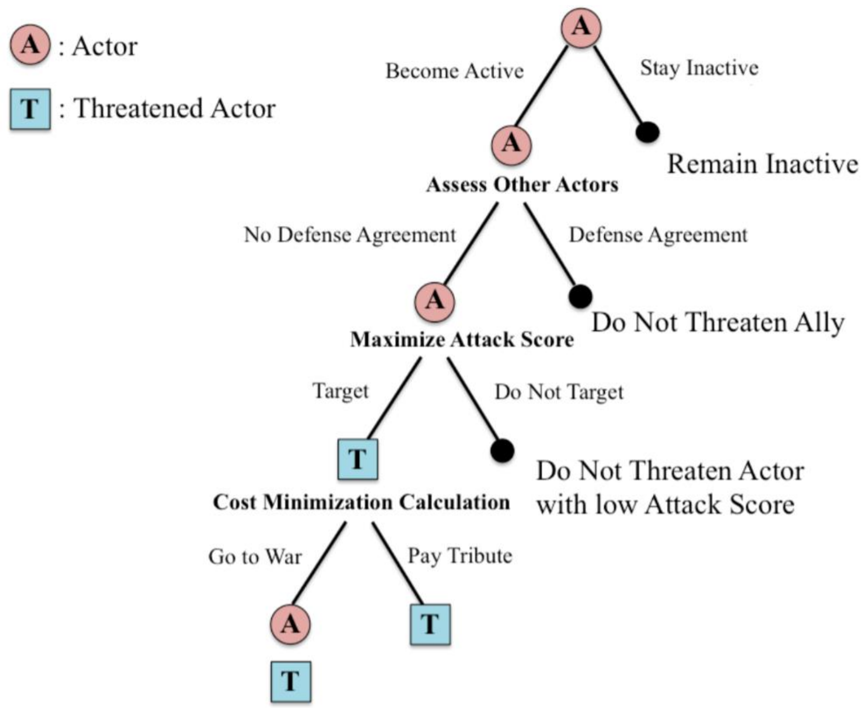

Figure 18: Overview of Global Tribute Model

3.3.1 Experiments and Results

As mentioned in Chapter 2, I run experiments with initial starting networks of the formal defense agreements between countries in the years 1945, 1960, 1980, and 2007. I conduct a sweep of values at low, medium, and high rates of tribute and observe the resulting distributions of wealth. For all parameter combinations, I run 100 trials.

Results of the experiments share many of the same characteristics of the original model. Axelrod (1995) notes that his model exhibits several interesting characteristics, including that things usually do not settle down in the model, the model histories can vary considerably, a networked cluster of countries may contain more than just one powerful country, and the wealth a country is instantiated with at the beginning of the model does not determine success.

Axelrod (1995) notes that things do not settle down in the original tribute model. My result is unique and different. Axelrod found that his model could see devastating wars and other large events long into a model run. A typical run of the Global Tribute model will see an initial period of turbulence in which many wars of varying size are fought. This behavior can continue many years into the run of the model, but after a time a sort of equilibrium will emerge and wealth with only grow at the rate of wealth increase in the model. This difference is because this model takes the existing network as given, alliance strength is not dynamic, and ties are not broken.

My model does comport with the original model in that it generates many varied histories with alternative worlds emerging with some probability. An examination of one run starting in a certain year could tell the story of many different worlds that could have existed. An examination of a period of history in a single run of the model shows the wealth of countries rising and falling. Sometimes a country many enjoy a time where it is left alone and grows at the rate specified in the model. You can observe a country's wealth rise and fall as they demand and pay tribute and as they engage and war. Other runs show devastating wars that will wipe out a large percentage of the world's wealth. Sometimes you see a powerful actor damaged because of their commitment to devote resources to a member of their defense network. Fights can occur between countries that share many allies in common. These are wars that cause damage and could be mitigated or avoided if a powerful country in a strong brokerage position could mediate.

The following figures show the first 100 years of two worlds that emerged from the same initial conditions in the 1960 data. Figure 19 tells the story of a world where the United States and Russia appear to have engaged in a very damaging conflict around tick 40 from which the Russia was never able to recover. The United States was able to come back from the conflict and emerge as dominant.

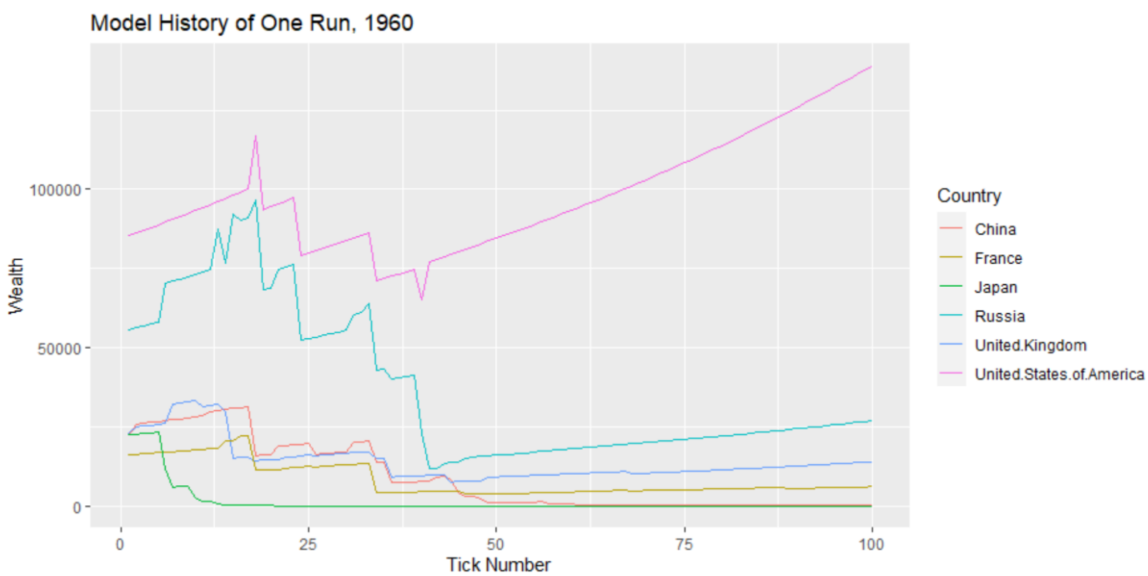

Figure 19: Model History of One Run where the US Emerges as Dominant, 1960

Population two in Figure 20 starts from the same initial conditions but tells a story where the United States experiences several early instances of having wealth destroyed. It is never able to recover and other countries including France and the United Kingdom are able to take over the more dominant positions. In this run Russia clearly emerges as the dominant power.

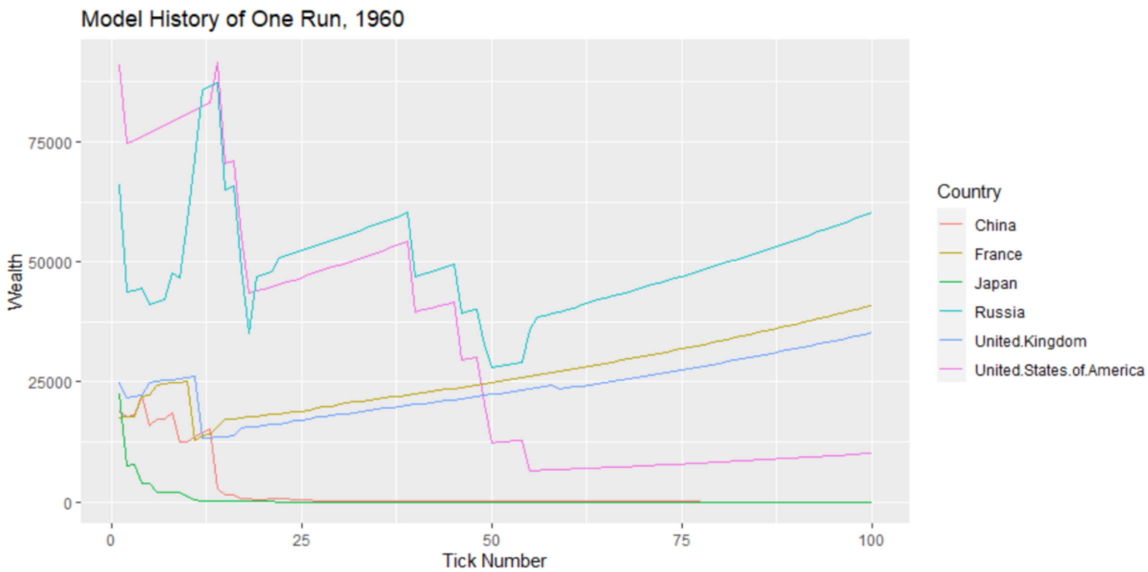

Figure 20: Model History of One Run where Russia Emerges as Dominant, 1960

In order to understand the Global Tribute model we have to understand the distribution of outcomes that emerge from the initial conditions in the various years. In order to do this I count the number of times a country emerges as wealthiest at the end of each run of the simulation across all years analyzed and all tribute levels. The distribution of results that shows which country emerges as dominant, shown in Tables 8 through 11. In the 1945 run (Table 8) the United States always emerges as dominant; initial wealth endowment is the main factor in this outcome.

Table 8: Top Two Powerful Countries at Different Levels of Tribute (1945)

Most Powerful	2nd Most Powerful	Count	Year	Tribute
United States of America	Russia	47	1945	0.25
United States of America	United Kingdom	43	1945	0.25
United States of America	Germany	10	1945	0.25
United States of America	Russia	67	1945	0.5
United States of America	United Kingdom	20	1945	0.5
United States of America	Germany	12	1945	0.5
United States of America	Czechoslovakia	1	1945	0.5
United States of America	Russia	58	1945	0.75
United States of America	Germany	31	1945	0.75
United States of America	United Kingdom	9	1945	0.75
United States of America	France	2	1945	0.75

The experiment results from the 1960 run (Table 9) show much more variability. At each level of tribute the first place outcome in 1960 usually goes to the United States with Russia occasionally getting the top spot. The second place outcome tells a similar story where Russia is most likely to emerge in second place, and a list of other countries have some lower probability of being in second place.

Table 9: Top Two Powerful Countries at Different Levels of Tribute (1960)

Most Powerful	2nd Most Powerful	Count	Year	Tribute
United States of America	Russia	92	1960	0.25
Russia	United States of America	8	1960	0.25
United States of America	German Federal Republic	34	1960	0.5
United States of America	United Kingdom	16	1960	0.5
United States of America	Japan	10	1960	0.5
United States of America	Russia	10	1960	0.5
United States of America	France	7	1960	0.5
United States of America	China	6	1960	0.5
Russia	German Federal Republic	5	1960	0.5
Russia	United Kingdom	4	1960	0.5
German Federal Republic	United States of America	2	1960	0.5
Russia	Japan	2	1960	0.5
China	United States of America	1	1960	0.5
Russia	China	1	1960	0.5
United Kingdom	United States of America	1	1960	0.5
United States of America	Belgium	1	1960	0.5
United States of America	German Federal Republic	58	1960	0.75
United States of America	France	14	1960	0.75
United States of America	United Kingdom	12	1960	0.75
United States of America	Japan	4	1960	0.75
German Federal Republic	United States of America	2	1960	0.75
United States of America	Belgium	2	1960	0.75
United States of America	China	2	1960	0.75
Japan	United States of America	1	1960	0.75
Russia	German Federal Republic	1	1960	0.75
Russia	United Kingdom	1	1960	0.75
United States of America	Italy	1	1960	0.75
United States of America	Luxembourg	1	1960	0.75
United States of America	Russia	1	1960	0.75

Table 10, the 1980 run, sees many different countries vying for the top position including Russia, Japan, the United States, and others. It should be noted that Japan emerges as a powerful actor because of its alliance with the United States. While the

United States is a node of high degree (meaning it has a lot of connections), Japan has only one connection: to the United States.

Table 10: Top Two Powerful Countries at Different Levels of Tribute (1980)

Most Powerful	2nd Most Powerful	Count	Year	Tribute
Russia	Japan	100	1980	0.25
Japan	United States of America	21	1980	0.5
Russia	Japan	16	1980	0.5
Russia	United States of America	14	1980	0.5
China	Russia	10	1980	0.5
Russia	China	7	1980	0.5
United States of America	Japan	7	1980	0.5
Japan	Russia	6	1980	0.5
Russia	German Federal Republic	6	1980	0.5
Japan	German Federal Republic	4	1980	0.5
Japan	China	3	1980	0.5
United States of America	China	2	1980	0.5
Russia	Czechoslovakia	1	1980	0.5
United States of America	German Federal Republic	1	1980	0.5
United States of America	Italy	1	1980	0.5
United States of America	Russia	1	1980	0.5
Japan	United States of America	33	1980	0.75
Japan	Russia	12	1980	0.75
Russia	China	6	1980	0.75
Russia	Japan	6	1980	0.75
Russia	United States of America	5	1980	0.75
Russia	Italy	4	1980	0.75
United States of America	Japan	4	1980	0.75
Russia	German Federal Republic	3	1980	0.75
United States of America	Russia	3	1980	0.75
China	Russia	2	1980	0.75
Russia	Czechoslovakia	2	1980	0.75
Russia	France	2	1980	0.75
Russia	Poland	2	1980	0.75
United States of America	France	2	1980	0.75
United States of America	German Federal Republic	2	1980	0.75
United States of America	Poland	2	1980	0.75
Belgium	United States of America	1	1980	0.75
German Federal Republic	Russia	1	1980	0.75
Japan	Czechoslovakia	1	1980	0.75
Japan	Poland	1	1980	0.75
Russia	Canada	1	1980	0.75
Russia	Romania	1	1980	0.75
United States of America	China	1	1980	0.75
United States of America	Italy	1	1980	0.75
United States of America	Romania	1	1980	0.75
United States of America	United Kingdom	1	1980	0.75

In 2007 (Table 11) every run shows China as emerging as dominant. Like the 1945 run, this is another case where initial endowment does make a large impact of who emerges as dominant.

Table 11: Top Two Powerful Countries at Different Levels of Tribute (2007)

Most Powerful	2nd Most Powerful	Count	Year	Tribute
China	Japan	100	2007	0.25
China	Japan	82	2007	0.5
China	United States of America	12	2007	0.5
China	South Korea	3	2007	0.5
China	Germany	2	2007	0.5
China	Turkey	1	2007	0.5
China	United States of America	45	2007	0.75
China	Germany	20	2007	0.75
China	Japan	14	2007	0.75
China	Turkey	6	2007	0.75
China	Italy	5	2007	0.75
China	Brazil	2	2007	0.75
China	South Korea	2	2007	0.75
China	Canada	1	2007	0.75
China	France	1	2007	0.75
China	Mexico	1	2007	0.75
China	United Kingdom	1	2007	0.75
Russia	Ukraine	1	2007	0.75
South Korea	United States of America	1	2007	0.75

Results of these experiments share many of the same characteristics of the original model Axelrod put forward. Axelrod (1995) notes that model runs show significant variation, and results from my experiments do show significant variation.

Across runs, a dominant player tends to emerge. Two powerful yet opposing players can also emerge, as is the case between Russia and the United States in many runs.

Axelrod (1995) found that his model could see devastating wars and other large events long into a model run. A typical run of the Global Tribute model will see an initial period of turbulence in which many wars of varying size are fought. This behavior can continue many years into the run of the model but after a time a sort of equilibrium will emerge and wealth will only grow at the rate of wealth increase in the model. This result is unique and different from one of the characteristics of the original Axelrod (1995) model where the model never settled down. As noted earlier, this difference is probably because this model takes the existing network as given, alliance strength is not dynamic, and ties are not broken.

3.3.2 Verification and Validation

Verification and validation are important parts of building and testing an agent-based model. Verification refers to making sure the model is coded properly and behaving as it is expected to behave. Validation refers checking whether or not the model actually represents the system you are trying to understand and if the model is able to generate either qualitative or quantitative agreements with things happening in the real world (Gilbert & Troitzsch, 2005). In the absence of data, validation can be done by asking subject matter experts if the model is behaving in a reasonable manner (Xiang et al., 2005).

There are different ways to verify that a model is behaving as expected (Balci, 1998). I used a combination of iterative code review and debugging as well as visual inspection of the model using NetLogo's (Wilensky, 1999) extensive array of visualizations. This visual inspection took the form of many individual runs being started, viewed, and investigated. Things like colors of agents, sizes of agents, and other characteristics were able to be visualized so any unexpected behavior could be identified and corrected in the code. A visual representation of the Global Tribute model, along with the model's interface, is shown in Figure 21. In the interface there is a main visualization pane to display the agents (countries represented as nodes in the graph) as well as the formal defense agreements (represented as links or edges in the network). The different colors represent each country's status as being in an active or targeted state or if it is in another country's defense network when it is attacked. More details can be found in the Netlogo model on my GitHub page (https://github.com/hwalbert/diss_repo). Also shown in the interface is the functionality to change between different years' defense networks and set the various parameters available in the model. Lastly, the interface includes charts that update as the model progresses and shows how levels of wealth change as well as information about the number of wars and tributes. This interface allowed for the visual inspection that verified this model.

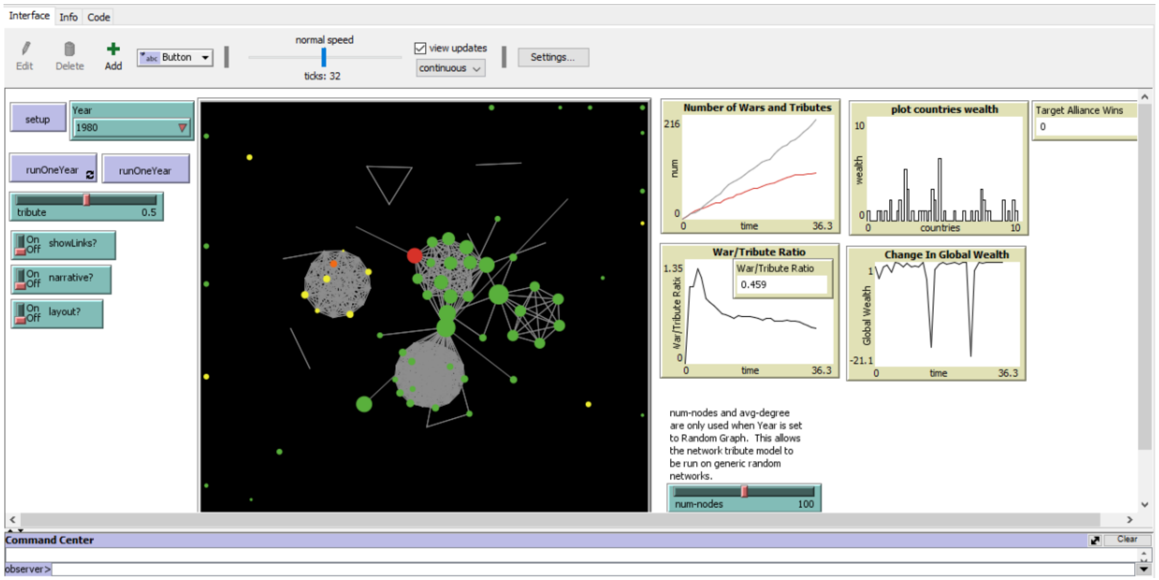

Figure 21: Interface for Global Tribute Model

Validation of a model checks to see if the results and behavior being observed in the model are what we see in the real world. While the Global Tribute model is a toy model, it does take on more realism in terms of empirical data than the Axelrod (1995) tribute model it is based on. Because the model generates many different alternative worlds and world histories, and the agents in the model are associated with actual countries, we can run the model many times as I did in Section 3.3.1 and see the distribution of who emerges as dominant. Even though this model was not designed to predict, it does simulate and report which countries emerge as most powerful, and this feature was used to validate the Global Tribute model. This was done by examining the results shown in Tables 8-11 and determining that the model simulation was returning results that qualitatively agree with what has been observed over the last half century. In the 1945 run, the only country that occupies the top spot is the United States. In the 1960 and 1980 runs the United States often appears at the top spot with some runs suggesting an alternative history with the Soviet Union emerging as most powerful. While it is too early to make a determination about the accuracy of the model runs from 2007, they suggest that China will emerge as dominant under all conditions.

4. CANDIDATE AND VOTER ELECTION BEHAVIOR

This chapter focuses on elections, candidates, and voters. Political discourse often uses words meant to describe some aspect of a person's belief system. Parties, political issues, and ideology are not the same thing. Terms such as Liberal, Conservative, Republican, Democrat, Libertarian, Socialist, Left, Right, Populist, and Nationalist all have a "textbook" definition and an associated intellectual and political history (Noel, 2013). These terms may mean different things to different people, and how people associate with these terms can differ from person to person (Campbell et al., 1960, pp. viii, 573; Converse, 1964/2006). In order to bring about more nuance in discussions about political ideology, the terms above are often combined in order to convey additional or more specific meaning, for example someone might speak about a conservative Democrat vs. a liberal Democrat. Using these terms to describe an individual or a party is an attempt to say something about the basket of positions or political beliefs that the individual or party holds. The very act of combining these terms is an acknowledgement that political ideology is complex, and in order to speak intelligently about a complex topic like politics you must recognize that an individual can hold multiple positions at the same time (Zaller, 1992). Because this is a complex system with agents of different types interacting within an environment, it is an attractive focus for agent-based modeling (Qiu & Phang, 2020; Gilbert & Troitzsch, 2005).

4.1 Introduction and Literature Review

In an electoral process there are essentially two main parts: People are deciding whether or not they are going to vote, and if they vote they are deciding who will receive their vote. This is a two-part process where before the voters actually vote they have to make a decision about whether it is even worth their time to do so. Candidates desire votes and have the ability to take political positions that potential voters may find appealing. Candidates may also update their political positions during a campaign in an attempt to gain more support. I construct an agent-based model under the assumption that electoral preferences of individual voters change over the course of a campaign as preferences are formed and updated as new information becomes available (Holbrook et al., 2001).

Hotelling (1929) put forth the idea of "minimum differentiation," which simply means that many times it is rational for two producers of some good to make that good similar in order to maximize some return (i.e., share of the market, votes). He makes the argument using businesses on a straight path—both of which will alter not only their prices but their location along the path to attract more customers. The businesses will lower their prices and begin to converge on the one-dimensional plane in an effort to seem more appealing to customers (Hotelling, 1929). The Hotelling model shows that there is a natural tendency to converge towards the middle. Almost 20 years later, Black (1948) refines and formalizes the behavior Hotelling noted in political stances and majority voting into the median voter theorem, which says that (given a set of assumptions, one of which being that possible opinions are distributed along a continuum) the election outcome will be determined by the preference of the median voter. The median voter is the voter who has the determining vote.

The Downs paradox (1957), also referred to as the paradox of not voting, states that a rational, self-interested voter will not vote if the cost of voting is greater than the expected benefit. Since the probability that the voter gets into a car crash on the way to the voting poll is higher than the probability that the voter will cast the deciding vote, the voter will most likely not vote since the cost of voting will be greater than the benefit (Downs, 1957; Feddersen, 2004). However, that is not the behavior that is exhibited. Voters will go through inclement weather, overcome the distance to the voting poll, wait in long lines, spend time pondering about whom to vote for—all of which are factors in the cost of voting—to go vote. "This finding suggests that voters participate because they hope to influence the ultimate outcome of the election" (Feddersen, 2004, p. 100).

The variations of what we deem as “left” or “right” can be generalized, but cannot be used as a blanket statement to describe groups of people in specific countries. A group of people in a certain context cannot always be brought out of their situation and generalized using incomplete knowledge. Certain patterns may arise and correlate themselves with policies, but that must be done on a case-by-case basis. Benoit and Laver (2006) state that policy can be a good tool in trying to categorize a current regime’s Left-Rightness on a spectrum. A third dimension capturing a local policy dimension may help explain what socioeconomic policies alone cannot.

Laver and Sergenti (2012) argued that up to three independent policy dimensions can be sufficient to capture most of the important information. They use Voronoi tessellation (a Voronoi diagram) to describe areas and geometric problems of Competitive Spatial Location (changing positions as a means of reaching objectives while using information to make decisions about where to move). Spatial models based on describing politics as leaning towards the left or the right, as well as other dimensions, are the basis for this research about political competition (Laver & Sergenti, 2012).

Laver and Sergenti (2012) examined politics as a dynamic process and laid out much of the basis for the model I present in this Chapter.

> It evolves. It never stops; It is never at, nor en route to, some static equilibrium. Politics evolves. Politics is complex. Political outputs today feedback as input to the political process tomorrow…. Politicians are diverse. In particular, different politicians attack the same problem in different ways…. Politics is not random. Systematic patterns in political outcomes invite systemic predictions, making a political science possible. (Laver & Sergenti, 2012, p. 23)

In this chapter, I focus on and examine multi-party competition between two parties. According to Laver and Sergenti (2012) the birth and death of political parties are endogenous to their model. Party leaders can be comfortable or uncomfortable and there can be different survivor thresholds. Punishment and rewards are administered by voters while the simulation runs or "ticks." There are two types of ticks. During campaign ticks, politicians make decisions about party policy to respond to new information (i.e., polls). For election ticks, voters make decisions about whom to vote for. Therefore, parties may die and new parties may be born.

Laver and Sergenti's (2012) model assumes that voters' preferences are characterized by an ideal policy position in an n-dimensional policy space. This describes how different policy positions differ from the voters' ideal points. The distances between policy positions are Euclidian. A crucial factor of the model is a description of the distribution of voters' ideal points. For policy dimensions of interest, they assume the overall population are normally distributed because an n-dimensional Euclidean real space extends to infinity in all directions. Real voters are not thought of to have infinitely extreme ideal policy points. However, the normal distribution assumption is an important restriction on possible distributions of voters' ideal points.

The main objectives of this chapter are to further the conversation about party competition from both the voter and candidate perspectives as well as understand distributions of voter preferences that may not follow normal distributions and may be scattered over multiple dimensions. Additionally, this chapter will allow the political spectrum to be more complex than the usual one or two-dimensional (2D) spectrums that are seen in the literature (Laver & Sergenti, 2012). Current research has targeted 2D applications of the Hotelling model to determine optimal locations and prices as well as analyze the outcomes of the two-dimensional competitive model (Larralde et al., 2006; Veendorp & Majeed, 1995).

Using empirical data on party classifications by country and applying principal components analysis (a method to reduce the dimensionality of datasets), I extract three axes on the political spectrum which will give voters a 3D environment in which to choose their preferred candidate. It will also give candidates the space in which to operate in order to seek and capture votes.

4.2 Data Analysis and Visualization

I start by asking: Can you model voting agents where these agents may take into account up to three dimensions of political ideology? Furthermore, can we give these agents an empirical basis for this distribution? An agent-based model is ideal for looking at questions where the interactions of individual, unique decision makers effect the macro-level emergent outcome. It allows simulations of interactions of autonomous individuals (the voters and candidates) in an environment, in order to determine the overall outcome. I do this by using Swank's (2018) Comparative Political Parties dataset, which includes country- and year-level detail with information on whether it was an election year, along with variables for political classifications (Castles & Mair, 1984). The dataset has 28 variables giving vote/seat/cabinet portfolio percentages for the following political classifications: Left, Right, Christian Democratic, Centrist Christian Democratic, Center Party, Right Wing Populist, and Left Libertarian. After incomplete observations are removed there are 1,310 observations left for the years 1950 to 2015 for 21 countries.

The data were transformed into a dissimilarity matrix using the method described by Gower (1971). Since the dataset contains multiple classes, a method was needed that allowed distance calculation across multiple classes. Once this matrix was calculated, a Principal Components Analysis (PCA) was used to reduce the dimensionality of the original transformed dataset. The first three components of the PCA explain approximately 80% of the variance. Adding two more components only gets us up to 90% (Table 12).

Table 12: Principal Components Summary Statistics

Principal Components Summary Statistics

	PC1	PC2	PC3	PC4	PC5	PC6
Standard deviation	24.76110	16.14976	12.78263	9.304406	7.912309	6.565529
Proportion of Variance	0.46802	0.19910	0.12473	0.066090	0.047790	0.032910
Cumulative Proportion	0.46802	0.66712	0.79185	0.857930	0.905720	0.938630

I use the rotations of the first three principal components as the first three dimensions of political ideology for the rest of the analysis and modeling in this chapter. Figure 22 shows the distributions of all three dimensions along with their correlations.

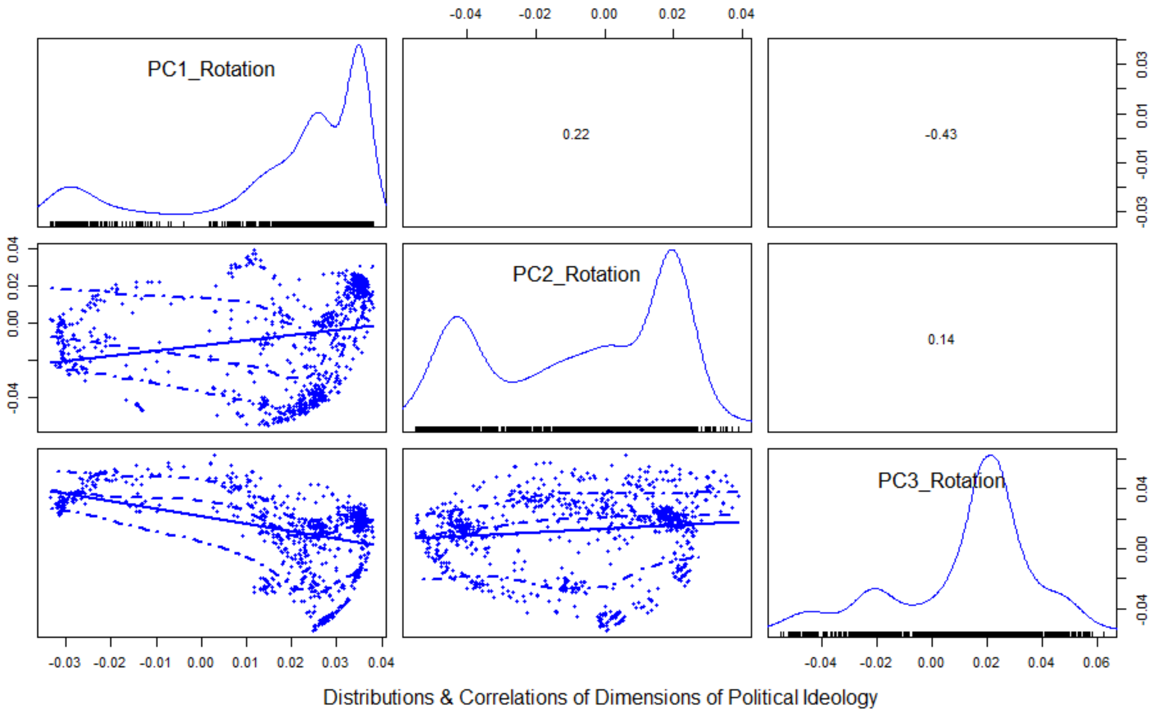

Figure 22: Distributions and Correlations of Dimensions of Political Ideology

The resulting empirical distributions cannot be described as appearing to follow a normal distribution. Principal Component 2 appears to be distributed in a bi-modal way. Plotting these dimensions can show us how the different distributions are related. Adding a third dimension to the visualizations adds to the way we understand how ideology is distributed. Figures 23 and 24 show how three dimensions of ideology might look when represented in 3D.

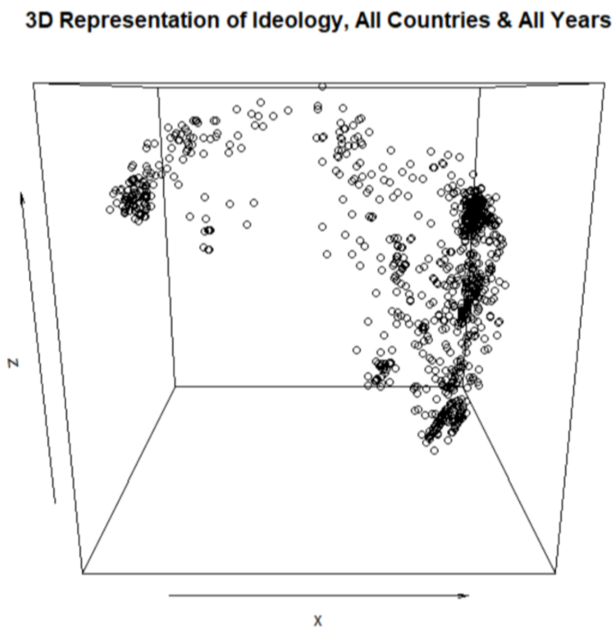

Figure 23: Front View of 3D Ideology Space

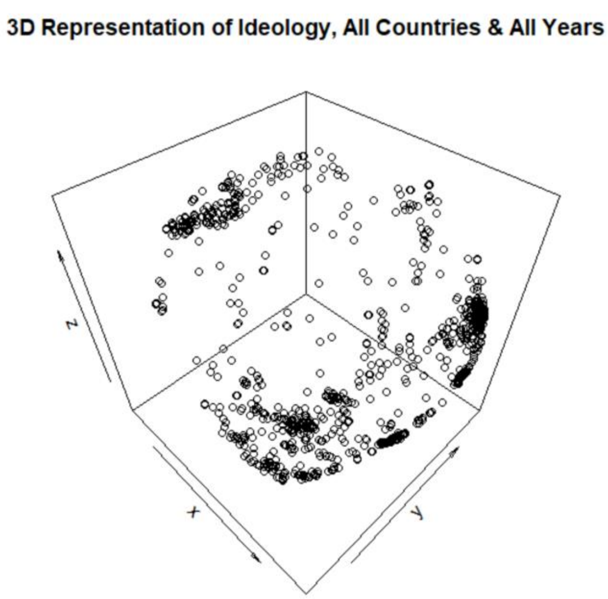

Figure 24: Side View of 3D Ideology Space

4.3 An Agent-Based Model of Candidates and Voters in a 3D Environment

In this chapter I model an electoral process where voters choose candidates based on the voters' self-interest. I use an agent-based model constructed using three dimensions of empirical distributions of ideology derived from the data discussed in Section 4.2. Over the course of a campaign, voters update their preference for a candidate based on a combination of information including their unique position in their social network (see Stiles et al. (2020) for an example of voters influencing other voters based on their network connections) and their unique position in the 3D political ideology space relative to candidates. Although voters can influence other voters' perceptions of the likelihood that their preferred candidate will win because of the network in which the agents are situated, the voters' decisions are also contingent on the cost-benefit analysis they perform. In addition, candidates are able to respond to the "polls" they take of voters and are able to make known updated "policy positions" in an effort to find more voters.

Even though my approach takes a network structure as a given parameter of the model, it still allows the voters to make decisions independently based on the location of the voter in 3D space (relative to the candidates), their cost of voting, and the private benefit they get from voting. The spatial voting model presented in Section 4.1 assumes independence of the voters and their decisions, and my approach confronts this assumption by explicitly modeling the dependent nature of agents' prior relationships using a network. The voters' connections with other voters do influence the voters' decision to vote by factoring in the voters' calculated subjective probability that their preferred candidate will win. This will be discussed more in the following section.

4.3.1 Description of Model

To begin, the Voter and Election model starts by instantiating voting agents within a network and instantiating candidate agents at random starting positions. The interface with which this is done can be seen in Figure 25. Each node (or vertex) in the network represents a different voter or candidate and each link represents a relationship between that voter and another voter in the model. The network imported and used in the model is generated according to a random, scale-free or small world distribution. The nodes representing voters are instantiated with political ideology coordinates drawn according to the empirical data described in the previous section. There are two candidate agents that start out at random starting political ideology coordinates (Figure 26).

When the simulation begins running each candidate will take a poll of the voters. Each of their polls is different and unique to the candidate. The candidates divide these polled voters into two groups: voters who support them and voters who do not support them. The candidates can discount the opinions (political coordinates) of the voters who do not support them. This discount parameter is set by the modeler and will be the subject of parameter sweeps and experiments in the next section (4.3.2). After polling the voters and discounting the options of certain voters, the candidate arrives at the position in the political spectrum space that they want to move toward. After the poll the candidates change their heading, pitch, and roll to be oriented to the mean positions on each of the three dimensions for the voters they care about. They move forward toward this position.

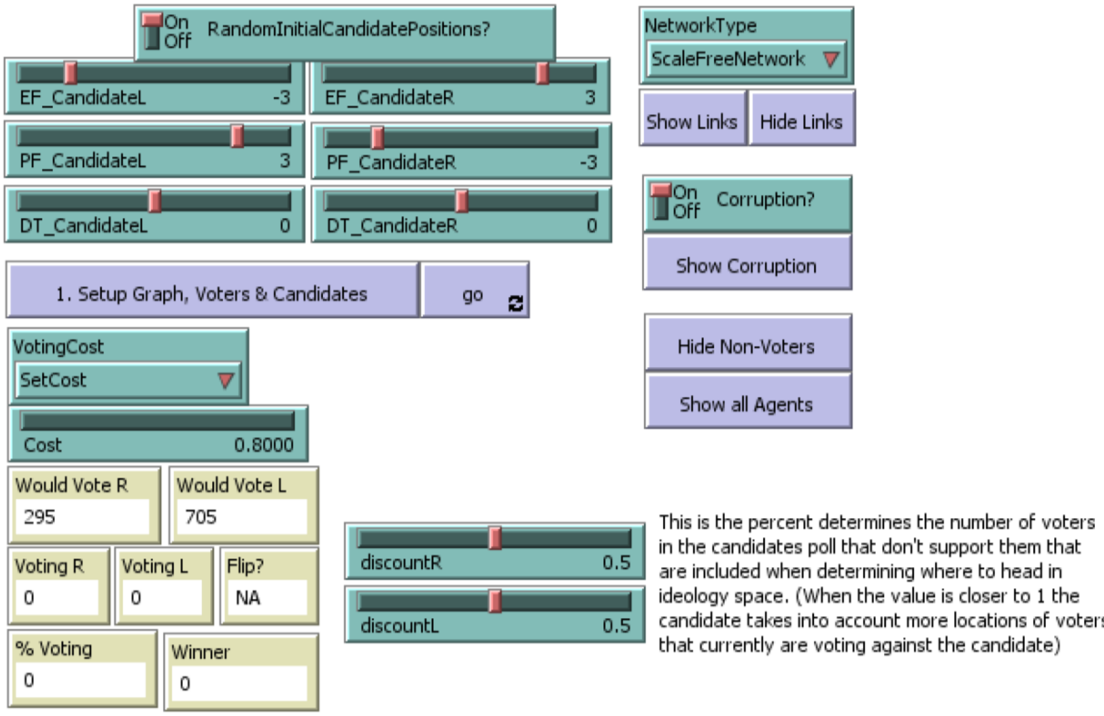

Figure 25: Candidates and Voters Model Interface

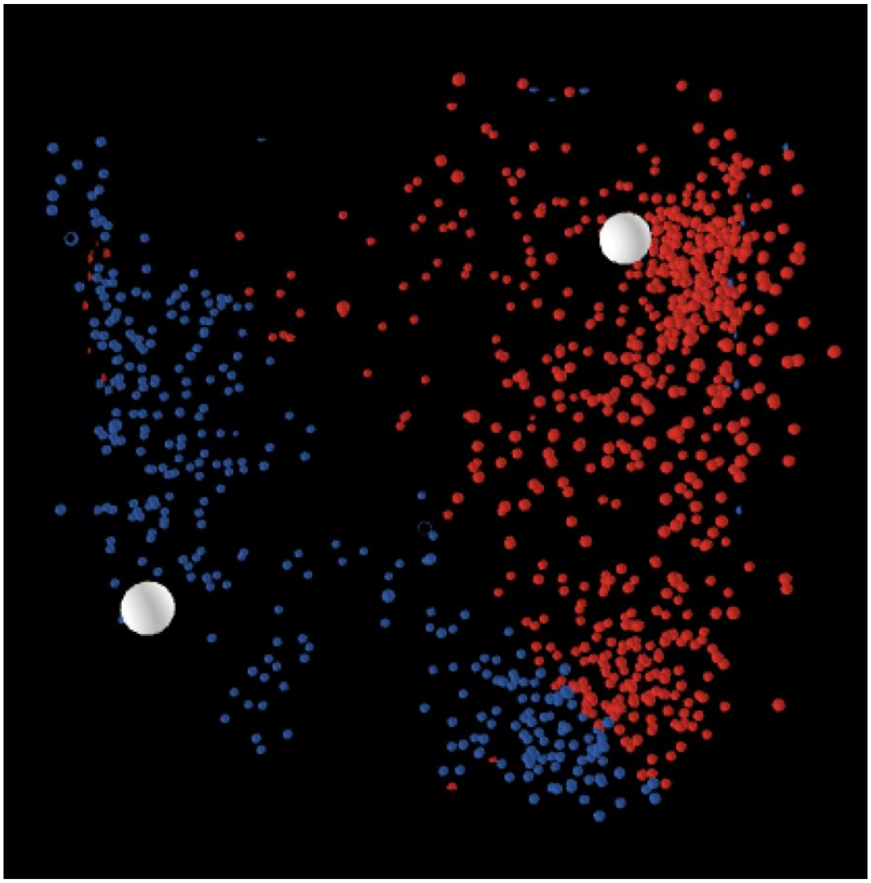

Figure 26: Example of Initial Conditions of Model

After the candidates have polled voters and moved to their new positions, the voters then have to make a decision about whom they would vote for and if they should vote at all. There are five variables that each voter agent must calculate. Three of the variables (P, B, and F) are calculated and updated as the simulation is run. The other two variables (C and D) are set at the beginning of the simulation and stay the same for the duration of the simulation. Each tick of the model sees candidates move first and then voters respond second to the updated positions of the candidates. The simplified process that occurs during each tick of the model is laid out in Figure 27.

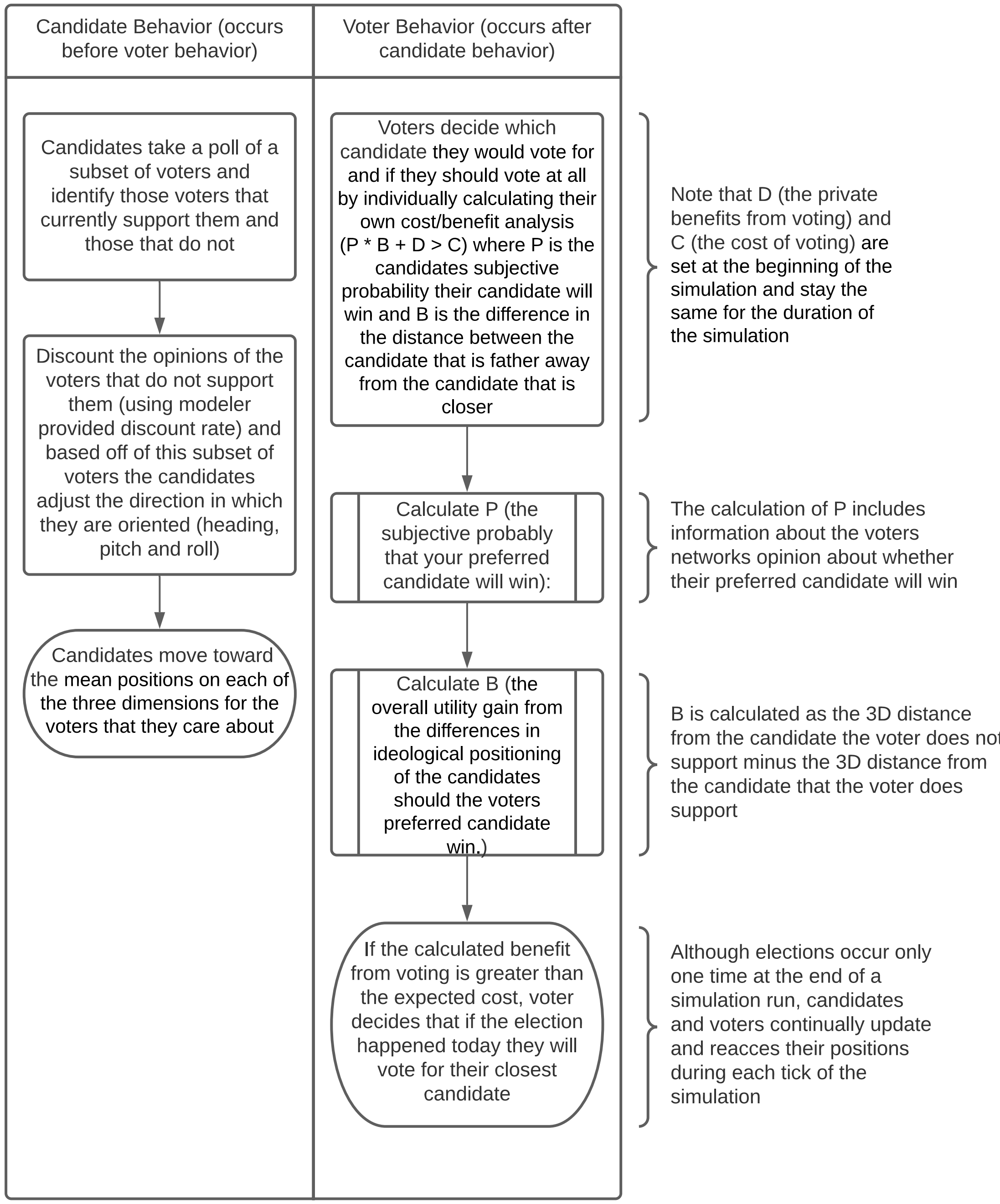

Figure 27: Candidate and Voters Model Flow

Equations describing the rational voter hypothesis were presented by Mueller (1989) and later by Stevens (1993). The core equations used to determine if an agent votes or not are shown in Equation 3 and Equation 4:

Equation 3: Voting Decision Equation

$$P * B + D > C$$

where P is the subjective probability that one's vote will make a difference in the outcome, B is the difference between the distance between the agent that is not my candidate and the agent that is my candidate, D is the private benefits from the act of voting, and C is the cost of voting. P itself is mathematically defined as:

Equation 4: Subjective Probability That One's Vote Will Change Outcome

$$P = \frac{3e^{-2(N-1)(F-0.5)^2}}{2\sqrt{2\pi(N-1)}} \text{ where } F = avg(B) \text{ of inlinks}$$

and represents the agent's individual belief that his or her preferred candidate will win. Simply, the variable P is each voter's subjective probability that his or her vote will make a difference in the outcome.

N is the number of voters participating in an election. As N increases the law of large numbers tends to apply, and we will see P approach one half. The law of large numbers necessitates such an outcome should occur, assuming an underlying Gaussian distribution. F is calculated using each voter's individual network. There are two types of voters in the network: voters who support the same candidate they support and voters who do not. F is a fraction where the numerator is the number of voters in their network who support their candidate multiplied by that voter's B value (how much they would benefit if their candidate wins). The denominator is the number of voters in their network who do not support their candidate multiplied by that voter's B value. If the voter does not have a network large or diverse enough to support this type of analysis, F is set to a random normal centered on 0.5.

B is the overall gain from the differences in ideological positioning in terms of utility. In graphical terms, it is the difference between the preferred candidate to the voter subtracted from the distance of the non-preferred candidate to the voter, or the difference between the 3D distance between the agent who is not my candidate and the agent who is my candidate. This difference between the policy positions relative to the voter's position is the utility the voter gets from voting and is the overall utility gain from the differences in ideological positioning of the candidates should the voter's preferred candidate win. B is the benefit from a difference in policy positions between the candidates. This value is calculated as the 3D distance from the candidate the voter does not support minus the 3D distance from the candidate the voter does support.

D is the private benefit of the actual act of voting, which could be defined as a subsidy, favorable legislation, pride in fulfilling civic duties, other private benefits, or a benefit from outright corruption in the government and election system. The act of voting may result in a positive value D, which is not necessarily tied to any legislation that gets passed (it just has to be perceived as beneficial), or it may help avoid a negative value D, which may be the feeling of guilt if one does not vote. For the experiments I assume a low level of corruption that is distributed according to an exponential distribution (Figure 28). This makes a world where most agents have a very low level of private benefits but some voters have large benefits should their candidate win. The minimum value D can take is 1, which is the default if there is no corruption in the model.

Lastly, C is defined as the costs of voting. Costs could include anything from typical costs accrued in travelling to a voting booth to opportunity costs incurred due to loss of the chance to partake in all other substitute options. When the probability of the preferred candidate winning by the utility a voter gains in picking a candidate is greater than the costs of voting less his or her personal gains from voting, the agent votes. If cost is not set to 0 then it is distributed according to a normal distribution and is constrained to be greater than or equal to 0.

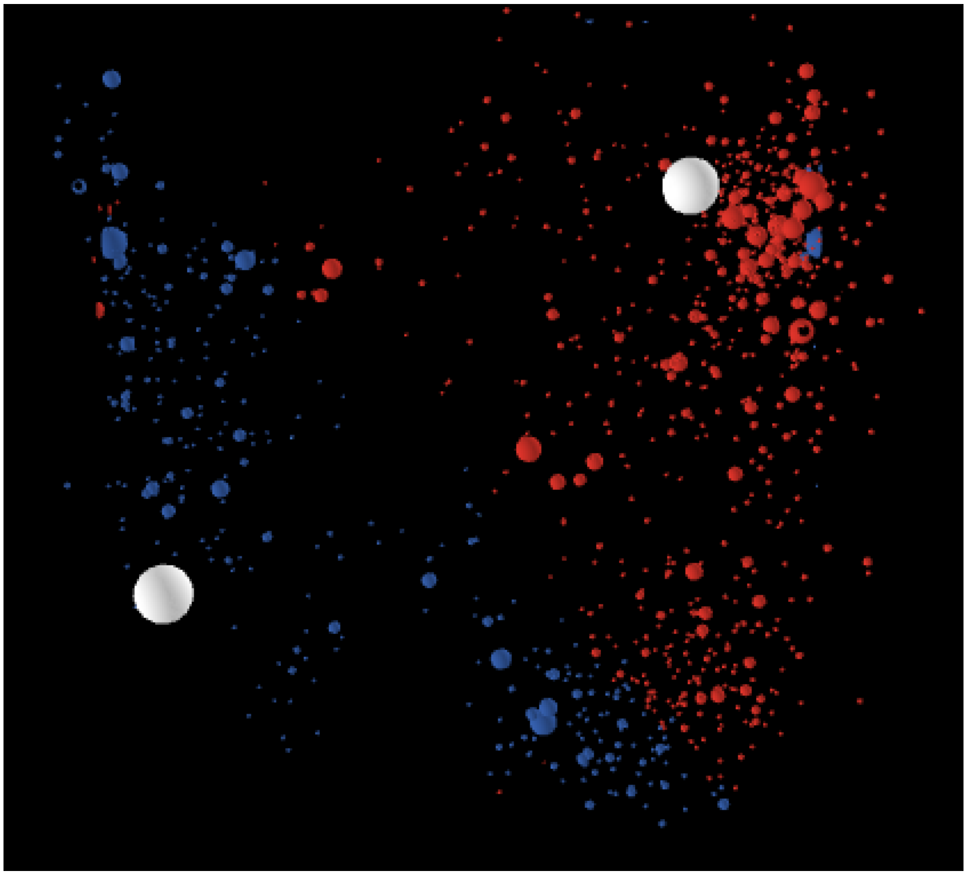

Figure 28: Example of Initial Conditions of Model with Voter Size Set to Show Corruption

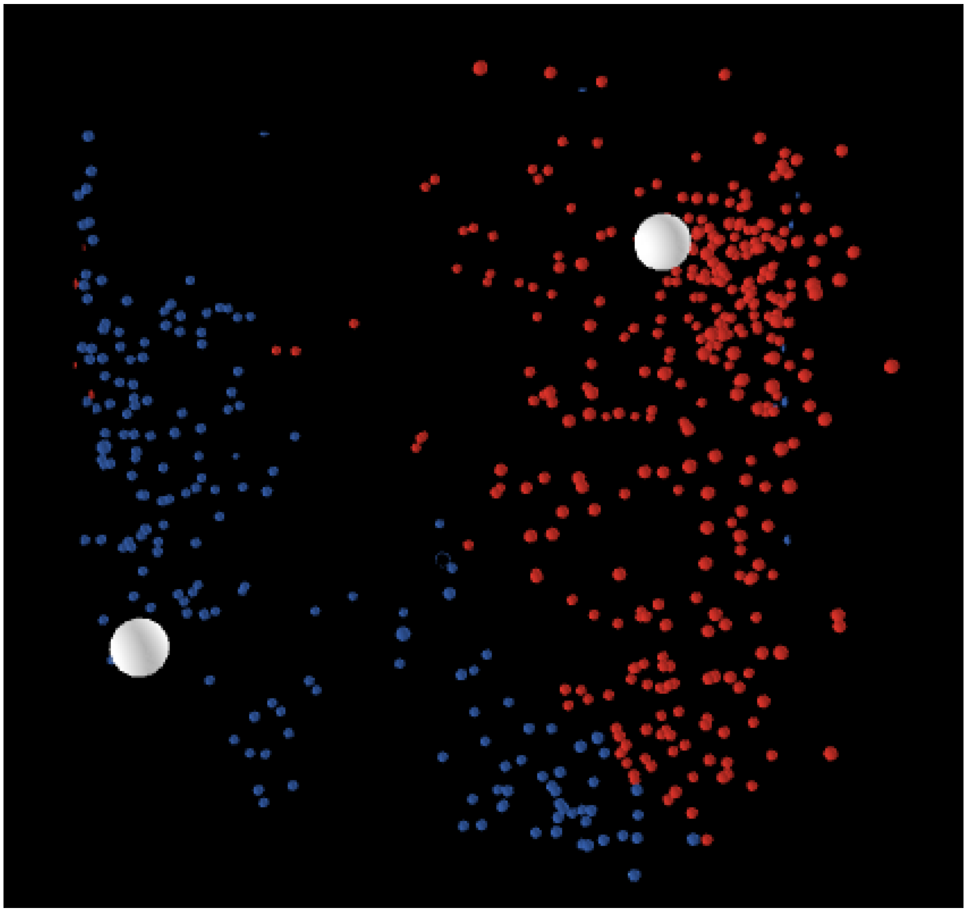
Figure 29: Example of Initial Conditions of Model with Not-Participating Voters Removed

When the expected value of the private benefits a voter would receive should his or her candidate win plus any unique benefits is greater than the cost of voting (i.e., when P×B+D>C), the voter will choose to vote should the election occur at that time. When the probability of the preferred candidate winning by the utility a voter gains in picking a candidate is greater than the costs of voting less his or her personal gains from voting, the agent votes. If this does not hold then the agent should not rationally vote. This is the Rational Voter Hypothesis from Downs (1957). Figure 29 shows an example of initial conditions in the model where only voters that are choosing to vote are shown and the voters that have chosen to not vote are removed from the visualization.

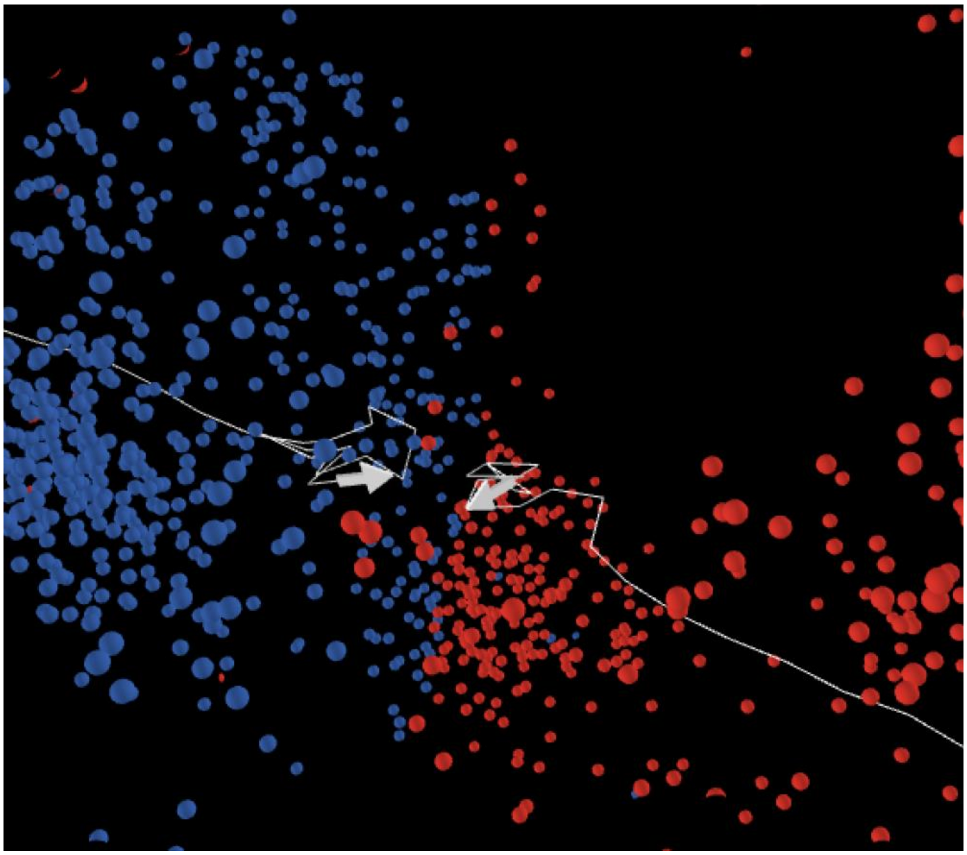

Figure 30: Candidates Searching for Votes in 3D Ideology Space

This change in position is noticed by the voting agents and they recalculate their variables for B, F, and P. They are able to change the candidate they support as well as decide if they even want to vote or not (were the election to occur at that moment). This movement of the candidates and the resulting change in the voters' decisions account for a one-time step. During a campaign there can be many instances where candidates can make updated positions known (i.e., debates or major policy speeches) (Figure 30). The length of election seasons varies across countries. This model is run for 20 periods that represent 20 opportunities for candidates to update their positions and for voters to respond (Laver & Sergenti, 2012). At the end of the simulation the winning candidate is the one who has the larger number of votes. If cost variable is turned off in the model, the voter turnout will be 100%. If the cost variable is on, voter turnout will vary depending on the level of the cost. This results in different voter participation rates and we would expect lower voter participation as the cost of voting increases.

4.3.2 Experiments

These model experiments focus on the discount parameter which is unique to each candidate. A sweep of discounts was done to compare the outcomes for a candidate who throws out the opinions of those voters that do not currently support him or her versus the outcomes for a candidate who values the opinions of those voters. Understanding how this discount changes outcomes in the model is in line with the work of Laver and Sergenti (2012) where they describe outcomes associated with different candidate strategies, categorized such as “Sticker,” “Hunter,” or “Aggregator,” where the sticker never changes his or her policy position, the aggregator tries to get closer to his or her own supporters, and the hunter looks for new votes.

Each change in the parameter sweep for these experiments was run 100 times and done across all three network types. The overall patterns are the same for all network types. To compare strategies, one candidate always stays at a value of 0.5 for his or her discount. This means that they throw out half of the voters in their polls who do not currently support them. The other candidate sweeps the discount parameter from 0.1 to 0.9 by 0.1 increments (Table 13).

Table 13: Number/Percent Each Candidate Won by Network Type – All Runs

Number/Percent of Times Each Candidate Won by Network Type (All Runs Included)

NetworkType	CandidateL	CandidateR
RandomNetwork	34.1% (395)	32.7% (505)
ScaleFreeNetwork	33.2% (384)	33.4% (516)
SmallWorldNetwork	32.7% (378)	33.8% (522)

When compared to candidateR with a static discount value of 0.5, when the network is Scale Free and candidateL has a discount of 0.2, they are seen to win 20% of the time. When candidateL has a discount of 0.8 they win 65% of the time (Table 14).

Table 14: Winner of Election Parameter Sweep - Scale Free Network

Winner of Election Parameter Sweep - Scale Free Network

discountL	CandidateL	CandidateR
0.1	3%	97%
0.2	20%	80%
0.3	30%	70%
0.4	37%	63%
0.5	43%	57%
0.6	49%	51%
0.7	66%	34%
0.8	65%	35%
0.9	71%	29%

When compared to candidateR with a static discount value of 0.5, when the network is Random and candidateL has a discount of 0.2, they are seen to win 17% of the time. When candidateL has a discount of 0.8 they win 68% of the time (Table 15).

Table 15: Winner of Election Parameter Sweep - Random Network

Winner of Election Parameter Sweep - Random Network

discountL	CandidateL	CandidateR
0.1	12%	88%
0.2	17%	83%
0.3	27%	73%
0.4	45%	55%
0.5	54%	46%
0.6	55%	45%
0.7	60%	40%
0.8	68%	32%
0.9	57%	43%

When compared to candidateR with a static discount value of 0.5, when the network is Small World and candidateL has a discount of 0.2, they are seen to win 13% of the time. When candidateL has a discount of 0.8 they win 70% of the time (Table 16).

Table 16: Winner of Election Parameter Sweep - Small World Network

Winner of Election Parameter Sweep - Small World Network

discountL	CandidateL	CandidateR
0.1	3%	97%
0.2	13%	87%
0.3	26%	74%
0.4	38%	62%
0.5	48%	52%
0.6	58%	42%
0.7	62%	38%
0.8	70%	30%
0.9	60%	40%

For all network types, the strategy of the candidate valuing those voters who do not currently support him or her is a better strategy for winning.

4.3.3 Verification and Validation

As discussed in Section 3.3.2, verification is the process of making sure the model is coded correctly and that it is working as intended, while validation is the process of comparing model outcomes against some real-world or other objective standard to see if the model is generating any qualitative or quantitative agreement (Gilbert & Troitzsch, 2005). In the absence of data, validation can be done by asking subject matter experts if the model is behaving in a reasonable manner (Xiang et al., 2005); this is the approach I take to validate the voter and election model.

As with the Global Tribute model from Chapters 2 and 3, verification of this model was done by using a combination of iterative code review and debugging, as well as visual inspection of the model using NetLogo’s customizable visualizations. This took the form of many individual runs being started, viewed, and investigated. Things like colors or agents, sizes of agents, and other characteristics were able to be visualized so any unexpected behavior could be identified and corrected in the code. The visual representation of the model along with the model interface is shown in Figure 31.

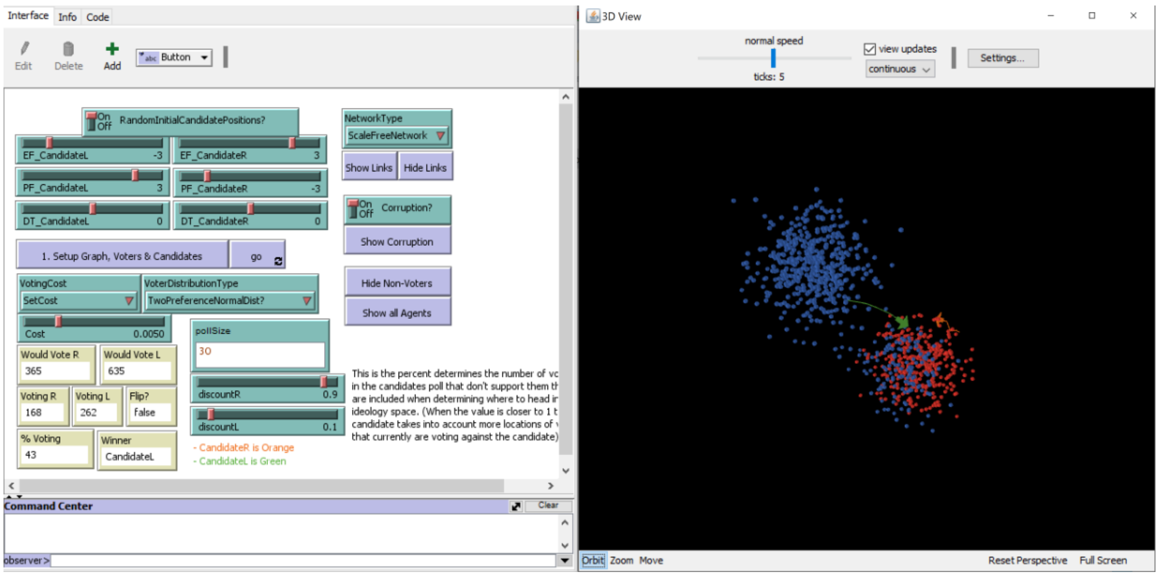

Figure 31: Interface for 3D Voter and Election Model

Validation checks whether the results and behavior being observed in the model are what we see in the real world. Although this model extends existing ideas and incorporates more information and decision-making rules, it is still a basic model that fails to take into account all the complexities that exist in a real-world election. This model is not designed to predict. However, because this model builds on the work of Laver and Sergenti (2012) I used outcomes from their work to compare behavior observed in my model. The voting model presents challenges with validation. Because of how abstract it is, it does not have data that can be compared to the results from the model. I approach this validation in a different way, then, by comparing the observed behavior of the model (visual inspection) to the behavior of the 2D model from Laver and Sergenti (2012). The movement of the agents does appear similar, although my model takes place in a 3D space as opposed to the 2D space of their model.

Laver and Sergenti (2012) note that:

> Scholars in the classical formal modeling tradition have used many different assumptions to account for the commonplace empirical observation that vote-seeking political parties in real party systems *do not* tend to engage in "Downsian" convergence on the ideological center ground. Our ABM of dynamic multiparty competition, in contrast, shows us that observed nonconvergence of vote-seeking parties is indeed to be expected with multiparty competition in multidimensional policy spaces. No special assumption is needed to generate a model of party competition in which vote-seeking party leaders have a strong tendency to avoid the dead center of the policy space. Center avoidance by vote-seeking parties *arises directly from the Voronoi dynamics of competitive location in multidimensional policy spaces*. This substantively important intuition flows directly from our dynamic ABM of multiparty competition. (p. 95; emphasis in original)

This observation is also realized in the multidimensional empirically derived 3D space that characterizes my model. Figure 32 shows a case where both candidates have a low discount rate (meaning they do not take into account many of the voters in their poll who do not currently support them) and we see their history of moving through 3D space. Both of the candidates do not converge on the dead center of one position, but move around locally identified areas that solidify the base of support they already enjoy.

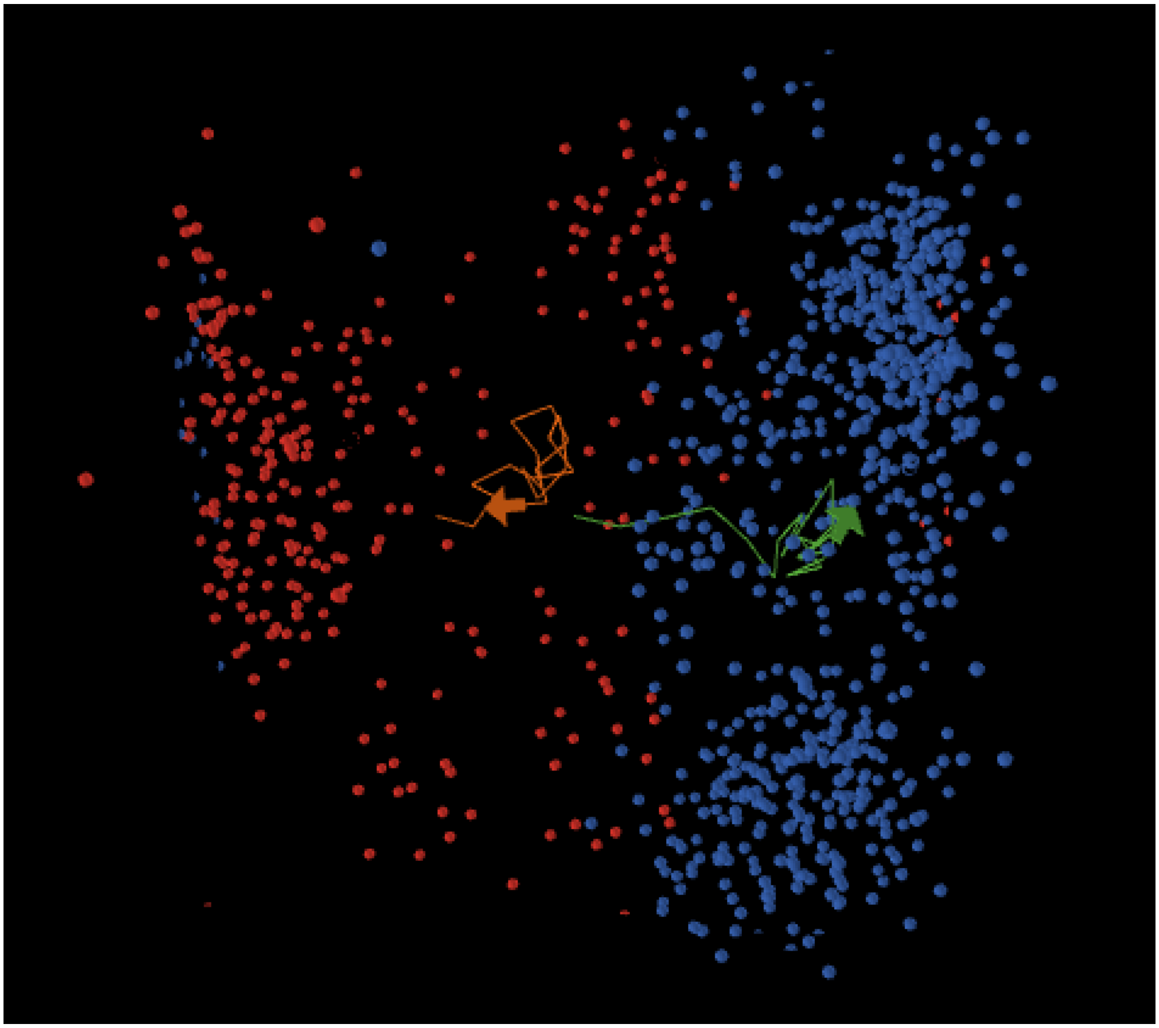

Figure 32: Two Candidates with Low Discount Rates in 3D Space

One additional validation of the model can be done by looking at the voter turnout that occurs in the model. A voter will only vote if the expected benefit is greater than the cost of voting (this can be seen graphically in Figure 29 where certain voters are removed from the visualization because the cost of voting is greater than their expected benefits), and as the costs of voting get larger we should expect a lower voter participation rate (Downs, 1957). Costs could take the form of many things including the time it takes to get to the polls, forgone wages from time not worked, or administrative and procedural barriers to voting. In my model costs are an exogenous parameter of the model that is controlled by the modeler. Table 17 shows the voter participation rate reported for different levels of the cost of voting. Unsurprisingly, this table shows larger voter turnout when costs are lower and smaller voter turnout as the cost of voting gets higher. This result should not be surprising given the setup of the model, but it does highlight that the model is behaving as expected and the directionality of the changes agrees with what we would expect in the real world.

Table 17: Voter Participation Rate at Different Costs of Voting

Cost of Voting	Voter Participation Rate
0.001	50.77
0.003	43.79
0.005	36.73
0.007	30.26
0.009	24.86
0.01	22.25
0.1	0.57
0.3	0.05
0.6	0.01

5. CONCLUSION

This dissertation began with a discussion of why a computational approach that integrates agent-based modeling with empirical data to understand complex social issues like a decision to go to war or whom to vote for was a good idea. It reviewed the models I extended and enhanced as well as other research in these areas. In Chapter 2 I presented an agent-based model that examines the ramifications of formal defense agreements between countries and builds on previous work to create an empirically based version of a tribute model, the Global Tribute model, in which actors within existing real-world networks demand tribute from one another. Chapter 3 expanded further on this model and explored the various histories that the model generates based on different initial conditions. In Chapter 4 I switched focus from inter-country dynamics to intra-country dynamics to look at candidates and voters in a simulated election where candidates move in a multidimensional space trying to find votes and voters make a decision about whom to vote for and whether or not to vote at all based on their unique position in 3D space as well as their unique social network. This chapter introduces a 3D spatial model of voting, the Voter and Election model, and also reviews other research around voting and how voters make decisions.

The main contribution of this dissertation is to show a useful methodological approach to learn and understand how systems with many interdependencies work and how abstracting these systems and focusing on their constituent components can help to understand systems' outcomes and emergent properties. It has shown how taking a computational approach that allows for a more complex treatment of these issues using simulation and agent-based modeling can enable a researcher to more fully show the processes that lead to emergent outcomes in complex systems. This dissertation has used tools from Computational Social Science (specifically agent-based modeling) to simulate two processes: a country's decision to go to war and an election process. These models are different and focus on different areas in political science and international relations, but they are both examples of complex systems. Research around these subjects is far from over and there is no doubt that more discoveries will be made as scholars apply more ideas and methods from complexity theory and Computational Social Science.

5.1 Future Work

5.1.1 Extensions to Global Tribute Model

In Chapter 3, on International Networks and Dynamics, I have provided a general model of international conflict and negotiation that builds upon previous models. It is not a predictive model in the sense that it accurately predicts future alliances and levels of wealth in each country, but it does provide qualitative agreement with historical outcomes over time. The simulation shows that network structure matters for how countries can expand and interact with one another; it also shows many diverse potential histories if the world were a little different. This model could be enhanced to include important information such as the type of government a country has, which is important for understanding a country's decision to go to war. Including information about polity and how authoritarian or democratic a country is could provide an even richer data environment in which to model country-to-country interactions.

Additionally, other types of networks could provide a useful decision space to enhance country-level decision making. Trade, nonaggression, and neutrality agreements should in theory have some bearing on a country's decision to go to war: Future research could factor this into the equation when constructing new models. Essentially, there is potential to include a more in-depth network-based theory of alliance formation that relies on a more expansive data environment for the country-agents to use in decision making in the style of Cranmer et al. (2012).

Other extensions for future work could include adding a focus on the role of power and geography in world politics. The model could be expanded by adding geographical components to the decisions the agents make regarding whether or not to go to war (i.e., small countries on opposite sides of the world may be less likely to go to war with each other than their physically closer neighbor countries).

Networks and structure also exist within a nation-state (elections, for example). This model does not consider such structure; however, in future work these structures could be simulated using voting models and other complex simulations of decision-making within government to connect domestic institutions and decision making with alliance formation. This work would be in the tradition of research done by Cederman (1997), Cederman (2001), and Cederman and Gleditsch (2004).

The current Global Tribute Model uses iron and steel production as a proxy for wealth in its instantiation of a country's attributes. This proxy, while useful, is imperfect and identifying alternative measures of a country's power or wealth which could provide better insight into what types of interactions occur between countries. Alternative measures of power could be attributes such as a country's technological capabilities (e.g., cybersecurity, offensive hacking, Artificial Intelligence) or a country's status as a nuclear power.

With regard to the CoW data used to inform much of this model, the R package I created and discussed in Section 5.2 could be developed into a CRAN product for easy installation. The current package was developed on a Windows 10 operating system which may not be portable to other operating systems. Developing a CRAN product would centralize several different disparate datasets in one place and allow easier access to the data for connection and analysis. It would also increase the CoW dataset's rigor as it would force the different datasets to all use the same dictionary of identifiers across datasets, and would allow repeatable conversion between them using the built-in dictionary and function. This effort would require data-sharing approval to be granted by the owners/maintainers of the different CoW datasets.

5.1.2 Extensions to Election and Voting Model

Spatial ABMs are a flexible approach to modeling and allow for a wide array of theoretical assumptions about what a space may look like (Manson et al., 2020). The extant 2D spatial voting model discussed in Chapter 4 is useful and has been around for a long time, but a voter's decision process and the things that influence it are too complex to be understood just by mere distances in space. It is also important to note that the spatial voting model is not without limitations. My 3D version of the model, which includes the dimension of “ideology,” does not add much value to understanding the system’s dynamics. This is in line with what Laver and Sergenti (2012) expected when they suggested that only 2 or 3 dimensions would be sufficient to categorize the ideology space. I believe that more realism in the model, introduced in the form of modeling groups and coalitions, will be required to make a spatial model like this one more useful and powerful.

Research suggests that people tend to vote as parts of groups or coalitions and voters feel sense of loyalty to those groups (Bawn et al., 2012). Much research also suggests that social context is very important when deciding if and how to vote (Beck et al., 2002; Burbank, 1997; Sokhey & Djupe, 2011). Even the order in which candidates’ names are printed on a ballot can have an effect on whom the voter ultimately decides to vote for (Söderlund et al., 2021). Understanding and incorporating factors like the party a person identifies with (Conover & Feldman, 1981), different levels of political sophistication (Zaller, 1992), and things like coalitions, networks, and social pressures (Rolfe, 2012; Sinclair, 2012; Krosnick, 2017) will be key to making progress with computational modeling in this area. Currently this model does not have a voter agent attribute that represents a party affiliation, and this association with a party can be quite powerful and have a large impact on deciding which candidate to support. Additionally, approaches taking decision models from neuroscience like active inference (Riddle & Hesp, 2020) where agents are allowed to use expectations and biases from the past in their decision making could add to our understanding of voting patterns and behaviors.

Incorporating these bits of realism would be a great first step to advancing my model and better understanding the complex systems we see in the real world.

The analysis for Chapter 4 does not try to connect the different dimensions of political ideology extracted from the Comparative Political Parties dataset (Swank, 2018) to any of the traditional things associated with a Left-Right political spectrum such as social issues (e.g., gun rights and reproductive rights), or economic concerns (e.g., taxation). My analysis only uses the identified principal components as an example of what a 3D ideology space might look like and makes no attempt to connect them to these real-world issues. Using data like the Comparative Political Parties dataset (Swank, 2018) or other datasets that quantify a voting landscape across ideas or parties, further research could expand on the data analysis beyond using just principal components analysis and employ analytics tools such as factor analysis to understand the connection between the extracted components (or factors) to the actual policy baskets or ideas they are capturing. Research like this could provide additional information regarding what ideas and policies are correlated with one another and would be in the style of work done by Banisch and Olbrich (2021) and Chen and Lan (2021).

5.2 Replication of Analysis

Rigorous, documented, and repeatable research in the social sciences has long been difficult to achieve. As stated in *A Study of War*,

> The presence of contingency, of purpose, of universal change, and of universal interrelatedness, flowing from the number, subjectivity, instability, complexity, and problematic character of the factors involved, renders the application of

scientific method to human and social problems exceptionally difficult and frequently unproductive. (Wright, 1942, p. 683)

In the midst of World War II, Quincy Wright's original (1942) *A Study of War* examined the complex nature of international conflict and the many factors that come together to shape the way humans order themselves and arrange society. He notes that applications of the scientific method to these complex social problems are often not very productive. Since Wright (1942) first made this observation the computational tools and technology to collate, analyze, model, and visualize the information needed to apply the scientific method to complex social problems has risen exponentially (Moore, 1965/2006). Researchers from many disciplines now have very few barriers to entry if they wish use computational tools to analyze and model phenomena, social or otherwise. This, however, has not necessarily led to research that would pass the high bar the scientific method should require for reproducibility. A more recent critique of how the scientific method is applied to complex problems in the social sciences was given by Peng (2011), who notes that disciplines that use computation have been asking for reproducible research to be the minimum standard when thinking about how to evaluate a study's claims. Peng says that code and data should not be hidden but shared with the scientific community.

I attempt to "make a difference" by releasing my code as well as creating an R package that allows historical analysis of country- and multicountry-level data in the CoW dataset. This package combines data that currently exists in disparate locations and allows a user to link data from different datasets together to create a more complete picture of a country or group of countries at a moment in time. R is an open-source programming language that is particularly suited to tasks that involve connecting the data to be understood to the methods used to understand the data. I use this new R package to perform two examples of data analysis that support two examples of agent-based models (built in NetLogo (Wilensky, 1999) and connected to the R package) where the agents are instantiated with features gathered from empirical data.

All analysis has been done using a combination of the R statistical programming language as well as a host of R packages, including cluster (to calculate a dissimilarity matrix), igraph (to manipulate, analyze, and visualize graphs), ggplot2 (for various visualizations), rgl (for interactive 3D visualizations), plot3d (for static 3D visualizations), and tidyverse (for various data manipulations). Agent-based modeling was done using NetLogo. Experiments were conducted using the Behavior Space tool available in Netlogo or by using the RNetLogo package to connect R to NetLogo. Code and data are available on my GitHub Page: https://github.com/hwalbert/diss_repo.

This dissertation shows a useful methodological framework to understand how complex systems with many interdependencies work by connecting empirical data to relatively simple models. Even though there are many areas of further work as discussed earlier in this chapter, it demonstrates how abstracting from these complex systems and focusing on the components that make them up can help to shed light on system outcomes and emergent results. The growth of publicly available data and powerful computation tools will only serve to help advance this exciting and interesting area of research.

REFERENCES

Abdollahian, M., Baranick, M., Efird, B., & Kugler, J. (2006, August). *Senturion: Predictive political simulation model* (Defense and Technology Paper 32). National Defense University Center for Technology and National Security Policy. http://www.ndu.edu/CTNSP/Def_Tech/DTP%2032%20Senturion.pdf

Arrow, K. J. (1950). A difficulty in the concept of social welfare. *Journal of Political Economy, 58(*4), 328–346. https://doi.org/10.1086/256963

Axelrod, R. (1995). A model of the emergence of new political actors. In N. Gilbert & R. Conte (Eds.), *Artificial societies: The computer simulation of social life* (pp. 19–39). University College Press.

Axelrod, R. (2006). Chapter 33 Agent-based modeling as a bridge between disciplines. In L. Tesfatsion & K. L. Judd (Eds.,), *Handbook of computational economics* (Vol. 2, pp. 1565–1584). Elsevier. https://doi.org/10.1016/S1574-0021(05)02033-2

Balci, O. (1998). Verification, validation, and testing. In J. Banks (Ed.), *Handbook of simulation* (pp. 335–393). John Wiley & Sons, Inc. https://doi.org/10.1002/9780470172445.ch10

Banisch, S., & Olbrich, E. (2021). An argument communication model of polarization and ideological alignment. *Journal of Artificial Societies and Social Simulation, 24*(1), 1. https://doi.org/10.18564/jasss.4434

Barbieri, K. (1996). Economic interdependence: A path to peace or a source of interstate conflict? *Journal of Peace Research, 33*(1), 29–49. https://doi.org/10.1177/0022343396033001003

Barbieri, K., & Keshk, O. M. G. (2016). *Correlates of War Project Trade data set codebook, version 4.0*. https://correlatesofwar.org/data-sets/bilateral-trade

Bawn, K., Cohen, M., Karol, D., Masket, S., Noel, H., & Zaller, J. (2012). A theory of political parties: Groups, policy demands and nominations in American politics. *Perspectives on Politics, 10*(3), 571–597. https://doi.org/10.1017/S1537592712001624

Beck, P. A., Dalton, R. J., Greene, S., & Huckfeldt, R. (2002). The social calculus of voting: Interpersonal, media, and organizational influences on presidential choices. *American Political Science Review, 96*(1), 57–73. https://doi.org/10.1017/S0003055402004239

Bennett, D. S., & Stam, A. C. (2000). A universal test of an expected utility theory of war. *International Studies Quarterly*, *44*(3), 451–480. https://doi.org/10.1111/0020-8833.00167

Benoit, K., & Laver, M. (2006). *Party policy in modern democracies* (1st ed.). Routledge. https://doi.org/10.4324/9780203028179

Benson, B. V. (2011). Unpacking alliances: Deterrent and compellent alliances and their relationship with conflict, 1816–2000. *The Journal of Politics*, *73*(4), 1111–1127. https://doi.org/10.1017/S0022381611000867

Benson, B. V., Bentley, P. R., & Ray, J. L. (2013). Ally provocateur: Why allies do not always behave. *Journal of Peace Research*, *50*(1), 47–58. https://doi.org/10.1177/0022343312454445

Berelson, B., Lazarsfeld, P. F., & McPhee, W. N. (1986). *Voting: A study of opinion formation in a presidential campaign* (Midway reprint ed.). University of Chicago Press.

Berglund, A. (1922). The iron and steel industry of Japan and Japanese continental policies. *Journal of Political Economy*, *30*(5), 623–654. https://doi.org/10.1086/253465

Besley, T., & Persson, T. (2008). Wars and state capacity. *Journal of the European Economic Association*, *6*(2–3), 522–530. https://doi.org/10.1162/JEEA.2008.6.2-3.522

Bhavnani, R., & Miodownik, D. (2009). Ethnic polarization, ethnic salience, and civil war. *Journal of Conflict Resolution*, *53*(1), 30–49. https://doi.org/10.1177/0022002708325945

Birkett, M. S. (1920). The iron and steel trades during the war. *Journal of the Royal Statistical Society*, *83*(3), 351. https://doi.org/10.2307/2340957

Black, D. (1948). On the rationale of group decision-making. *Journal of Political Economy, 56*(1), 23–34. https://doi.org/10.1086/256633

Boettke, P. J., & Leeson, P. T. (2002). Hayek, Arrow, and the problems of democratic decision-making. *Journal of Public Finance and Public Choice, 20*(1), 9-21. https://doi.org/10.1332/251569202X15665366114815

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences, 99*(Supplement 3), 7280–7287. https://doi.org/10.1073/pnas.082080899

Bremer, S. A. (2019). *The GLOBUS model: Computer simulation of worldwide political and economic developments*. Routledge.

Buchanan, J. M. (1954). Individual choice in voting and the market. *Journal of Political Economy, 62*(4), 334–343. https://doi.org/10.1086/257538

Buchanan, J. M. (1975). *The limits of liberty: Between anarchy and leviathan*. University of Chicago Press.

Buchanan, J. M. (1985). *Liberty, market, and state: Political economy in the 1980s*. New York University Press.

Buchanan, J. M., & Tullock, G. (1962). *The calculus of consent: Logical foundations of constitutional democracy*. University of Michigan Press. https://doi.org/10.3998/mpub.7687

Burbank, M. J. (1997). Explaining contextual effects on vote choice. *Political Behavior, 19*(2), 113–132. https://doi.org/10.1023/A:1024806024732

Campbell, A., Converse, P. E., Miller, W. E., & Stokes, D. E. (1960). *The American voter*. John Wiley.

Caplan, B. (2011). *The myth of the rational voter: Why Democracies choose bad policies*. Princeton University Press. https://doi.org/10.1515/9781400828821 (Original work published 2008)

Castles, F. G., & Mair, P. (1984). Left-Right political scales: Some “expert” judgments. *European Journal of Political Research, 12*(1), 73–88. https://doi.org/10.1111/j.1475-6765.1984.tb00080.x

Cederman, L.-E. (1997). *Emergent actors in world politics: How states and nations develop and dissolve*. Princeton University Press. https://doi.org/10.1515/9780691218038

Cederman, L.-E. (2001). Modeling the democratic peace as a Kantian selection process. *The Journal of Conflict Resolution, 45*(4), 470–502. https://doi.org/10.1177/0022002701045004004

Cederman, L.-E. (2003). Modeling the size of wars: From billiard balls to sandpiles. *American Political Science Review, 97*(01), 135–150. https://doi.org/10.1017/S0003055403000571

Cederman, L.-E., & Girardin, L. (2007). *Toward realistic computational models of civil wars* [Paper presentation]. Annual Meeting of the American Political Science Association, Chicago, IL.

Cederman, L.-E., & Gleditsch, K. S. (2004). Conquest and regime change: An evolutionary model of the spread of democracy and peace. *International Studies Quarterly*, *48*(3), 603–629. https://doi.org/10.1111/j.0020-8833.2004.00317.x

Chen, Z., & Lan, H. (2021). Dynamics of public opinion: Diverse media and audiences' choices. *Journal of Artificial Societies and Social Simulation*, *24*(2), 8. https://doi.org/10.18564/jasss.4552

Conover, P. J., & Feldman, S. (1981). The origins and meaning of liberal/conservative self-identifications. *American Journal of Political Science, 25*(4), 617. https://doi.org/10.2307/2110756

Converse, P. E. (2006). The nature of belief systems in mass publics (1964). *Critical Review, 18*(1–3), 1–74. https://doi.org/10.1080/08913810608443650 (Original work published 1964)

Cowhey, P. F. (1993). Domestic institutions and the credibility of international commitments: Japan and the United States. *International Organization, 47*(2), 299–326. https://doi.org/10.1017/S0020818300027958

Cranmer, S. J., & Desmarais, B. A. (2011). Inferential network analysis with exponential random graph models. *Political Analysis*, *19*(1), 66–86. https://doi.org/10.1093/pan/mpq037

Cranmer, S. J., Desmarais, B. A., & Kirkland, J. H. (2012). Toward a network theory of alliance formation. *International Interactions, 38*(3), 295–324. https://doi.org/10.1080/03050629.2012.677741

Cusack, T. R., & Stoll, R. J. (1990). *Exploring realpolitik: Probing international relations theory with computer simulation*. Lynne Rienner.

de Mesquita, B. B., Morrow, J. D., Siverson, R. M., & Smith, A. (1999). An institutional explanation of the democratic peace. *American Political Science Review, 93*(4), 791–807. https://doi.org/10.2307/2586113

DeCanio, S. (2014). Democracy, the market, and the logic of social choice. *American Journal of Political Science, 58*(3), 637–652. https://doi.org/10.1111/ajps.12072

Deutschmann, E., Lorenz, J., Nardin, L. G., Natalini, D., & Wilhelm, A. F. X. (Eds.). (2020). *Computational conflict research*. Springer International Publishing. https://doi.org/10.1007/978-3-030-29333-8

Directorate-General for Trade (European Commission), Civic Consulting, & Ifo Institute (2018). *Evaluation of the implementation of the free trade agreement between the EU and its member states and the Republic of Korea: Final report*. EU Publications Office. https://data.europa.eu/doi/10.2781/897452

Downs, A. (1957). An economic theory of political action in a democracy. *Journal of Political Economy*, *65*(2), 135–150. https://doi.org/10.1086/257897

Doyle, M. W. (1983). Kant, liberal legacies, and foreign affairs, Part 2. *Philosophy and Public Affairs, 12*(4), 323–353. http://www.jstor.org/stable/2265377

Doyle, M. W. (2012). *Liberal peace: Selected essays*. Routledge. https://doi.org/10.4324/9780203804933

Epstein, J. M., & Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Brookings Institution Press. https://doi.org/10.7551/mitpress/3374.001.0001

Feddersen, T. J. (2004). Rational choice theory and the paradox of not voting. *Journal of Economic Perspectives*, *18*(1), 99–112. https://doi.org/10.1257/089533004773563458

Fieldhouse, E., Lessard-Phillips, L., & Edmonds, B. (2016). Cascade or echo chamber? A complex agent-based simulation of voter turnout. *Party Politics, 22*(2), 241–256. https://doi.org/10.1177/1354068815605671

Fowler, J., & Smirnov, O. (2005). Dynamic parties and social turnout: An agent-based model. *The American Journal of Sociology, 110*(4), 1070–1094. https://doi.org/10.1086/426554

Garfinkel, M. R., & Skaperdas, S. (2007). Chapter 22 Economics of conflict: An overview. In T. Sandler & K. Hartley (Eds.), *Handbook of defense economics* (Vol. 2, pp. 649–709). Elsevier. https://doi.org/10.1016/S1574-0013(06)02022-9

Gibler, D. M. (2009). *International military alliances, 1648-2008*. CQ Press. https://doi.org/10.4135/9781604265781

Gibler, D. M., & Vasquez, J. A. (1998). Uncovering the dangerous alliances, 1495–1980. *International Studies Quarterly, 42*(4), 785–807. https://doi.org/10.1111/0020-8833.00106

Gilbert, G. N., & Troitzsch, K. G. (2005). *Simulation for the social scientist* (2nd ed.). Open University Press.

Gilbert, N., & Conte, R. (1995). *Artificial societies: The computer simulation of social life*. Taylor & Francis. http://www.oapen.org/download?type=document&docid=1005826

Girardin, L., & Cederman, L.-E. (2007). A roadmap to realistic computational models of civil wars. In S. Takahashi, D. Sallach, & J. Rouchier (Eds.), *Advancing social simulation: The first world congress* (pp. 59–69). Springer Japan. https://doi.org/10.1007/978-4-431-73167-2_7

Glick, R., & Taylor, A. M. (2010). Collateral damage: Trade disruption and the economic impact of war. *The Review of Economics and Statistics, 92*(1), 102–127. https://doi.org/10.1162/rest.2009.12023

Gochman, C. S., & Sabrosky, A. N. (Eds.). (1990). *Prisoners of war? Nation-states in the modern era*. Lexington Books.

Gower, J. C. (1971). A general coefficient of similarity and some of its properties. *Biometrics, 27*(4), 857–871. https://doi.org/10.2307/2528823

Gulati, G. J., Hadlock, C. R., & Gainsborough, J. F. (2011). VODYS: An agent-based model for exploring campaign dynamics. *Social Science Computer Review, 29*(2), 250–272. https://doi.org/10.1177/0894439310372790

Harrison, M., & Wolf, N. (2012). The frequency of wars. *The Economic History Review, 65*(3), 1055–1076. https://doi.org/10.1111/j.1468-0289.2011.00615.x

Hayek, F. A. (2010). *The constitution of liberty*. The Institute of Economic Affairs. (Original work published 1960)

Hayek, F. A. von. (1993). *Law, legislation, and liberty: A new statement of the liberal principles of justice and political economy*. Routledge. (Original work published 1982)

Hegre, H., Oneal, J. R., & Russett, B. (2010). Trade does promote peace: New simultaneous estimates of the reciprocal effects of trade and conflict. *Journal of Peace Research, 47*(6), 763–774. https://doi.org/10.1177/0022343310385995

Hirshleifer, J. (1995). Anarchy and its breakdown. *Journal of Political Economy, 103*(1), 26–52. https://doi.org/10.1086/261974

Holbrook, A. L., Krosnick, J. A., Visser, P. S., Gardner, W. L., & Cacioppo, J. T. (2001). Attitudes toward presidential candidates and political parties: Initial optimism, inertial first impressions, and a focus on flaws. *American Journal of Political Science, 45*(4), 930–950. https://doi.org/10.2307/2669333

Holsti, O. R. (1989). Models of international relations and foreign policy. *Diplomatic History, 13*(1), 15–43. https://doi.org/10.1111/j.1467-7709.1989.tb00042.x

Hotelling, H. (1929). Stability in competition. *The Economic Journal, 39*(153), 41. https://doi.org/10.2307/2224214

Inwood, K., & Keay, I. (2013). Trade policy and industrial development: Iron and steel in a small open economy, 1870−1913. *Canadian Journal of Economics/Revue Canadienne d'économique, 46*(4), 1265–1294. https://doi.org/10.1111/caje.12048

Jackson, M. O., & Nei, S. (2015). Networks of military alliances, wars, and international trade. *Proceedings of the National Academy of Sciences*, *112*(50), 15277–15284. https://doi.org/10.1073/pnas.1520970112

Japanese iron and steel production. (1908). *Journal of the Royal Society of Arts, 56*(2910), 903-903. http://www.jstor.org/stable/41338179

Jouvenel, B. (1963). *Pure theory of politics*. Yale University Press.

Kant, I. (1991). *Kant: Political writings* (H. Reiss, Ed., H. Nisbet, Trans.; 2nd ed.). Cambridge texts in the history of political thought. Cambridge University Press. https://doi.org/10.1017/CBO9780511809620

Kennedy, P. M. (1989). *The rise and fall of the great powers: Economic change and military conflict from 1500 to 2000* (1st ed.). Vintage Books.

Keshk, O. M. G., Pollins, B. M., & Reuveny, R. (2004). Trade still follows the flag: The primacy of politics in a simultaneous model of interdependence and armed conflict. *The Journal of Politics, 66*(4), 1155–1179. https://doi.org/10.1111/j.0022-3816.2004.00294.x

Kim, H. M., & Rousseau, D. L. (2005). The classical liberals were half right (or half wrong): New tests of the "liberal peace", 1960-88. *Journal of Peace Research, 42*(5), 523–543. https://doi.org/10.1177/0022343305056225

Kinsella, D. (2005). No rest for the democratic peace. *American Political Science Review, 99*(3), 453–457. https://doi.org/10.1017/S0003055405051774

Kononovicius, A. (2017). Empirical analysis and agent-based modeling of the Lithuanian parliamentary elections. *Complexity, 2017*, 1–15. https://doi.org/10.1155/2017/7354642

Koppl, R. (2002). *Big players and the economic theory of expectations*. Palgrave Macmillan. https://doi.org/10.1057/9780230629240

Krosnick, J. A. (Ed.). (2017). *Political psychology: New explorations*. Routledge. https://doi.org/10.4324/9781315445687

Laffer, A. B. (1981). Government exactions and revenue deficiencies. *Cato Journal, 1*(1), 1–21. https://www.cato.org/sites/cato.org/files/serials/files/cato-journal/1981/5/cj1n1-1.pdf

Larralde, H., Jensen, P., & Edwards, M. (2006). *Two dimensional Hotelling model: Analytical results and numerical simulations*. https://hal.archives-ouvertes.fr/hal-00114288/document

Laver, M., & Sergenti, E. (2012). *Party competition: An agent-based model*. Princeton University Press. https://doi.org/10.1515/9781400840328

Leeds, B. A. (2003). Do alliances deter aggression? The influence of military alliances on the initiation of militarized interstate disputes. *American Journal of Political Science, 47*(3), 427–439. https://doi.org/10.1111/1540-5907.00031

Leeds, B. A., & Johnson, J. C. (2017). Theory, data, and deterrence: A response to Kenwick, Vasquez, and Powers. *The Journal of Politics*, *79*(1), 335–340. https://doi.org/10.1086/687285

Machiavelli, N. (1981). *The prince*. Penguin Books.

Madsen, J. K., & Pilditch, T. D. (2018). A method for evaluating cognitively informed micro-targeted campaign strategies: An agent-based model proof of principle. *PLOS ONE, 13*(4), e0193909. https://doi.org/10.1371/journal.pone.0193909

Mansfield, E. D., & Bronson, R. (1997). Alliances, preferential trading arrangements, and international trade. *American Political Science Review, 91*(1), 94–107. https://doi.org/10.2307/2952261

Manson, S., An, L., Clarke, K. C., Heppenstall, A., Koch, J., Krzyzanowski, B., Morgan, F., O'Sullivan, D., Runck, B. C., Shook, E., & Tesfatsion, L. (2020). Methodological issues of spatial agent-based models. *Journal of Artificial Societies and Social Simulation, 23*(1), 3. https://doi.org/10.18564/jasss.4174

Maoz, Z. (2017). Democracy and cooperative networks (In J. N. Victor, A. H. Montgomery, & M. Lubell, Eds., *The Oxford handbook of political networks*, Vol. 1, Part 5). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190228217.013.32

Maoz, Z., Johnson, P. L., Kaplan, J., Ogunkoya, F., & Shreve, A. P. (2019). The Dyadic Militarized Interstate Disputes (MIDs) dataset version 3.0: Logic, characteristics, and comparisons to alternative datasets. *Journal of Conflict Resolution, 63*(3), 811–835. https://doi.org/10.1177/0022002718784158

Maoz, Z., & Russett, B. (1993). Normative and structural causes of democratic peace, 1946–1986. *American Political Science Review, 87*(3), 624–638. https://doi.org/10.2307/2938740

Masad, D. (2016). *Agents in conflict: Comparative agent-based modeling of international crises and conflicts* (Publication No. 1800284944) [Doctoral dissertation, George Mason University]. ProQuest Dissertations and Theses.

Masad, D., & Crooks A. T. (2012, November 9). *Towards arms and influence networks: A network analysis of international arms transfers* [Paper presentation]. 4th Annual Complexity in Business Conference, Washington, DC.

Menger, C. (1985). *Investigations into the method of the social sciences with special reference to economics*. L. Schneider (Ed.), F. J. Nock (Transl). New York: New York University Press. (Reprinted from *Problems of economics and sociology (Untersuchungen uber die Methode der Socialwissenschaften und der Politischen Oekonomie insbesondere*), 1963, Board of Trustees of the University of Illinois)

Miller, J. M., Krosnick, J. A., & Fabrigar, L. R. (2017). The origins of policy issue salience: Personal and national importance impact on behavioral, cognitive, and emotional issue engagement. In J. A. Krosnick, I-C. A. Chiang, & T. H. Stark (Eds.), *Frontiers of social psychology: Political psychology: New explorations* (pp. 125–171). Routledge/Taylor & Francis Group.

Miller, J. H., & Page, S. E. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton University Press.

Moore, G. E. (2006). Cramming more components onto integrated circuits. *IEEE Solid-State Circuits Society Newsletter, 11*(3), 33–35. https://doi.org/10.1109/N-SSC.2006.4785860 (Reprinted from "Cramming more components onto integrated circuits," 1965, April 19, *Electronics, 38*[8], 114–117)

Morgan, T. C., & Palmer, G. (2003). To protect and to serve: Alliances and foreign policy portfolios. *Journal of Conflict Resolution, 47*(2), 180–203. https://doi.org/10.1177/0022002702251028

Most, B. A., & Starr, H. (1984). International relations theory, foreign policy substitutability, and "nice" laws. *World Politics, 36*(3), 383–406. https://doi.org/10.2307/2010380

Mueller, D. C. (1989). *Public choice II*. Cambridge University Press.

Noel, H. (2013). *Political ideologies and political parties in America*. Cambridge University Press. https://doi.org/10.1017/CBO9781139814775

North, D. C., Wallis, J. J., & Weingast, B. R. (2009). *Violence and social orders: A conceptual framework for interpreting recorded human history*. Cambridge University Press. https://doi.org/10.1017/CBO9780511575839

Olson, M. (1965). *The logic of collective action: Public goods and the theory of groups*. Harvard University Press.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511807763

Palmer, G., d'Orazio, V., Kenwick, M., & Lane, M. (2015). The MID4 dataset, 2002–2010: Procedures, coding rules and description. *Conflict Management and Peace Science*, *32*(2), 222-242. https://doi.org/10.1177/0738894214559680

Palombi, F., & Toti, S. (2015). Voting behavior in proportional elections from agent-based models. *Physics Procedia*, *62*, 42–47. https://doi.org/10.1016/j.phpro.2015.02.009

Peng, R. (2015). The reproducibility crisis in science: A statistical counterattack. *Significance*, *12*(3), 30–32. https://doi.org/10.1111/j.1740-9713.2015.00827.x

Qiu, L., & Phang, R. (2020). Agent-based modeling in political decision making. In L. Qiu & R. Phang (Eds.), *Oxford research encyclopedia of politics*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190228637.013.913

Riddle, R., & Hesp, C. (2020). *2020 US elections: Modelling subjectivity in voting behaviours using active inference*. ResearchGate. https://doi.org/10.13140/RG.2.2.24251.85289

Rodgers, A. (1948). The Manchurian iron and steel industry and its resource base. *Geographical Review*, *38*(1), 41–54. https://doi.org/10.2307/210738

Rolfe, M. (2012). *Voter turnout: A social theory of political participation*. Cambridge University Press. https://doi.org/10.1017/CBO9781139058513

Ruths, D. (2017). What can political science learn from computer science? An interview with Derek Ruths. In J. N. Victor, A. H. Montgomery, & M. Lubell (Eds.), *The Oxford handbook of political networks* (Vol. 1, Part 7). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190228217.013.45

Salter, A. W., & Wagner, R. E. (2018). Political entrepreneurship, emergent dynamics, and constitutional politics. *Review of Social Economy*, *76*(3), 281–301. https://doi.org/10.1080/00346764.2018.1425897

Sandler, T. (2000). Economic analysis of conflict. *Journal of Conflict Resolution*, *44*(6), 723–729. https://doi.org/10.1177/0022002700044006001

Schelling, T. (1960). *The strategy of conflict*. Harvard University Press.

Shone, R., & Fisher, H. R. (1958). Industrial production and steel consumption. *Journal of the Royal Statistical Society. Series A (General)*, *121*(3), 269. https://doi.org/10.2307/2342902

Sinclair, B. (2012). *The social citizen: Peer networks and political behavior*. University of Chicago Press. https://doi.org/10.7208/chicago/9780226922836.001.0001

Singer, J. D., & Diehl, P. F. (Eds.). (1990). *Measuring the correlates of war*. University of Michigan Press.

Singer, J. D., & Small, M. (1966). Formal alliances, 1815—1939: A quantitative description. *Journal of Peace Research*, *3*(1), 1–31. https://doi.org/10.1177/002234336600300101

Singer, J. D., & Small, M. (1972). *The wages of war, 1816-1965: A statistical handbook*. Wiley.

Singh, V. K., Basak, S., & Modanwal, N. (2011). Agent based modeling of individual voting preferences with social influence. In D. Nagamalai, E. Renault, & M. Dhanuskodi (Eds.), *Trends in Computer Science, Engineering and Information Technology* (pp. 542–552). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-24043-0_55

Smith, A. (1995). Alliance formation and war. *International Studies Quarterly*, *39*(4), 405. https://doi.org/10.2307/2600800

Smith, E. R. A. N. (1980). The levels of conceptualization: False measures of ideological sophistication. *American Political Science Review*, *74*(3), 685–696. https://doi.org/10.2307/1958150

Söderlund, P., von Schoultz, A., & Papageorgiou, A. (2021). Coping with complexity: Ballot position effects in the Finnish open-list proportional representation system. *Electoral Studies*, *71*, 102330. https://doi.org/10.1016/j.electstud.2021.102330

Sokhey, A. E., & Djupe, P. A. (2011). Interpersonal networks and democratic politics. *PS: Political Science & Politics, 44*(1), 55–59. https://doi.org/10.1017/S1049096510001861

Stevens, J. B. (1993). *The economics of collective choice*. Westview Press.

Stiles, E. A., Swearingen, C. D., Seiter, L., & Foreman, B. (2020). Catch me if you can: Using a threshold model to simulate support for presidential candidates in the invisible primary. *Journal of Artificial Societies and Social Simulation, 23*(1), 1. https://doi.org/10.18564/jasss.4158

Suzuki, S., Krause, V., & Singer, J. D. (2002). The Correlates of War Project: A bibliographic history of the scientific study of war and peace, 1964-2000. *Conflict Management and Peace Science*, *19*(2), 69–107. https://doi.org/10.1177/073889420201900204

Swank, D. (2018). *Comparative Political Parties dataset: Electoral, legislative, and government strength of political parties by ideological group in 21 capitalist democracies, 1950-2015* [Electronic database], Department of Political Science, Marquette University. http://www.marquette.edu/polisci/faculty_swank.shtml

Taghikhah, F., Filatova, T., & Voinov, A. (2021). Where does theory have it right? A comparison of theory-driven and empirical agent based models. *Journal of Artificial Societies and Social Simulation, 24*(2), 4. https://doi.org/10.18564/jasss.4573

Taylor, G., Bechtel, R., Morgan, G., & Waltz, E. (2006, June 22-23). A framework for modeling social power structures. In *Proceedings of the North American Association for Computational Social and Organizational Sciences*. Notre Dame, IN. https://soartech.com/wp-content/uploads/2016/04/PowerStructre_Model.pdf

Toft, P. (2005). John J. Mearsheimer: An offensive realist between geopolitics and power. *Journal of International Relations and Development, 8*(4), 381–408. https://doi.org/10.1057/palgrave.jird.1800065

Troitzsch, K. G. (2021). Validating simulation models: The case of opinion dynamics. In T. Rudas & G. Péli (Eds.), *Pathways between social science and computational social science* (pp. 123–155). Springer International Publishing. https://doi.org/10.1007/978-3-030-54936-7_6

Vasquez, J. A. (Ed.). (2012). *What do we know about war?* (2nd ed.). Rowman & Littlefield Publishers.

Veendorp, E. C. H., & Majeed, A. (1995). Differentiation in a two-dimensional market. *Regional Science and Urban Economics, 25*(1), 75–83. https://doi.org/10.1016/0166-0462(94)02075-R

Victor, J. N., Montgomery, A. H., & Lubell, M. (2017). Introduction. In J. N. Victor, A. H. Montgomery, & M. Lubell (Eds.), *The Oxford handbook of political networks* (Vol. 1). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190228217.013.1

Villarreal, M. A., & Fergusson, I. F. (2020). *The United States–Mexico–Canada Agreement (USMCA)* (CRS Report No. R44981). Retrieved from Congressional Research Service website: https://fas.org/sgp/crs/row/R44981.pdf

Wagner, R. (2016). *Politics as a peculiar business*. Edward Elgar Publishing. https://doi.org/10.4337/9781785365485

Walbert, H. J., Caton, J. L., & Norgaard, J. R. (2018). Countries as agents in a global-scale computational model. *Journal of Artificial Societies and Social Simulation, 21*(3), 4. https://doi.org/10.18564/jasss.3717

Wayman, F. W., Singer, J. D., & Goertz, G. (1983). Capabilities, allocations, and success in militarized disputes and wars, 1816-1976. *International Studies Quarterly, 27*(4), 497–515. https://doi.org/10.2307/2600558

Wilensky, U. (1999). *NetLogo*. *Center for Connected Learning and Computer-Based Modeling, Northwestern University*. http://ccl.northwestern.edu/netlogo/

Wittman, D. (1989). Why democracies produce efficient results. *Journal of Political Economy, 97*(6), 1395–1424. https://doi.org/10.1086/261660

Wittman, D. (1995). *The myth of democratic failure: Why political institutions are efficient*. University of Chicago Press.

Wittman, D. (2000). The wealth and size of nations. *Journal of Conflict Resolution, 44*(6), 868–884. https://doi.org/10.1177/0022002700044006010

Wright, Q. (1942). *A study of war* (Vol. 2). University of Chicago Press.

Xiang, X., Kennedy, R., Madey, G., & Cabaniss, S. (2005, January). *Verification and validation of agent-based scientific simulation models* [Paper presentation]. Agent-Directed Simulation Conference.

Zaller, J. R. (1992). *The nature and origins of mass opinion* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511818691

Zimmern, D. M. (1918). The wool trade in war time. *The Economic Journal, 28*(109), 7-29. https://doi.org/10.2307/2222106

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