An agent-based model of military mechanization

Tom Wallace

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1 Introduction

This paper presents an agent-based model of military mechanization. First, it provides a theoretical discussion of military mechanization, states the research hypothesis, and explains why agent-based modeling is an appropriate research strategy. Then, it details an original agent-based model; presents results; and discusses their implications for the academic debate on military mechanization.

In summary, the orthodox view of military mechanization is that it is a reflexive process: states choose their mechanization posture largely based on that neighbors and enemies. This paper argues that this view—based on traditional longitudinal data analysis—is ripe for agentization:

2 Background

2.1 Military mechanization

States differ in the composition of their military ground forces.[1] One notable axis of comparison is *mechanization*: the degree to which an army consists of infantry vs. combat vehicles. Treating mechanization as a continuous variable, one extreme is an army consisting exclusively of dismounted, small arms-wielding infantry units; the other extreme is an army consisting solely of tank units, armored personnel carriers, artillery, and the like. Clearly, no modern state embodies either extreme, but the 1970s-era Vietcong are a good example of a low-mechanization army and the 1980s-era Israeli army of high mechanization.

The consequences of choices regarding mechanization are large. There is academic consensus that defense policy—including but not limited to mechanization—conditions battlefield effectiveness. Lyall and Wilson 2009 finds that highly mechanized militaries are less effective at counterinsurgency, while Biddle 2004 argues that mechanization-enabled mobility aids conventional warfighting. It

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[1]States may have multiple organizations that conduct ground combat operations: e.g., the United States operates both an Army and a Marine Corps as independent services. Henceforth, this paper uses the terms "army" and "ground forces" interchangeably.

thus pays to have an army that is designed to win the kinds of conflicts that a state is likely to face. Lacking a crystal ball, however, leaders cannot always forecast conflict, and armies are large, complex organizations that typically are held to change only infrequently and slowly at that, even if there is a pressing need (Murray and Millett 1998, Locher 2004, Zegart 2000). A state suddenly faced with a war for which its mechanization posture is ill-suited can either concede or pay a cost in blood and treasure; what it cannot do is quickly overcome the constraints imposed by past mechanization decisions. A quote from then-Secretary of Defense Donald Rumsfeld—made in 2004, when the U.S. military was confronted in Iraq with the consequences of past choices regarding mechanization—emphasizes the point: "you go to war with the army you have" (Schmitt 2004).

The causes of military mechanization are disputed. *Realists* believe that mechanization choices are driven by security environment. States choose mechanization policies that they believe will allow them to prevail against potential adversaries, or to send a signal of deterrence, or to learn from the perceived mistakes of the last war (Mearsheimer 1983; Huth 1988; Murray 2011). The other school of thought is more diverse and so harder to name, but may be termed *institutionalists*. They believe that factors other than strategic calculation determine military mechanization. Domestic political institutions—e.g., democracy vs. autocracy, politically stable vs. coup-prone, the state of civil-military relations, and so on—may influence force structure (Reiter and Stam 2002; Quinlivan 1999; Talmadge 2015; Brooks 2008). Economic factor endowments may play a role: e.g., capital-rich states may mechanize more than labor-rich states (Gartzke 2001). Lastly, ideology (Van Evera 1984) and culture (e.g., Pollack 2004) are hard-to-measure but perhaps influential. Consider Ireland: between the 1920s and 1940s, it expended a large portion of its defense budget on building a small number of tanks. They were wholly insufficient to repel a British invasion (their ostensible purpose), and Ireland would have been better-served to pursue a low-mechanization guerrilla defense strategy, but tanks were seen as a prestigious signifier of a "real" professional military, an important factor for the young Irish state (Farrell 1998; Farrell 2001).

Sechser and Saunders 2010 is the landmark study on military mechanization. They assemble a longitudinal dataset at the country-year level of the mechanization of all states between 1979 and 2001, and conduct regression analysis to identify the effect of covariates on mechanization. They conclude that "choices about mechanization are strongly associated with a state's security environment." The more mechanized a state's geographic neighbors and enemies, the higher the state's own mechanization; also, states learn from defeat in insurgency by subsequently decreasing their mechanization.

2.2 The case for agent-based modeling

The findings of Sechser and Saunders 2010 are ripe for agentization. The conclusions drawn implicitly claim that states are autonomous agents; that they have cognition regarding how to perceive the outside world in terms of mechanization

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and how to adjust their own mechanization to it; that spatiality and neighborhood matter; that inter-agent relationships (e.g. whether you are my enemy or not) matter; and that agents learn from experience. Agent-based modeling is uniquely well-suited to represent such phenomena (Gilbert and Troitzsch 2005; Miller and Page 2009).

Importantly, the findings of Sechser and Saunders 2010 imply a positive feedback loop. State A has high mechanization, causing enemy State B to raise their mechanization, causing State A to raise their mechanization... and so on. Such feedback loops are a hallmark of complex systems and again are well-suited for representation by agent-based modeling. This specific one—states changing their military in response to other states change in military in response to... and so on—feedback loop—is often called the "security dilemma" and was a main research interest of Thomas Schelling, one of the pioneers of agent-based modeling (Schelling 1960; Schelling 2006).

2.3 Research question and strategy

I hypothesize that the arguments of Sechser and Saunders 2010 are incomplete and that some omitted variable or set of variables acts as a "brake" on military mechanization.[2] An agent-based model is used to test this hypothesis. In broad terms, agents (states) are defined to have the cognitive and learning behavior implicitly claimed by Sechser and Saunders 2010. The model is initialized with real-world data from 1979 and allowed to run until 2001. The micro- and macro-outcomes are then validated against real-world 2001 data. If Sechser and Saunders 2010 are correct, the model's 2001 outcomes should match real-world 2001 outcomes. If the model mechanization levels in 2001 are much higher, then their claimed behavioral rules are incomplete and fail to include some "brake" on mechanization, matching my hypothesis. Proving exactly what that missing variable or set of variables is is outside the scope of this model and paper, though it is discussed.

3 Model

This section of the paper describes the model. It does not use the ODD protocol of Grimm et al. 2006 but covers many of the same points.

3.1 Agents

There is one agent type: states. Agents exist at a fixed location and do not move. The set of agents encompasses all diplomatically-recognized states in the world at a particular point in time, minus microstates (defined as those with a population less than 750,000).

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[2]By "omitted", I mean that they conclude that the variable is not very important for mechanization, not that they do not address the variable at all.

Agents have attributes. *Name* is self-explanatory. *Mechanization* is the agent's level of mechanization at a given timestep. Mechanization is calculated as the number of armored vehicles per 100 soldiers, per Sechser and Saunders 2010. *Neighbors* is a list containing the *Names* of an agent's geographic neighbors at a given point in time—more on this in the subsequent **Environment** section. *NeighborsMech* is the average mechanization level of an agent's *Neighbors* at a given point in time. *Enemies* is a list containing the *Names* of an agent's enemies at a given point in time. An enemy is an agent with which the agent in question has had a militarized interstate dispute in the preceding ten years, per the Correlates of War (COW) Militarized Interstate Disputes Database (MIDB) (Palmer et al. forthcoming). *EnemiesMech* is the average mechanization score of enemies. Agents also have attributes that affect their perception of other agents and cognition for changing their own behavior. These attributes are discussed in the **Cognition and Actions** section.

3.2   Environment

Agents exist in a spatial environment. Spatiality is represented by neighbor relationships. Two states are defined as being neighbors if they share a contiguous land border or a stretch of water less than 400 miles. Data on neighbor relationships is taken from the Correlates of War (COW) Direct Continuity dataset (Stinnett et al. 2002). Modeling spatiality as dyadic neighbor relationships, rather than a more detailed raster or vector GIS implementation, is justified on the basis that the academic literature on mechanization suggests that two states neighboring each other is the important factor, not more detailed geographic information (e.g., topographical features along the border). As such, this paper's modeling choice captures the phenomenon of interest while avoiding the overhead of a full-blown GIS implementation.

3.3   Cognition

Agents have global perception of other agents: they can "see" the mechanization state of all other agents. This modeling choice is reflective of the real world, in which states devote significant resources to stay informed of the military posture of others. Agent cognition centers on updating their own mechanization in response to the external security environment. This occurs in three ways. One, if an agent's *NeighborsMech* increases—i.e., the agent's neighbors become more mechanized—the agent will increase its own mechanization by some proportional amount controlled by the agent's unique *NeighborMechSensitivity* attribute, which is heterogenous across agents (more on this below). Two, if an agent's *EnemiesMech* increases—i.e., the agent's enemies become more mechanized—the agent will increase its own mechanization by some proportional amount controlled by the agent's unique *EnemyMechSensitivity* attribute, again heterogenous across agents. Three, agents occasionally suffer an "anti-mechanization lesson": defeat in a counter-insurgency conflict. Such events are scripted to occur for agents and years as per the historical record:

e.g., the Soviet Union experienced such a lesson in the 1980s in Afghanistan. An agent experiencing such an event will decrease their own mechanization by some amount controlled by the agent's unique *LessonSensitivity* attribute, again heterogenous across agents.

An important note is that these three factors—neighbors, enemies, and defeat in counter-insurgency—correspond to the factors identified by Sechser and Saunders 2010 as most important for mechanization. Because the research goal is essentially to see whether their findings stand up to agentization, it is critical to make agent cognition work in about the way that their findings predict. Inclusion of other factors not identified as important for mechanization—e.g., alliances, economic factors, culture, etc.—would be interesting but counterproductive to the research question. They are discussed along with this model's findings.

Data for *NeighborsMechSensitivity*, *EnemiesMechSensitivity*, and *LessonSensitivity* come from Sechser and Saunders 2010. Specifically, they estimate coefficients and standard errors for these three factors, thus defining a statistical distribution for each. Upon instantiation, every agent makes a random draw from each of the three distributions, the resulting values of are taken for these three attributes. This introduces a stochastic element to the model and variation across runs, providing a richer body of data to draw upon.

3.4 Time

The model starts in 1979 and runs in 2-year time increments until 2001. This timespan and periodicity reflects data availability: a longer time period and more frequent updates would be ideal but is not practically achievable. Agent attributes are initialized, and then then the model iterates through timesteps.

In discussing what happens each timestep, it is useful to distinguish between things that depend on agents' actions and those that do not.

Some changes are deterministically programmed into the model and do not depend on agent behavior. Every timestep, neighbor relationships and enemy relationships are updated in accordance with the historical record. The occurrence of counter-insurgency defeats also is hardwired into the model and does not depend on agent behavior within the model.

Other changes do depend on agent behavior. Agent activation order in a particular timestep is random. Every timestep, every agent perceives the world aorund them; recalculates *NeighborsMech* and *EnemiesMech*; updates their mechanization level according to *NeighborMechSensitivity* and *EnemyMechSensitivity*; and updates their mechanization level according to *LessonSensitivity* if an anti-mechanization lesson occured.

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3.5 Output Data

4 Results

5 Discussion

6 References

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