Introduction: Joining Behavior

The war between Austria-Hungary and Serbia that began in July 1914 quickly expanded to include additional countries. Only three months into the war, two additional countries had **joined** on the side of Austria-Hungary and five on the side of Serbia. By the time the war ended in November 1918, thirteen additional countries had joined; three on the side of Austria-Hungary and ten on the side of Serbia. What began as a war between two countries **expanded** into what we now know as World War I, a war that alone is responsible for an astonishing 27% of the battle-connected fatalities across all interstate wars between 1816 and 1997. Most interstate wars (80%) do not follow this pattern; they end without ever expanding to include countries beyond the initial belligerents. But those wars that do expand (20%) account for an exorbitant 88% of the battle-connected fatalities across all interstate wars during this time period. Certainly, countries in the international system beyond the initial belligerents have an interest in the outcome of wars. Some countries, such as allies, neighbors, or trade partners, may have a greater interest than others. But despite the interests that might push such countries to join ongoing wars, war expansion is still a relatively rare phenomenon. When it does occur, however, it results in escalated loss (see Figure 1).

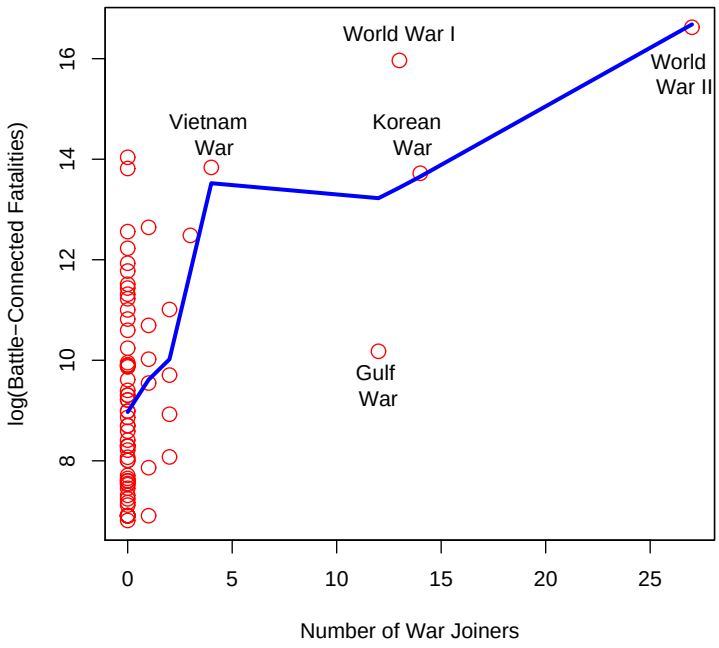

Figure 1: War Joining & Fatalities in Interstate Wars, 1816-1997

War, the country interaction that produces it, and the behavior of other countries during it, are all complex phenomena. Scholars have developed theories to explain the onset, escalation, duration, and outcome of interstate war but have paid relatively little attention to war expansion, even though war expansion is directly related to each of these other processes. We know comparatively little about why some third parties (i.e., countries) decide to **join** ongoing interstate wars and why others do not; how third party participation affects the **dynamics** of these wars; and how participation by each third party influences the participation decisions of other third parties. In order to overcome this deficit of attention in the literature, in my dissertation I develop a **theory of war expansion** to explain three interrelated puzzles: 1) Why do some wars expand while others do not? 2) How does war expansion affect the dynamics of war (i.e., battlefield events and outcomes)? 3) How does participation by a third party influence the likelihood of participation by other third parties?

I investigate these puzzles using a combination of formal and empirical techniques. I begin by employing **agent-based modeling**, consisting of computer-based simulation experiments performed in an artificial international country system. This artificial world is

analogous to a laboratory in which I "grow" war expansion to examine how the behaviors of many interacting agents (i.e., countries) generate the **emergent behavioral patterns** of war expansion (i.e., the decision of third parties to join an ongoing war and the effects of third party intervention on the dynamics of war). These emergent patterns serve as theoretical predictions of the real-life behavioral patterns that should emerge in the world under parallel conditions. After conducting experiments in this artificial world (in the form of computer simulations) under varying initial conditions, I then subject the theoretical predictions derived from these computer experiments to empirical evaluation using **statistical analysis** to evaluate how well the predictions withstand the empirical scrutiny of real world data.

The **scientific contributions** of this research are threefold. **First**, I develop a theory of an important and under-researched question in political science; war expansion. This theory provides insights into an important process using a methodological technique (agent-based modeling) that is relatively new to political science and combining it with empirical testing (statistical analysis), a research strategy identified by the National Science Foundation as an important way of promoting scientific progress. Additionally, the data collected will be of use to scholars examining other research questions related to the onset, duration, escalation, and outcome of international conflict. **Second**, the theoretical predictions of agent-based models are not frequently tested in political science using statistical analysis. The types of statistical tests used and developed in this dissertation are a first step towards developing a suite of statistical techniques to evaluate predictions from computational models. **Third**, the theory being developed is general enough that it can applied to research questions within political science and other social and behavioral sciences to understand similar types of joining behavior: the expansion of civil wars to include other countries or opposition groups, the expansion of U.S. presidential elections to include third party candidates, the expansion of class action law suits to include additional plaintiffs, and the expansion of publicly traded companies to include additional owners.

The Process of War Expansion

War expansion, defined as the military intervention of one or more third parties into an ongoing interstate war, consists of interconnected relationships between: 1) the original belligerents, 2) the original belligerents and each third party considering joining the war, and 3) each third party and all other third parties. A theory of war expansion must explain how these relationships affect and are affected by one another, as well as how the dynamics of war (i.e., battlefield events and outcomes) affect the strategic interaction with and across these three relationships.

A third party's decision to join an ongoing war is based, in part, on the strategic interaction between the initial belligerents, the current conditions of the war (i.e., which side is winning and which is losing and by how much), and this third party's beliefs about how the war would evolve with and without its participation. However, this decision about whether or not to join is complicated by the third party's expectations regarding the potential participation of other countries. And this third party's decision to join the war in turn affects the strategic interaction between the initial belligerents, as well as those strategic interactions between all other third parties.

Moreover, each of these relationships affects and is affected by the dynamics of war — battles won, battles lost, current troop formations, etc. As a war evolves, events on the

battlefield change the dynamics of the war, even absent third party participation. These dynamics alter each country's decision calculus. The dynamics of the war influence whether a given third party will participate, and this third party's decision to join in turn alters the dynamics of the war and influences other third parties decisions. Moreover, the *expected* dynamics of war also influence the war's initial onset. If a given country expects other third parties to intervene on the opposing side, it may decide not to fight in the first place. In contrast, if this same country expects other third parties to join the side of the war that the country favors, the country may be encouraged to participate — especially if doing so would put the country in good favor with fellow victorious nations. In short, the process of war expansion is complex, requiring a theoretical model capable of capturing the varied strategic interactions between countries as well as shifting dynamics of the war itself.

Modeling War Expansion: Past Approaches

Past research examining war expansion has typically focused on identifying those factors believed to influence a third party's decision to join an ongoing interstate war. The primary contextual factors considered in this extant research are a third party's material capability (Altfeld & Bueno de Mesquita 1979), proximity to the initial participants (Siverson & Starr 1991), alliances with the initial participants (Smith 1996, Leeds 2003), and regime type (Werner & Lemke 1997, Raknerud & Hegre 1997, Gartzke & Gleditsch 2004). These previous war expansion studies have relied on two methodologies. The first, and most common, approach has been the construction of "mental models" followed by verbal arguments relating the likelihood of third party participation to the contextual factor(s) of interest. The hypotheses that follow from these arguments are then subjected to empirical evaluation, often by using statistical analysis. A second group of studies have used mathematical models, frequently a decision theoretic model (Altfeld & Bueno de Mesquita 1979, Kim 1991). For example, Altfeld & Bueno de Mesquita (1979) create an expected utility model to predict which side a third party would join during an ongoing war. In this model, a third party's expected utility includes its ability to influence the outcome of the war (i.e., material capability) and the respective utilities it would derive for of each of the initial participants winning the war. The main findings from current research are: third parties that are most likely to join an ongoing interstate war are those that are a) relatively powerful, b) in close proximity to the original belligerents, c) allied with one of the initial participants, and d) have democratic institutions.

While these two approaches serve as important building blocks for future research, each suffers from a critical drawback. Although the dynamic nature of the process of war expansion is likely to inform third parties' decisions, studies focusing on contextual factors fail to capture these dynamics. In particular, the decision theoretic approach ignores the strategic interaction between a single third party and all other third parties. This strategic interaction is important because a third party's estimate of whether other third parties will also join the war is likely to influence its participation decision. Thus, a third party's decision is, in part, a strategic reaction to the decisions of other third parties. In these ways, existing attempts to model war expansion have employed tools that ignore critical components of war expansion: strategic interaction and the dynamic characteristics of the expansion process.

In order to model the essential elements of war expansion, different tools must be employed.

An Agent-Based Modeling Approach to War Expansion

The many strategic interactions embedded in the process of war expansion suggest that a game-theoretic approach would be a good way to model the contingent nature of country decisions. However, for this research project, a game-theoretic approach is limited by simplifications required for analytic tractability. At a minimum, a dynamic model with three actors and informational asymmetries would be required. This model would allow us to examine the strategic interaction between a third party and the original belligerents, but such a model would be incapable of capturing all the relevant strategic interactions of war expansion, as it ignores the strategic interactions between a single third party and all other third parties. More importantly, such a model could not account for the dynamic effects of war expansion on these strategic relationships. In order to account for the inadequacies of the game-theoretic approach in modeling the process of war expansion, this project draws on the strengths and flexibility of agent-based modeling.

In my dissertation I use agent-based modeling, a technique not commonly used in political science, to model the complexities of the process of war expansion. Agent-based modeling is a computational methodology that allows a researcher to create, analyze, and experiment with artificial worlds populated by diverse "agents." The characteristics and behaviors (i.e., decision making rules) of the agents are controlled by computer programs written by the researcher. The strengths of this approach include: the ability to examine the behaviors of a large number of diverse agents; the ability to model agent behavior in a dynamic environment; and the potential to uncover emergent patterns from agent interactions. In the case of my dissertation project, an agent-based model will add to our understanding of the process of war expansion because its flexibility enables us to model the original belligerents, the strategic behavior between the original belligerents and each third party considering joining the war, and the strategic behavior between each third party and all other third parties, as well as the effects of the dynamics of the war on all these strategic relationships. Additionally, as with other formal techniques, agent-based models produce empirical implications that can be evaluated by examining real-world behavior.

The Current Model

Currently, I have developed and programmed a basic model of war expansion in Java using the Recursive Porous Agent Simulation Toolkit (Repast)(North, Collier & Vos 2006). The construction of the model begins with the creation of an artificial international system populated by 100 heterogeneous agents (i.e., countries) that interact in an anarchic environment. From the initial set of agents, two are randomly chosen to be designated as the initial participants in a war. Following the onset of this war, each additional agent (i.e., third party) decides whether or not to participate. The decision rule each agent uses to make its decision is based, in part, on the expected utility model from Altfeld & Bueno de Mesquita (1979). This expected utility model contains two components: a third party's ability to influence the outcome of the war (i.e., material capability), and the different utilities the third party would derive from each of the initial participants winning the war. Each agent is randomly assigned values to represent these two components. The values are drawn from distributions that resemble the distributions of these same components in widely used data sets

in international relations, and so reflect real-world empirical distributions. Drawing agent characteristics from empirical distributions lends some realism to the model and contributes to empirical testing of the model's implications.

I generalize the expected utility model from Altfeld & Bueno de Mesquita (1979) by incorporating two additional components. First, we know that relatively few third parties actually join ongoing wars, and one likely reason is that joining is costly; countries will only incur these costs if the benefits of joining the war are greater than the costs. Thus, agents pay a cost of participating in the war. The costs of participating are subtracted from their expected utility for the outcome of the war (i.e., the benefits of joining).

Second, third party participation influences the dynamics of the war and third parties update their beliefs about which side will win the war as it persists. Thus, in the model, once an agent joins, the probability that the side it aligns with will win the war increases because its capability contribution necessarily alters the balance of capability between the initial participants. Based on this new balance, all agents update their expected utility calculations and when called upon to make their decision use their updated expected utility. In this way, third party decisions are endogenous to the dynamics of the war and the participation decisions of other agents. This updating mechanism results in third parties having a larger ability to influence the outcome of the war in its early stages, since as the war proceeds and more countries join, each additional third party's ability to influence the outcome of the war declines.

Simulation Results

In order to demonstrate the feasibility of my project and methods, in this section I present a sampling of preliminary findings. As discussed above, one advantage of agent-based modeling is that it affords the opportunity to conduct perfectly controlled experiments, through which the modeler can explore how the behaviors of agents vary when the model's parameters are altered. I begin by varying the costs that third parties pay for joining the ongoing war. In this way, I can explore how the dynamics of war expansion change when the parameter of joining costs is systematically varied. I present findings from experiments in which I increased the cost of participating from 0 (no costs) to 0.5 (high costs) in increments of 0.1. As the costs of participating increase, the benefits of joining outweigh the costs of joining only for more powerful agents and/or agents that derive a high utility from one of the initial participants winning the war. These findings are based on 1000 simulations performed across the range of joining costs; this many simulations ensures that the model's output is not contingent on the system's initial conditions. The model is implemented sequentially (Bremer & Mihalka 1977): one agent is randomly selected at each time point to make its decision, then another agent is selected, and so on until all agents have made their decisions.

Figure 2 shows, across the range of cost values, the average percentage of all potential third-party participants that joined either of the two initial belligerents. The figure reveals that as the costs of participating in the ongoing war increase, the average percentage of agents that join the ongoing war decreases. When joining is costless, nearly all agents in the international system participate; a far higher number than that reflected in the historical record. However, as the cost of participating increases, the percentage of countries that join ongoing wars remains low, as we see from history. This result is due to the fact that as the cost of joining increases, the number of agents in the system that are powerful, and/or that

derive a high utility from one of the initial participants winning the war, come to comprise a smaller and smaller percentage of the international system. This percentage is small because the values assigned for these components were drawn from empirical distributions that are highly skewed toward zero. Thus, the modal country is one that is not very powerful and that derives little utility from either war outcome and, therefore, has low expected utilities from either side winning.

Figure 3 shows, again across a range of cost values, how the probability of one side winning changes during a war. The random selection of initial actors allows for the possibility that the two warring parties would start out with the same capabilities and, thus, equal probabilities of winning. However, as illustrated in this figure and as seen in the real world, there is usually a discrepancy in strength between two initial belligerents. The solid lines track the probability of the stronger side S winning the war and the dotted lines track the probability of the weaker side W winning the war. Importantly, the figure reveals that, over time, the probability of S winning decreases while, conversely, the probability of W winning increases. This pattern is robust across the range of war cost values.

This is an interesting finding and one that deserves additional exploration to determine whether it is an emergent property or whether it is instead the result of a particular assumption that I hard-coded into the program. One such assumption that might be producing this result is the assumption about the distribution from which values are drawn and randomly assigned to agents to represent the utility they have for each of the initial participants winning the war. For example, if there are more agents in the system that derive a higher utility from W winning the war than S, the sheer number of third parties joining W might produce the result seen above, where over time the probability gap between the two sides diminishes. In order to determine whether this assumption is driving my result, I conducted additional simulations in which I drew the utility each agent derives from the two possible outcomes of the war from three different distributions: a positively skewed distribution that should result in more agents joining S, and discrete and continuous uniform distributions that should both result in the same number of agents preferring S or W to win the war. I ran 1000 simulations for each of these distributions, and the same finding emerged, suggesting that this result is an emergent property. The resulting conclusion — that the disparity in winning probabilities between two sides diminishes as additional countries join — implies that when a single powerful third party joins W early in the war it shifts the dynamics of the war and, thus, has powerful influence over other third parties' own abilities to influence the outcome of the war. These preliminary results illustrate the wealth of insight that can be gained by varying a single element in the model.

Extending the Current Model

While the current model hints at novel insight into the dynamics of war expansion, and while it has survived the test of varying the underlying distribution of third party utilities, it remains to be seen whether the result at hand is an emergent feature of the model or whether it is driven by one of two additional key assumptions. Two extensions are necessary to test the result across variance in each of these assumptions.

The **first extension** modifies the sequence in which the model calls upon third-party agents to make their decision of whether or not to join. In the current execution of the model, agents are called upon to make their decisions sequentially, according to an exogenously

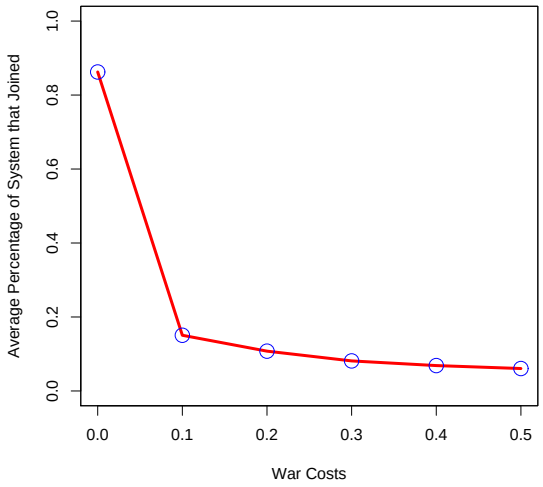

Figure 2: Average Percentage of System that Joined Across Cost Values

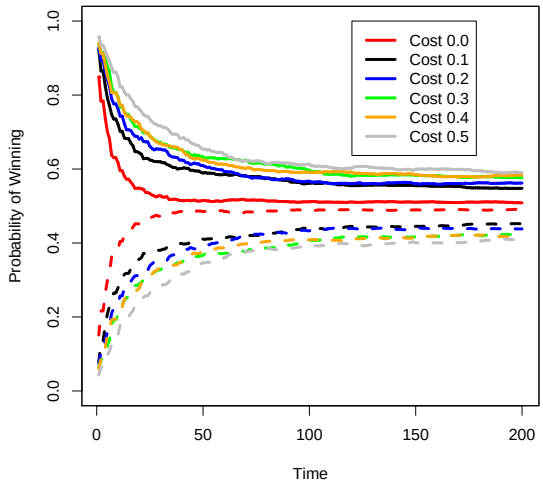

Figure 3: Average Probability of Winning Over Time Across Cost Values

defined rule that distributes the opportunities for joining randomly among the agents. To test the robustness of the result discussed above, this extension would implement a parallel execution of the model: (Duffy 1992, Cederman 1997) at each time point, all agents would simultaneously make their decision of whether or not to participate. This extension allows multiple third parties to join in the same time period and also allows third parties who joined in the prior period the opportunity to exit the war as it persists.

The **second extension**, which follows directly from the first, imposes a per period cost on third parties for participating in the ongoing war. In the sequential implementation, countries can only join the ongoing war once and thus only pay a one-time cost for joining. In the parallel implementation, since countries must (re)decide to join the war in each time period, they would pay a per period cost for participating. This implementation is a more realistic way of modeling the process of war, since the costs that a third party suffers for participating in the current period could reduce that third party's expected utility for joining in the next period. After all, the cost of participating directly affects a third party's ability to influence the outcome of the war (i.e., its capability) and, therefore, its expected utility. Thus, third parties that are relatively more powerful have the potential to participate longer in a war than third parties with relatively less power.

These two extensions capture crucial components of war expansion, allow for additional insights not found in past research, and generate alternative theoretical predictions about a potential emergent property. Two additional extensions are planned.

The **third extension** endogenizes war termination. In the current model, the war ends at an exogenously specified time point. However, the timing of a war's termination is actually dependent on which, if any, third parties participate and on which side. When third parties join the war they shift the balance of capabilities between the two coalitions of participants and alter the dynamics of the war. I endogenize the termination of the war by creating a victory ratio that indicates the point at which the stronger side obtains a preponderance of

capability (Cederman 1997). When the victory ratio is crossed the war ends. This extension would result in the ability of a relatively more powerful third party to end the war when it joins and provide a more realistic depiction of when wars actually end and also link third party participation with war termination. Importantly, this extension is necessary to be able to understand the process that leads some interstate wars to expand while others do not.

The **fourth extension** adds an explicit spatial representation (e.g., grid, torus, etc.) of the international system. This extension would allow for the incorporation of war diffusion (i.e., physical space) into a model of war expansion. Following the onset of the war between two agents, the remaining agents would become aware of the spatial location of the original participants. Their proximity to the war would then be incorporated into their expected utility by discounting their ability to influence the outcome of the war through the loss-of-strength gradient (Boulding 1962). Thus, two agents with the same material capability but one farther away from the spatial location of the war would have a smaller ability to influence the outcome of the war than the closer agent.

Testing the Empirical Implications of the Theoretical Model

The theoretical models produce implications about real-world behavior, in the form of hypotheses, that can and will be tested empirically. There two several empirical strategies that will be employed to evaluate the theoretical predictions derived from the agent-based model.

The first strategy is to set the initial conditions of the artificial international system so that they accurately resemble the real-world international system immediately preceding the onset of a particular war. Simulations of the agent-based model would then be conducted and the results would then be compared to the results recorded in the historical recorded. This type of empirical evaluation is useful in establishing some external validity of the theoretical model and allows for the opportunity of conducting counterfactual computer experiments to answer "what if" questions about critical junctures in particular wars. This type of empirical evaluation would be conducted for the larger and more severe wars: World Wars I and II, the Korean War, Vietnam War, and Gulf War.

The second strategy is to conduct a more systematic empirical evaluation using traditional statistical techniques including time series and event history analysis. Time series analysis will be using to compare the dynamics produced by the theoretical model to the dynamics of actual wars. Event history analysis, in particular competing risk and repeated events models (Box-Steffensmeier, DeBoef & Joyce 2006), will be used to study the time until third parties join a particular side, how third party participation influences the hazard of a war ending in either victory for the initiator, target, or negotiated settlement, and the decision to third parties of enter and exit ongoing wars.

In order to test the theoretical predictions pertaining to the dynamics of war expansion it is necessary to collect data on several crucial variables including: 1) the side a third party aligned with during a war, 2) which countries on the opposing side it actually engaged in combat with, and 3) the military contribution (e.g., number of tanks, aircraft, or military personnel) of the third party to the side that it joined.

In order to facilitate data collection, I use the interstate war data collected by the Correlates of War project (Sarkees 2000). The data set contains 79 interstate wars and their country participants between 1816 and 1997. Data needs to be collected for the 13 wars

that expanded to include at least one third party participant. While this data set identifies country participants in interstate wars it suffers from several limitations. First, while the data suggests which side the third party aligned with it does not provide the side actually joined. Second, while the data set identifies "all" country participants in a war, the data is structured in such a way that it is not clear which countries engaged in actual combat with one another. Third, it does not contain a variable for the contribution the third party made to the side it aligned with.

Conclusion: Intellectual Merit and Broader Impacts

My dissertation develops a theory to explain an important and under-research question in political science; why some interstate wars expand to include additional participants and others do not. The use of multiple methods–the integration of agent-based modeling and the statistical analysis of empirical data–will allow me to gain more insight into the process of war expansion than either method used in isolation would provide. Agent-based modeling allows me to uncover the emergent behavioral patterns of third parties during an ongoing war, as well as the effects of third party intervention on the dynamics of war. Statistical analysis allows me to determine whether the empirical implications derived from the model withstand empirical scrutiny.

The results of this research will provide important insights into 1) why third parties join interstate wars, 2) how third parties influence the decisions of other third parties, 3) how third parties effect the dynamics of the war, and in turn, how the dynamics of the war influence why wars expand, and 4) ultimately, how third parties influence whether conflicts of interest escalate to war or are resolved peacefully.

Research Schedule

- In the fall semester of 2006, I will complete the first two extensions of the agent-based model, run additional simulations, derive empirical implications, and draft chapters pertaining to the model and the current simulation results. I will also complete a manual, set up a data base system, and identify key sources for the data collection effort.

- In the spring semester of 2007, I will train and supervise two political science undergraduate assistants in collecting the data on 7 of the interstate wars. During this semester, I will complete the second two extensions of the agent-based model, run the necessary simulations, and derive additional empirical implications.

- During the summer of 2007, I will complete drafts of all of the theoretical chapters.

- In the fall semester of 2007, the research assistants will finish collecting data on the 6 remaining interstate wars. I will begin the statistical analysis and draft a dissertation chapter that presents and interprets the results.

- In the spring semester of 2008, I will complete the statistical analysis and the final chapters of the dissertation in time for a doctoral defense in June 2008.