



MASON RebeLand: An Agent-Based Model of Politics, Environment, and Insurgency¹

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Social simulation models from computational social science are beginning to provide significant advances in terms of implementing more complex social, human, and natural dynamics that are characteristic of how countries operate in the real world. In particular, increasingly realistic agent-based models can improve capacity for early warning, understanding, and prediction. The MASON RebeLand model presents three innovations over earlier models: (i) an explicit polity model with politically complete structure and processes; (ii) social and natural model components within an integrated socio-natural system; and (iii) generative dynamics where insurgency and the state of the polity (stable, unstable, failing, failed, and recovering) occur as emergent phenomena under a range of social and environmental conditions. Three scenarios are demonstrated, showing stable, unstable, and failing polity conditions. The MASON computational system for agent-based and network modeling also permits additional experiments and extensions.

The state of any given polity—in every country, ancient or contemporary, universally—depends on multiple internal and external factors. Exactly *how* is the state of a polity or its political stability affected by internal (endogenous) or environmental (exogenous) processes, such as changing conditions in its economy, demography, culture, natural environment (ecosystem), climate, or combined socio-natural pressures? This general question and its many variations represent a major unsolved challenge in social science in general and computational social science in particular. It is also a question of significant interest in policy circles. Answering such a question and related versions is also necessary for improving applied research, such as for early warning and prediction. This article presents an agent-based model of a polity with structure and process based on contemporary political science concepts and principles—that is, a political system specifically composed of a geographically situated society with a system of government that produces policies for addressing public issues. Moreover, aggregate or collective features such as public moods, domestic political instability, insurgency, and state failure are generated endogenously as emergent phenomena from individual (actor-level) and institutional behaviors. Both the polity and its natural environment in this model can be extended in a number of research directions.

¹Funding for this study was provided by the Center for Social Complexity of George Mason University and by ONR MURI grant no. N00014-08-1-0921. Thanks to members of the Mason-HRAF Joint Project on Eastern Africa (MURI Team) and to Armando Geller, Rebecca Goolsby, Gerald Schneider, John Tagney, Peter Turchin, Nils B. Weidmann, and anonymous reviewers for comments. The opinions, findings, and conclusions or recommendations expressed in this work are those of the authors and do not necessarily reflect the views of the sponsors.

Background

The terms *stability* and *instability* have two different meanings in social and political science (for example, compare Bhatia and Szego 2002 with Choucri, Goldsmith, Madnick, Morrison and Siegel 2007):

1. Political stability in the classical dynamical sense of Ljapunov and systems theory, means that a polity is stable, if and only if, it can withstand changes under a given range of various forms of stress, such as social, economic, political, or environmental stress that may or may not include violence. In this sense a polity may or may not be violent when it is unstable; and vice versa, because stability and violence are not always directly correlated. Stability in this sense is a deep dynamical property.
2. Political stability also means lack of political violence, so—conversely—political instability in this second sense means (that is, is synonymous with) occurrence of public violence in a given polity. Accordingly, stability in this second common sense is an observed behavior unrelated to deeper dynamical properties.

Clarifying these meanings is important for basic (theory, understanding) and applied purposes (early warning, prediction). For model-building purposes we use the terms political stability and instability in the former sense of systems theory, although the latter type (political violence) is obviously also relevant.

Earlier Empirical Studies

Prior empirical studies have identified several variables responsible for political instability. Early research uncovered relative deprivation as an impetus to civil unrest (Gurr 1970), showing that the probability of political instability increases as the gap between “perceived” needs and “actual” gains of a given state’s population grows. Subsequently, others argued that revolutionary movements serve as an outlet for the general population’s frustration with the current social structure of the state, leading citizens to use violence to realign this structure to attain expected social benefits (Morrison 1971). Political instability as violence is still relevant despite some criticisms (Gurney and Tierney 1982) as being too individualistic (that is, not explaining why citizens would respond to their frustrations collectively), not separating cause from effect (that is, not distinguishing between relative deprivation as a structural as opposed to perceptual feature of society), and a number of its assumptions rest on weak psychological foundations (that is, the aggressive response as the only response to social frustration).

Weaknesses in the theory relative deprivation have led to development of the “culturalist” argument, positing ethnic or religious differences as sources of political instability. While researchers continued to maintain the classic economic argument of the “haves” versus the “have-nots,” other studies (for example, Horowitz 1985; Connor 1994; Huntington 1996) have investigated the role of nationalism and identity as proposed by culturalists (Deutsch 1953; Anderson 1983; Gellner 1983). This group hypothesized that political instability was higher not just when relative deprivation was present or perceived to be present, but when deep-seated cultural differences (latent unobservables) served as the defining characteristic of competing groups. The salience of this argument grew at the end of the Cold War as religious and ethnic conflicts began to make headlines. Some important points should be noted about this research. First, it has not entirely replaced relative deprivation theory, as it was understood that differences alone provide little impetus for conflict. Second, culturalism seemed to

claim that conflict was inevitable (Huntington 1996), although historical circumstances might indicate otherwise.

Some recent empirical studies provide conflicting support for earlier work, leaving culturalist claims open to debate. Two independent studies have recently cast doubt on the culturalist argument. Fearon and Laitin (2003) argue that the opportunity to rebel is as important as the motivation or willingness for rebellion (consistent with Cioffi-Revilla and Starr 2003[1995]), showing that the probability of civil unrest does not depend on cultural fractionalization or economic disparity but rather on particular features of a state that favor insurgency (that is, different opportunity structures), such as rough terrain, large populations, and financial and/or bureaucratic weakness. Others have extended this “opportunity” argument by focusing on the financing of insurgency activity through “lootable” resources (Collier and Hoeffler 1998, 2004). Political violence is more likely in states with weak institutional structures and highly accessible natural resource endowments with high marketability such as diamonds or gold. These two studies have been important in emphasizing the dichotomy between state and rebel capacity in regard to political instability. Recent work by Cederman and Girardin (2007), despite questioning the research methods of Fearon and Laitin, further supports an opportunity-based process for political instability albeit with the presence of ethnic conflict. The failure of institutions is also highlighted by studies on the political instability of partial or weak democracies (King and Zeng 2001).

In summary, previous empirical work has highlighted a set of variables that should underlie a model of civil unrest. This research typically maps some combination of motivation and opportunity to the onset of insurgency and political instability. Researchers have defined motivation primarily as a relationship between the perceived needs of the general population and the ability of the state to fulfill these needs. One can measure capacity in this manner by identifying the state’s ability to provide collective goods in times of need (Fortin 2008), an approach that is also consistent with the dynamical meaning of stability (not the former based just on violence). Yet, this literature has also shown that motivation is meaningless without the means to execute insurgencies. This has led researchers to define a set of enabling and constraining features of states that increase the likelihood of political instability. In terms of enabling insurgency, empirical studies highlight the importance of financial resources and social alliances. These are then buffered by constraints such as the strength of the institutional and military capacity of the state or the cover offered by its social–political terrain (that is, population demographics or geographic features). Finally, if an insurgency were to get off the ground, success is often tied to a mixed strategy using violence to disrupt government legitimacy and funding social programs to win over the general population (Kalyvas 2006; Mousseau and Mousseau 2007). Some of these features have already made their way into existing computational models of civil unrest, as mentioned in the next section. However, as demonstrated below, our model provides a wider treatment of these phenomena for understanding (and eventually predicting; O’Brien 2009) how micro-level dynamics between society and government affect overall polity stability.

Earlier Computational Modeling

The first computational models of civil unrest appeared during the Cold War, in parallel to but methodologically distinct from empirical studies. These early models focused specifically on the dynamics of asymmetric conflict—that is, irregular war, guerilla war, insurgency, and other forms of domestic political violence that may induce instability in a polity for both pure (theoretical) and applied (prediction) purposes. From a formal methodological perspective, these earlier models

used systems of ordinary differential or difference equations (ODEs) to represent the main macro-structural relations among belligerents and, consequently, were typically implemented using the system dynamics approach (Forrester 1968; Hanneman 1988). These models attained their greatest success when representing asymmetric conflict at the most aggregate level (Gilbert and Troitzsch 2005:53). These models were also often empirically specialized to represent prominent insurgency cases at the time, such as the Vietnam War or the Soviet invasion of Afghanistan (Milstein and Mitchell 1969; Ruloff 1975; Allan and Stahel 1983; Stahel 1985). In fact, from the birth of computational modeling until the more recent introduction of object-oriented methodology of agent-based modeling (ABM), the dominant approach to computational exploration of civil unrest was through the use of system dynamics models (Choucri *et al.* 2007) or through large-*N* studies (for example, King and Zeng 2001; Bates 2008).

Most computational research in civil unrest is now undertaken using the ABM approach, with relatively fewer models using the system dynamics approach (Choucri *et al.* 2007). The turn toward ABM is due to the recognition of the importance of “bottom-up” causal processes in the development of civil unrest (Fearon and Laitin 2003; de Rouen and Sobek 2004; Kalyvas 2006; Cederman and Girardin 2007). ABM permits researchers to move beyond the limitations of the aggregate approach underlying system dynamics models, encouraging researchers to identify and experiment with the micro-processes involved in the production of emergent macro-scale social patterns or distributions (Epstein and Axtell 1996). This has led researchers to attempt to understand the complex relationships of critical actors involved in socio-political instability—that is, civilians, government (at various organizational levels), rebels, and government forces (military or police). The Sugarscape model of Epstein and Axtell was one of the first ABM simulations to demonstrate the significance of this “emergence” method (Epstein and Axtell 1996; Bigbee *et al.* 2007). With a few simple rules, Sugarscape was able to reproduce macro-social patterns in the abstract, permitting experimental investigation of micro-dynamics capable of driving conflict, as well as analysis of other economic and social dynamics (for instance, wealth distributions).

In subsequent work, Epstein (2002) has applied Sugarscape’s conflict mechanisms to produce one of the first civil violence ABM simulations, investigating the emergence of rebellion and ethnic cleansing behavior as a product of the perception of police force numbers and intervention tactics at the level of individual agents. Unlike early state-level ABM simulations incorporating concepts of nationalism and domestic culture (such as the GeoSim model, Cederman 2003; Gioffi-Revilla and Gotts 2003) or collective identity models (Lustick 2000), the Sugarscape/Civil War model (Epstein 2002) takes a highly magnified approach to examine the citizen-based impetus for rebellion as opposed to simply outlining the effects of domestic unrest upon international relations. The ISAAC and EINSTEIN models (Ilachinski 2004) use a similar technique to model combat at the level of individual soldiers. These models were also the first to rigorously apply insights from complex adaptive systems, such as the notion of self-organization, to replicate a range of nonlinear dynamics commonly found in irregular warfare. These early models set examples that led to the development of a small suite of civil unrest models in subsequent years.

Current models of civil unrest extend earlier models through the introduction of some form of either natural or social complexity. For example, the IRUBA model (Doran 2005)—a meso-scale replication of Epstein’s civil violence model at the level of provincial conflict—uses simple geographic features such as terrain and spatial distribution of rebel resources and forces to test various insurgency and counterinsurgency tactics. Bennett’s (2008) most recent work in this same area omits variations in terrain but instead includes social emotions, such

as the distinction between the perception of fear and anger in domestic populations, resulting in a favorable evaluation of the US military's new "hearts and minds" strategy. The REsCape model (Bhavnani, Miodownik and Nart 2008) also omits geographic features but provides the first representation of selected institutions within a repressive state. These models use social networks (for instance, news media), weather events (tsunami), social identities (ethnicities), and political/economic freedom to explore the development of civil unrest. The MASON RebeLand model builds on these extant efforts in the most recent generation of computational models.

The MASON "RebeLand" Model

RebeLand is a model of a simple abstract polity designed to highlight essential and recognizable features of socio-natural complexity required to generate "bottom-up" civil unrest that can (although not always) lead to state failure. Similar to REsCape (Bhavnani *et al.* 2008) and in a more specialized way than GeoSim, events in RebeLand are driven by spatio-temporal interactions of abstract civilian agents whose social support is needed to maintain governmental legitimacy and capacity in an effort to either quell (from the point of view of the government) or foment (from the perspective of the rebel) rebellion possibly leading to regime change. RebeLand builds on previous meso-scale simulations of civil unrest, such as REsCape, as well as micro-scale simulation models such as IRUBA, Bennett's insurgency model, Epstein's civil violence model, ISAAC, and EINSTEIN, particularly with respect to emphasis on emergent or generative collective behaviors and their impact on the state. At the level of the individual, RebeLand models movement patterns and attack strategies of both rebel and government forces, the success of which influences resulting struggles for state power. In sum, RebeLand builds on the meso- and micro-level strengths of its predecessors, aiming to model socio-political behaviors that are recognizable to a political scientist while maintaining minimalist (parsimonious) socio-natural complexity.

The basic research questions addressed by RebeLand are two:

1. How does a polity respond to various levels and combinations of societal stress and governmental performance?
2. How can insurgency, domestic political instability, or even state failure in some extreme cases emerge as a bottom-up phenomenon in the life of a polity?

Both questions have pure and applied motivation, linked to theory and policy, respectively. The simulated model polity must be spatially situated (geography is a constituent, not optional, feature of every country in the world) and possess a system of government that conforms to canons of political science. The latter requirement means that the governmental architecture must be recognizable to a political scientist, not implicit or arbitrary. Additionally, following a complexity perspective, emergent phenomena must be generated by the interaction of agents in a "bottom-up" way; it must not be hard-wired.

The RebeLand model is written in MASON (Multi-Agent Simulator of Networks or Neighborhoods; Luke, Cioffi-Revilla, Panait and Sullivan 2005), an agent-based modeling simulation toolkit written in the Java programming language. (The MASON Project URL is: <http://cs.gmu.edu/eclab/projects/mason/>). Examples of other agent-based modeling toolkits include Netlogo, Repast, and Cormas (Gilbert 2008; Nikolai and Madey 2009).

An important design feature of the MASON system for developing social simulations is its original architecture in terms of completely separating computation

from visualization, thus increasing speed and other desirable features needed in this investigation (for example, “data fields” for individual cognitive structures in subsequent versions; see Discussion). Another MASON feature (not yet used in current versions of *RebeLand*) is its ability to run in combination with ECJ, a widely used evolutionary computation software.

Other related MASON models developed thus far include the Wetlands, HouseholdsWorld, Hierarchies, and AfriLand models, all of which are also spatially oriented agent-based models with interactive societal and natural environments to reflect geographically situated polities (Collier and Hoeffler 2004; Cioffi-Revilla, Luke, Parker, Daniel Rogers, Fitzhugh, Honeychurch, Frohlich, Depriest and Amartuvshin, 2007, Cioffi-Revilla et al. 2008; Cioffi et al. 2008; Cioffi-Revilla and Rouleau 2009). *RebeLand* is a single-country model, whereas other MASON models thus far represent other forms of social organization: Wetlands represents a society of simple hunter-gatherers with minimal social complexity at one end of the spectrum, while the international system in AfriLand represents another end of the spectrum as a multi-country model with a substantial level of social complexity.

Model Structure

Figure 1 shows a “map” view of *RebeLand* as a polity or country that is situated in a natural environment, with a basic socio-natural system or socio-ecological ontology (Simon 1996; Liu, Dietz, Carpenter, Alberti, Folke, Moran, Pell, Deadman, Kratz, Lubchenco, Ostrom, Ouyang, Provencher, Redman, Schneider and Taylor 2007; Ostrom 2009). The country itself consists of an island surrounded by water, therefore omitting external or neighboring interactions with other countries (that is, lacking any neighboring international relations in this initial

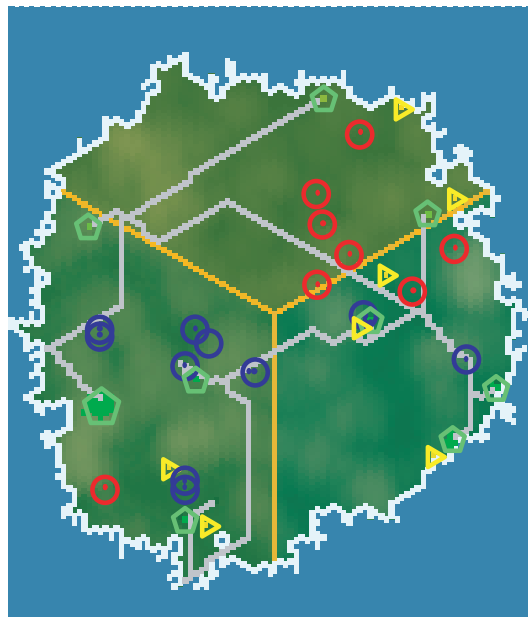


FIG 1. Map of *RebeLand* Island showing its main natural and social features. Cities are shown in green, natural resources in yellow, and rebel and government forces in red and blue, respectively. Roads and provincial boundaries are in gray and yellow, respectively. Physical topography is shown on a green-tone scale and the island is surrounded by ocean. *Source:* Prepared by the authors.

version). Both polity and environment are simple, but grounded in each relevant domain. The socio-natural interaction is also intentionally simple, reflecting mostly environmental effects on the polity. (Subsequent research will also examine long-term anthropogenic effects on the environment.) The environmental and political components of RebeLand are as follows.

Environmental Component

The RebeLand environment consists of terrain and a simple weather system that simulates climate dynamics. For example, climate change events such as prolonged droughts, climate variability, and other climatological features can be simulated in RebeLand. Research on societal effects or consequences of climate change and variability was a design requirement.

In turn, the terrain consists of physical topography and land cover. Additionally, generic natural resources (for example, oil, diamonds, gold, or similar; yellow triangles in Figure 1) are distributed over the terrain. Additional features (such as hydrology and other ecosystemic components) can also be added.

Political Component

The political component of RebeLand is specifically designed to answer the basic research questions stated earlier. Following a political science orientation, the RebeLand polity consists of a society and a system of government for dealing with public issues through public policies (see Figures 2 and 3), as in the standard model of a basic polity (Almond, Bingham Powell, Dalton and Strom 2006; Cioffi-Revilla 2009). Initially, and as we demonstrate in the subsequent section, the government formulates policies to address issues that affect society. Later in the simulation, under some conditions, the society can also generate insurgents that interact with government forces, as well as other emergent phenomena.

There are three provinces in RebeLand (see Figure 1), each with a subset of population centers, resources, roads, and other features of the country. Provincial boundaries (yellow) were drawn to produce approximately equal size, but this and other features can be easily modified.

Following a social geography orientation, the population (society) is not arbitrarily located, but rather is concentrated in centers (a capital city, provincial cities, towns, and villages) and the set of population centers is distributed throughout the island according to a Zipf distribution with some noise. A system of roads connects population centers with natural resource locations. The roads

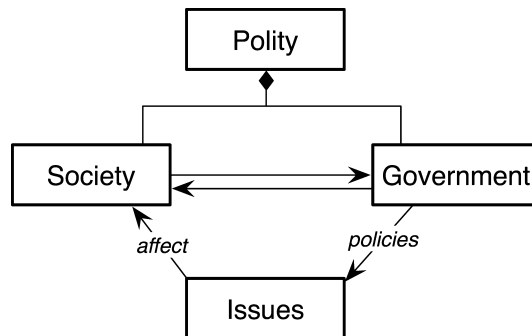


FIG 2. High-level UML class diagram of a simple polity such as that represented in RebeLand. Government manages public issues through policies. A more detailed UML class diagram of RebeLand (omitted here for space considerations) would include levels of public administration across the country (State and Cities in the three provinces) as well as heterogeneous agents (general population, rebels, and military). *Source:* Adapted from Cioffi-Revilla (2009).

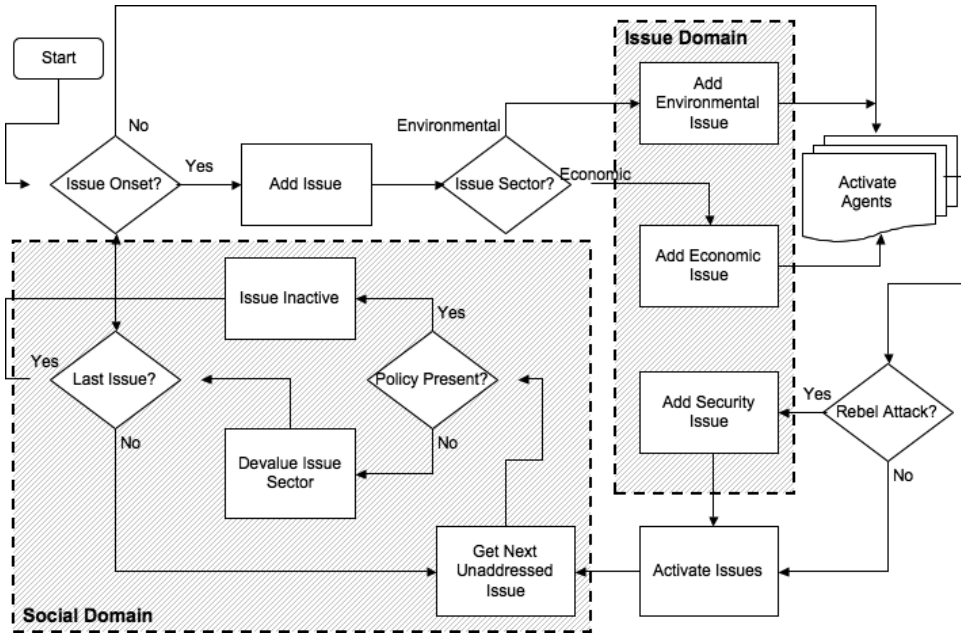


FIG 3. Graphical interpretation of the main simulation loop from the perspective of the RebeLand socio-natural environment. Issues enter the environment with a user-defined issue onset rate, a log-normal decay rate, and a power-law distributed magnitude. This allows users to define the level of stress a government will probably face in a given simulation run. The agent activation state (“Activate Agents”) is detailed Figures 4–6.

were drawn using a gradient-driven algorithm that takes into consideration distance and terrain, as detailed below.

Given the ontology just described, there are two classes of RebeLand agents. Primary agents consist of the general population, cities, and the state. Cities represent local public administration organizations, whereas the state represents the system of government of the overall polity (national government). Secondary agents consist of rebels generated from the general population under a range of conditions (discussed below), rebel groups, and government forces representing police and military units. Rebels are supported by rebel group organizations (“horizontal polities”; Ferguson and Mansbach 1996) that support them and fund alternative policies that rival official state policies. Thus, rebel groups represent horizontal or alternative polities or organizations (such as Hamas, Hizbullah, or Sendero Luminoso) that compete with the state (the official “vertical” polity) regarding the provision of public goods to the population. Government forces seek to destroy insurgents by attacking them and guarding the home city.

Dynamics

Besides the formalization of entities in a structural sense, a key strength of agent-based models lies in the ability to formalize dynamics in complex social systems—such as in a polity.

From a high-level perspective, RebeLand aims to operate as all polities do: At any given time, a public issue affects the population, which causes societal stress. In response, government formulates and implements policies that aim to eliminate or mitigate stress on the population. Government operates with capacity derived from revenues produced by taxes (public finance), and taxes are paid by

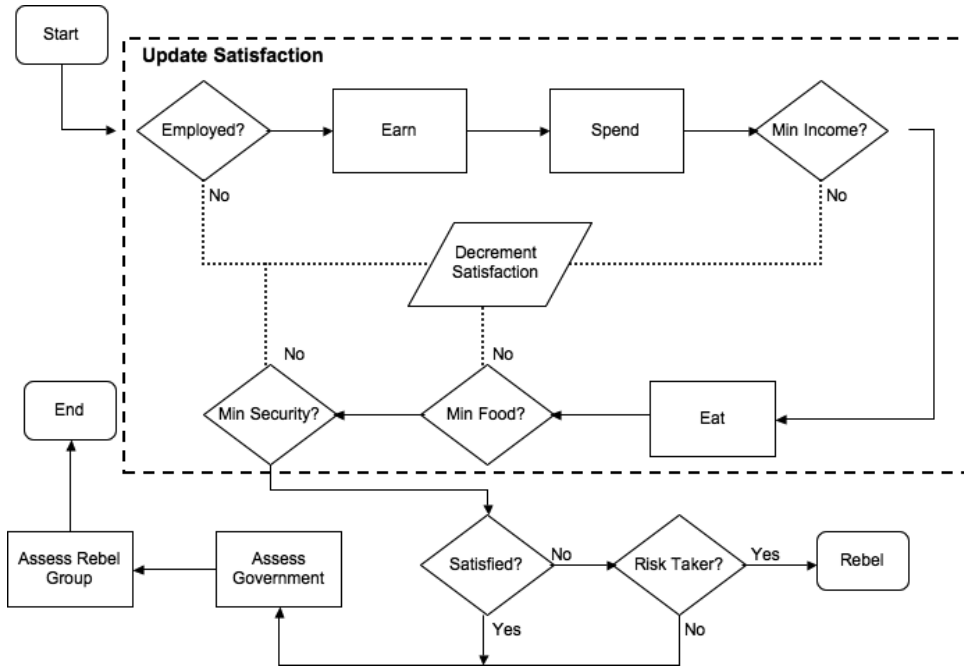


FIG. 4. Graphical representation of the main simulation loop from the perspective of the general population. When activated by the scheduler, a general population agent will perform its day-to-day functions, update its satisfaction, assess its support for the government (based on the government's ability to address pending social issues), and assess its support for a rebel faction (based on the rebel group's funding of alternative policies and the rebel use of violence as it affects the general population)

the population based on disposable income derived from labor. Normally, state capacity is sufficient to deal with public issues, but various factors can contribute to instability and even political change—just like in real-world polities.

More specifically, *initialization* and the *main simulation loop* in RebeLand are as follows. Understanding these dynamics is important for purposes of both analysis and applications (early warning, prediction), as lack of familiarity with the underlying computational processes of the simulation model can be a source of misinterpretation.

Initialization

The RebeLand simulation begins by generating a random island environment. Starting from the center-most cell, a “greedy” algorithm selects a pre-defined number of contiguous grid cells that will serve as the island's land cells. Next, a terrain generation algorithm makes a series of random elevation changes conditioned by a user-defined parameter of three possible natural environments: grassland, hills, and mountains. The simulation then randomly distributes resources (oil, gold, and diamonds) throughout the island and calculates their profitability based on current market value, amount of resource present, distance to nearest shoreline (tradeability), and distance to the next nearest resource.

Following a Zipf distribution of cities sizes (Berry, Griffith and Tiefelsdorf 2008), the city center of the largest city is placed on the cell of the most profitable resources. One thing to note is that each cell has a maximum general population capacity. Thus, if the city center cell is overpopulated, a random neighboring cell is chosen and the remaining population inhabits this

cell. This process continues until all general population agents belonging to this city have been placed onto the map. The city placement algorithm is repeated with the city center of the next largest city being placed on the cell of the next most profitable resource, and so on, until all cities have been placed on the island. Finally, an A* algorithm is used to draw a “shortest path” road network between the cities, accounting for both elevation changes and linear distances.

Main Simulation Loop and Typical Simulation Run

The RebeLand main simulation loop conforms to the known system and processes of a polity based on contemporary political science theory (Cioffi-Revilla 2009). In a typical model run primary agents (general population, cities, the state) perform day-to-day tasks including a basic subsistence cycle for the general population (see Figures 3–6). Issues affect the population in the cities or, more generally, the national population as a whole. Issues can originate within the society itself (such as inflation increasing; an issue endogenous to the society) or in the environment (drought or other ecological change or disaster affecting agricultural productivity; exogenous to the society). Local city governments produce policies to deal with public issues. If population dissatisfaction increases due to stress, insurgents may be generated from the population. If so, then government generates counterinsurgency units to combat and manage the insurgency—if and when it is capable. Insurgency is also a source of public issues and stress on the population, along with other sources such as the environment and/or endogenous social processes.

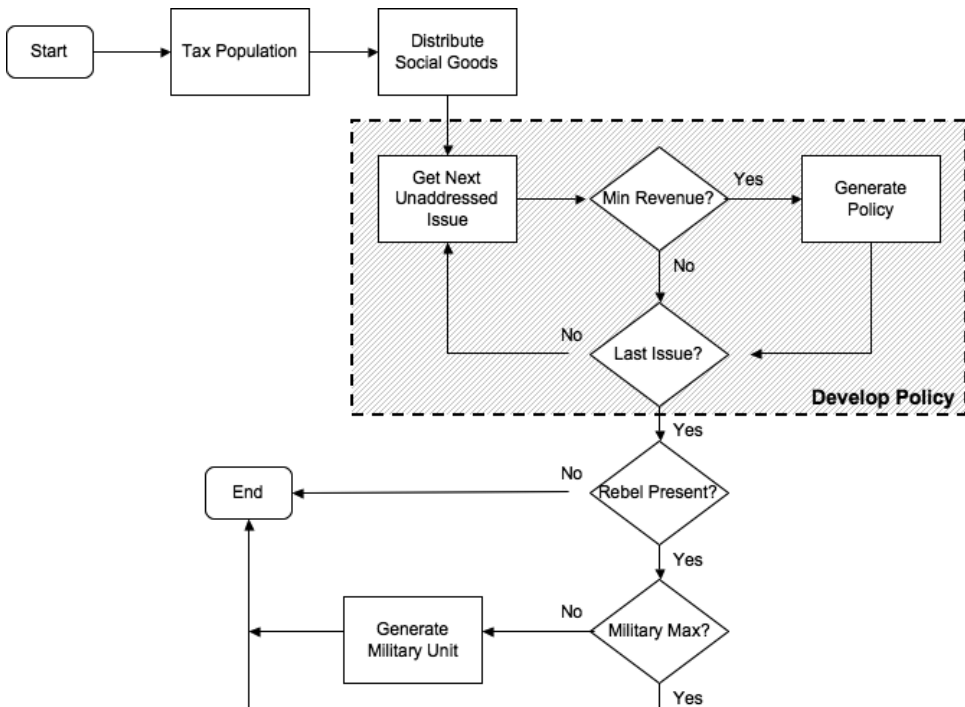


FIG 5. Graphical representation of the main simulation loop from the perspective of the city agent. Each city will tax its population to gain a source of revenue. This revenue is then used to implement policies as a means of offsetting the effects of a pending social issue (inflation, flood, etc.). The city is also responsible for generating military units to defend itself from rebel attacks.

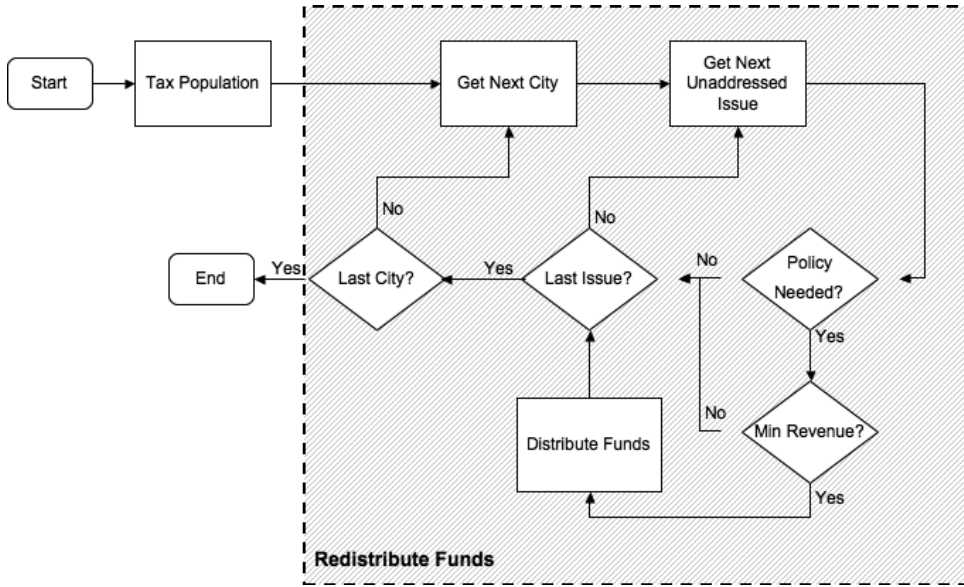
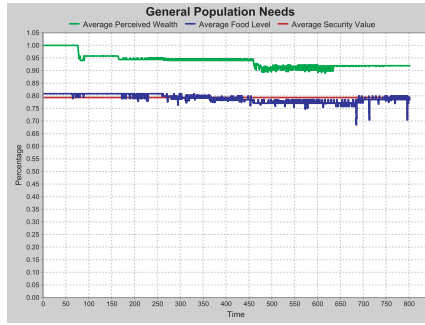


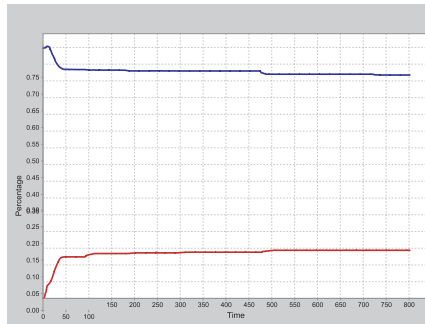
FIG 6. Graphical representation of the main simulation loop from the perspective of the state. The state is a high-level decision maker responsible for revenue redistribution in the case where some cities have an excess of funding while other cities lack the funding needed to support necessary policies.

More specifically, once the RebeLand island environment and society are defined, a typical simulation run involves a number of potential agent-to-agent and agent-to-environment interactions. The simulation schedule activates agents at random and, once activated, each agent both performs expected tasks and responds to its current environment. For example, general population agents attempt to earn income, purchase goods, and maintain their subsistence needs as expected tasks. Depending on their social condition, general population agents will adjust their satisfaction and regime support values appropriately. City government agents tax the general population to build revenue and distribute welfare benefits. If economic or environmental issues are present, the city agent will attempt to use its available revenue to generate policies which then dampens the effects of these issues on their citizens (that is, mitigates social stress, a key function of government and public policy in a stable polity). If rebel forces are present, city agents use conscription to create a military force to defend the city. Finally, the last of the non-mobile agents, the state agent, simply directs a share of the remaining city revenue toward the most pressing issues left unsupported.

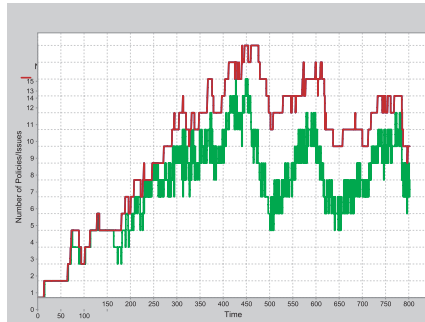
Both general population agents and city agents are also capable of producing mobile agents when conditions necessitate. For example, general population agents can create rebel groups or individual rebel agents when their satisfaction level drops below a minimum threshold and their risk propensity is relatively high. On the other hand, city agents create military units in response to the presence of these rebels. Both these rebel and military agents are then added to the simulation schedule and the main simulation loop changes to include their actions. Upon activation, rebel agents pick a target for terrorism and attempt to move toward this objective. If no military units are present, the rebel agent moves toward its target and, when reaching the target, commits the terrorist act. If military units are present,



(a) General population needs under a stable scenario. Perceived wealth (green), available food (blue), perceived security (red).



(b) Support for government (blue) and support for rebels (red) under a stable scenario.



(c) Trends in state capacity under a stable scenario. Number of concurrent issues (red), concurrent policies (green).

FIG 7. RebeLand simulation run under a “stable” scenario where government has sufficient capacity to manage public issues that arise in the normal life of the polity and public support remains favorable. General population needs under a stable scenario. Perceived wealth (green), available food (blue), perceived security (red). Support for government (blue) and support for rebels (red) under a stable scenario. Trends in state capacity under a stable scenario. Number of concurrent issues (red), concurrent policies (green).

rebels simply attempt to move away. Military units, on the other hand, seek out rebels and engage in combat on sight. The success of these combats is then determined by a random draw weighted by the size and resource endowment of each combatant force. In sum, the main simulation loop of RebeLand consists of a number of expected and reactive actions that result in the development of recognizable patterns of civil unrest as an emergent phenomenon.

Computational Demonstration Results

In this section we report results from three experimental scenarios simulated in RebeLand to illustrate its potential for basic and applied research. Each scenario was run numerous times with similar results and the results reported here are representative of each scenario.

The first scenario represents a *stable* political situation—in the sense defined above—where government successfully manages public issues and society is satisfied (Switzerland). The second scenario is a significantly more *contentious* political situation where public issues produce extensive societal discontent, dissent, and incipient insurgency which, however, is managed by government (Mexico, Russia, and Columbia). The third scenario is an *unstable* political situation where the insurgency manages to topple the government, bringing about state failure (Somalia).

For each scenario we report three sets of simulation results using the time-series graphs shown in Figures 7–9:

- (a) General population needs in terms of average perceived wealth (green), average food level (blue), and average security value (red);
- (b) Population support for government (blue) versus support for rebels (red), representing key dimensions of public opinion; and
- (c) Trends in state capacity in terms of number of current public issues being managed (red), number of non-security issues (blue), and number of current polices (green).

Stable Scenario

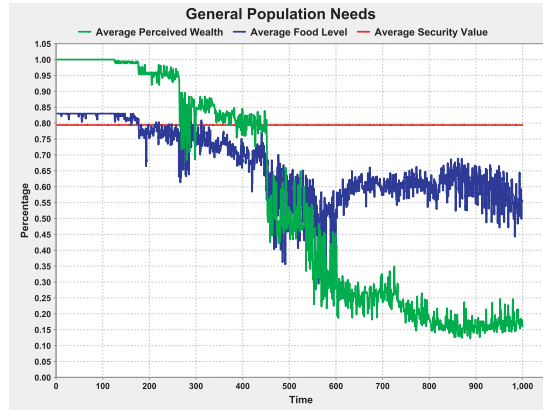
Figure 7 shows results from the first scenario or stable regime. This baseline case shows the general population quite happy in terms of average perceived wealth, eating well, and feeling secure (Figure 7a), as in a stable and prosperous country. Concurrently, levels of support for government are high and, conversely, support for rebels remains low (Figure 7b). As well, governmental policies keep track of emerging public issues (Figure 7c) so the polity is operating in a stable mode. Some minor support for rebels can exist, even in this stable scenario, because the state has sufficient capacity to deal with issues.

Contentious Scenario

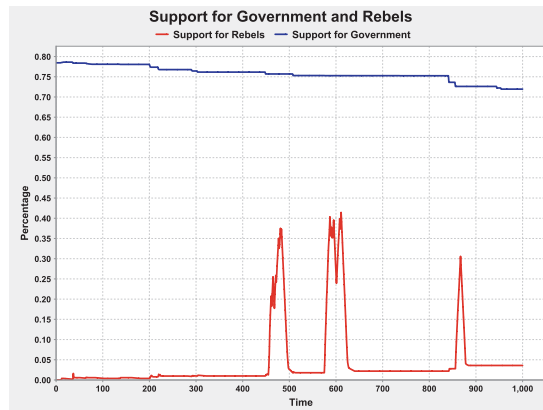
Results from the second, contentious scenario are shown in Figure 8. This case shows the general population as being less satisfied in terms of average perceived wealth, eating less well, and feeling somewhat less secure (Figure 8a), as in a less stable but still mostly viable country. In this case levels of support for government can remain high but, conversely, support for rebels is occasionally spiked when hunger and poverty begin to take hold (Figure 8b). In this scenario governmental policies have a harder time keeping up with emerging public issues (Figure 8c) so the polity is operating in a decreasingly stable (increasingly unstable) mode. Note that support for rebels (8b, red) drops back down after each spike, but resettles at slowly rising levels, indicative of a fundamental (diachronic) rift.

Unstable Scenario (State Failure)

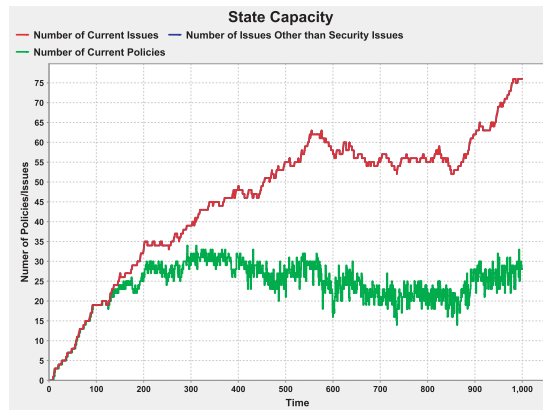
Results from the third, unstable scenario are shown in Figure 9. This case shows a more severe decrease in the average perceived wealth of the general population, in addition to eating less well, and feeling significantly less secure



(a) General population needs under a contentious scenario.

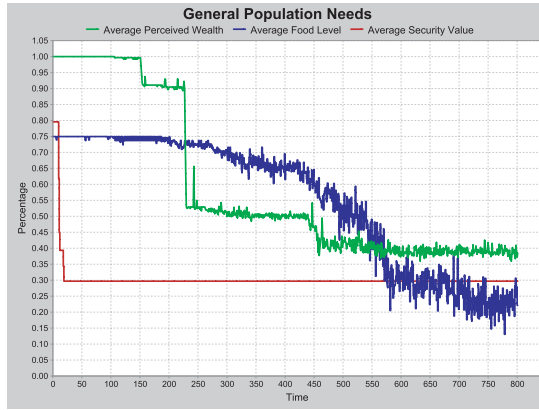


(b) Support for government and support for rebels under a contentious scenario.

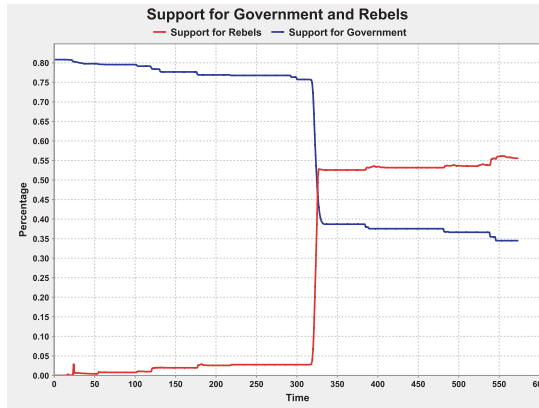


(c) Trends in state capacity under a contentious scenario.

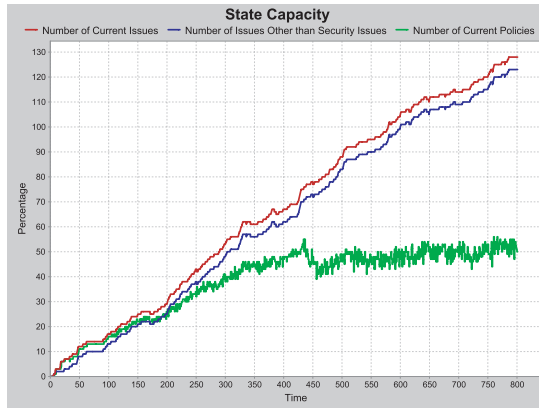
FIG 8. RebeLand simulation run under a “contentious” scenario where government still has sufficient capacity to manage public issues that arise in the normal life of the polity but insurgency emerges as a consequence of popular dissatisfaction. Legend is the same as in Figure 7. General population needs under a contentious scenario. Support for government and support for rebels under a contentious scenario. Trends in state capacity under a contentious scenario.



(a) General population needs under an unstable scenario.

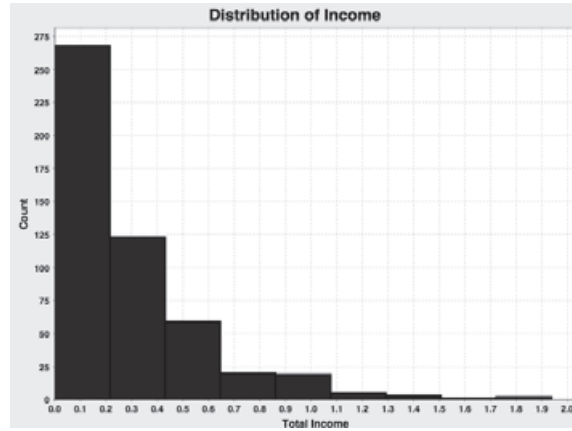


(b) Support for government and support for rebels under an unstable scenario.

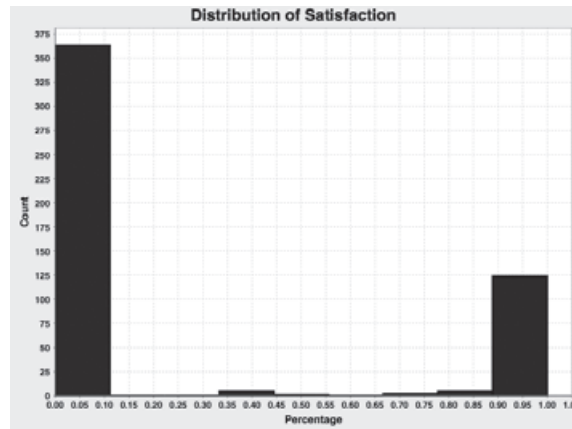


(c) Trends in state capacity under a contentious scenario.

FIG 9. RebeLand simulation run under an “unstable” scenario where government has insufficient capacity to manage public issues and the emergent insurgency manages to topple the government. Legend is the same as in Figure 7, plus non-security issues (blue). General population needs under an unstable scenario. Support for government and support for rebels under an unstable scenario. Trends in state capacity under a contentious scenario.



(a) Pareto distribution (power law) of individual agent income.



(b) Bimodal distribution of agent satisfaction.

FIG 10. Individual agent distributions in RebeLand: Income and satisfaction. These simulated results resemble known empirical patterns. *Source:* Prepared by the authors. Pareto distribution (power-law) of individual agent income. Bimodal distribution of agent satisfaction.

(Figure 9a), as in an increasingly unstable polity with declining prosperity. In this case levels of support for government plummet catastrophically (around time = 325), with a corresponding rise in support for rebels (Figure 9b). In this unstable scenario governmental policies do not keep track of emerging public issues (Figure 9c), even when such issues no longer concern security (as shown by the blue non-security issues metric on Figure 9c). This scenario produces state failure as an emergent phenomenon; a consequence of the government being overwhelmed by public issues relative to state capacity and concomitant popular support for rebels.

The interesting political phenomena in RebeLand—namely shifts in public moods, onset of insurgency and its subsequent development, and governmental crises and state failure episodes—always occur as emergent phenomena, not as directly hard-wired processes or events; and consistently across all three scenarios. In other words, RebeLand is universally capable of producing these

phenomena as a result of its own endogenous dynamics, as a generative computational theory should (Epstein 2006). These properties are as significant for theoretical purposes as they are for practical policy and analysis purposes. Interventions on complex systems based on poorly understood dynamics can lead to undesirable consequences.

In addition to these results, RebeLand is also able to replicate two significant patterns commonly found in real-world polities: a Pareto (power-law) distribution of income (Figure 7a) and a bimodal distribution of popular satisfaction (7b). Both results lend face validity to the model. Empirical features such as these and others are necessary in models intended for applied purposes (early warning, prediction), whereas they are less necessary in purely theoretical models for developing basic understanding or insights.

Discussion

Our results so far demonstrate two important points related to the initial research questions that RebeLand was designed to investigate: (i) the state of the polity as a whole does indeed respond to various levels of societal stress and governmental performance, by remaining stable (scenarios 1 and 2) or in some extreme situations (scenario 3) undergoing regime failure, consistent with contemporary political theory; and (ii) the overall political dynamics (insurgency, political instability, and state failure) emerge as “bottom-up” phenomena (they are not hard-wired) through complex mechanisms and feedback loops that can be traced down to the perceptions, decisions, and actions of many individual agents in the populations in interaction with government and a natural environment. Although many features and processes would still have to be included to approximate a real-world country, these basic results provide significant face validity and encouraging prospects for further analysis and development.

In reference to the extant empirical literature mentioned in the introduction, RebeLand resembles a semi-democracy, that is somewhere between a democracy and autocracy. This is because the polity is designed to respond to societal stress with governmental policies aimed at mitigating or eliminating stress, as in a democracy that responds to citizen’s needs. However, RebeLand lacks a constitutional specification for governmental turnover and accountability (“institutional design”; Landman 2008:218), in this respect resembling more an autocracy. Interestingly, as a semi-democracy, state failure in RebeLand (scenario 3) shows the effects of stress and insufficient governmental capacity recently reported by the empirical literature. For example, very high levels of infant mortality (reflecting a high level of stress on the population) and legislative inefficiency correlate with high risk of state failure (King and Zeng 2001). Similarly, predation on governmental resources (rent seeking) and corruption, which are common features in many countries on a global basis, can similarly bring about state failure in semi-democracies that once stood a reasonable chance of becoming more stable democratic polities (Bates 2008). In sum, results from RebeLand are consistent with the empirical finding that “partial democracies have a higher risk of failure than either full democracies or autocracies” (King and Zeng 2001:650). This is mostly because partial democracies have many of the same structural and processual features of full democracies (mainly the issue–stress–policy response cycle of a basic open polity), but lack the efficiencies and capabilities of a well-developed democratic polity due to rent seeking and other pathologies. Further computational analysis with very low and very high levels of democracy are needed to simulate lower levels of state fragility in those extreme cases.

The MASON RebeLand model, along with other similar agent-based models that inspired it (for example, Bennett 2008; Bhavnani *et al.* 2008), contributes to the scientific literature on state stability and failure analysis in several ways:

1. The ABM approach enables the formalization of an entire polity in a way that goes beyond what other types of modeling approaches (statistical or mathematical; game-theoretic or dynamical system) can formalize or model. This feature also contributes to social science interdisciplinary integration and the implementation of a whole-system approach.
2. Computational simulation modeling enables the experimental analysis of policies and other features that cannot be implemented through earlier approaches. For example, the agent-based modeling approach lends itself to asking many “what-if” questions of theoretical and practical interest (for example, for early warning and prediction), well beyond what can be accomplished through earlier approaches (such as econometric models).
3. Spatial agent-based models also permit a viable implementation of coupled-socio natural systems and the complex interaction that arise in the normal life of a geographically situated polity. Additionally, this can be done without excluding other non-spatial features, such as social networks, social organizations, or institutions.

The agent-based modeling approach in social science—such as but not limited to areas of interest in political science and international relations—can be used for early warning and prediction if and only if the simulation system passes a variety of rigorous verification and validation tests (also known as formal tests of internal and external validity; Taber and Timpone 1996; Cioffi-Revilla 2002). In the case of *RebeLand*, this would require the specification of a target system (some real world country) to be represented by the simulation system in such a way that the early warning and prediction questions to be investigated by the latter would be within the range of accuracy provided by the specification of the former. For example, in *RebeLand* a single public issue is usually insufficient to bring about state failure, even in less than optimal situations when government corruption exist or policy implementation is not very efficient. By contrast, the concurrent stress of several major public issues affecting society (such as the conjunction of inflation with climate change, with resource depletion, and with insurgency) can cause state failure even when government corruption and policy inefficiencies are low. In terms of early warning, the agent-based model offers the opportunity to “look under the hood” and examine precursory dynamics *before* the onset of major changes, such as is typical of complex systems that can fail catastrophically through continuous drift failure in critical subsystems at lower micro levels. In *RebeLand*, the catastrophic collapse of support for government around time $T = 320$ is detectable by earlier warning signs that begin to drift (Figure 9), such declines in perceived wealth, food availability, and increasing inability of government policies in tracking emergent public issues. The timing of sudden change will become better understood as we mark progress in the understanding of these precedent anticipatory dynamics and stresses.

The key difference between the agent-based modeling approach to predicting state stability/failure and earlier methodological approaches that were less integrative lies in the ABM focus on antecedent processes and causal dynamics that lead to emergent phenomena: coups, rebellions, and large-scale violence can occur through a variety of modes or complex combinations of state variables that can be understood through simulation but are difficult or impossible to discover (let alone explain) through statistical models that lack causal processes. The representation of causal processes, attitudes, and behaviors is explicit in ABMs, just as they are in the real world when decision makers estimate risk, individuals assess their well-being, and populations experience collective dynamics. The significance and potential contribution of ABMs in social science is comparable

with that of other object-based computational models in other areas of science, such as seismology or ecology (population biology)—both areas where macro-phenomena emerges from the interaction of many individual micro-agents. Improvements in early warning and prediction of social and international events will become more feasible through future advances in ABM verification and validation.

In future research we plan to experiment with RebeLand in several directions:

1. Additional experiments need to be conducted to gain a better understanding of the relationship between societal stresses, state policy responses, and polity stability. For example, a better understanding of societal versus natural stress is desirable.
2. A much more detailed understanding of precedent dynamics and aggregate change is necessary for early warning and prediction purposes. Such applied goals are feasible, but can only be attained through greater emphasis on the conditions under which sudden changes and other “surprises” can occur—in addition to advances in empirical validation (verification).
3. Norms are not explicit in this initial version of RebeLand. In the referent/target system, norms are used by population agents, government agents, and rebel agents, so the simulation system could make greater use of norms as explicit entities that govern agent decisions and behaviors, perhaps within a BDI framework (beliefs, desired, and intentions).
4. RebeLand can be used to populate a region or continent—an international system on some scale, not just a single country—with appropriate variations in polity features. Efforts in this direction are already under way under this same project (MASON AfriLand model; Cioffi-Revilla and Rouleau 2009).
5. Greater emphasis on cognitive agent architecture is desirable, especially for scenarios where the polity becomes unstable or failing; when perceptions also play an increasing role.

Conclusions

Computational models of politics and insurgency (civil unrest, guerrilla, violent rebellion, and internal war) have a research tradition dating back several decades, across the social sciences. That earlier generation of models was written in procedural programming languages, as opposed to the current generation of computational models that are written primarily in object-oriented programming languages such as Java. Earlier agent-based models (ABMs) on similar topics of domestic politics have been useful in covering parts of RebeLand’s scope, just as we hope RebeLand will inspire further developments.

The Java-based MASON RebeLand model presented here offers three innovations with respect to earlier models of politics and insurgency: (i) an explicit polity model with politically complete structure and processes for society, government, and policy making; (ii) social and natural model components within an integrated socio-natural system that captures ecosystemic complexity; and (iii) generative dynamics where insurgency and the state of the polity (stable, unstable, failing, failed, and recovering) occur as emergent phenomena under a range of social and environmental conditions, not as predetermined aggregate outcomes. Taken together, these three innovations allow researchers to conduct a variety of new computational or “virtual” experiments with RebeLand. Such experiments can be particularly valuable in terms of providing new

insights into and understanding of the complex dynamics between society, government, violent opposition, policy alternatives, and environmental ecosystems—the later included but simplified in RebeLand.

Three scenarios were demonstrated in this article, showing stable, unstable, and failing polity conditions. An important result pertains to the general overall resiliency of a polity, normally requiring not just one or a few stressful issues to experience polity failure, but a large set in combination (such as inflation plus insurgency plus environmental stress). Although more research is needed in terms of model validation, the overall behavior of RebeLand has face validity, including the generation of realistic distributions such as those for income (Pareto distribution) and public opinion (bi-modal when under stress).

The MASON computational toolkit also permits additional experiments and extensions beyond the initial set reported in this article. In the area of early warning and forecasting models like RebeLand are more likely to be useful in terms of revealing unforeseen dynamics or consequences, in a qualitative sense, rather than exact quantitative predictions concerning the precise timing and intensity of events. From empirical research we know that the frequency of political events of many kinds (coups, crises, wars, and revolutions) occurs with approximately Poissonian (random) distribution. However, the intensity or severity of events is more often of a different kind, such as a Weibull distribution. Experiments conducted with agent-based models such as RebeLand and others should attempt to replicate such distributions and provide new insights for developing a better understanding of the underlying socio-natural dynamics. For example, improvements in governmental capacity, implementation reliability, and lower levels of corruption should show significant improvements on polity stability—an important prospect for stabilization and reconstruction operations. Such results may not immediately yield actionable policy recommendations in terms of specific programs, but at the very least they may offer new insights of value to both researchers and policy analysts.

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