An Evolutionary Agent-Based Model of Pre-State Warfare Patterns: Cross-Cultural Tests

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Unpredictable natural disasters destroying food supplies tend to produce rather different impacts on warfare frequency in pre-state vs. *state societies. Both our model simulations and cross-cultural tests suggest resource unpredictability as one of a major warfare factors in pre-state societies but not state ones as demonstrated by further cross-cultural analyses.*

1. INTRODUCTION: MODEL

Our model belongs to a set of classic ALife models (see, e.g., Ackley and Littman 1992; Packard 1989; Riziki and Conrad 1986) with simple agents and a simple world.

The world in the model is a two dimensional grid, which is closed to form a torus. There are agents and patches of resource in the world. Only one patch of resource can exist in any cell at a given moment of time, but the number of agents in any cell is unlimited. Patches of resource appears randomly at the constant rate and are uniformly distributed in the space.

An agent can observe its local environment and perform certain actions. The agent is oriented in space and has a field of vision. The field of vision consists of four cells: the cell the agent currently occupies, and the adjacent cells directly to the left, front, and right relative to the orientation of the agent. The agent lives in a discrete time. The agent executes one of seven actions during the one time step: to rest, to consume a resource, to turn to the left/right, to move forward to the next cell, to divide, or to fight.

When the agent rests, it changes nothing in the environment. If there is a resource patch in the cell with an agent and it executes the "consume" action, the patch disappears. If the agent divides, an offspring is created and placed in the cell. The agent might also “fight” a randomly chosen agent in the cell.

Each agent stores a finite amount of resource on which to live. When the agent performs any action, its internal resource decreases. If the agent executes the action "to consume" and there is resource in the cell, the internal resource of the agent increases. When the agent produces offspring, the parent spends some amount of resources in this process and gives half of the rest to the newborn. After executing the "fight" action, the agent takes some amount of resource from the victim. If the internal resource goes to zero, the agent dies.

Behavior of the agent is governed by a simple control system, in which each output, associated with a certain action, is connected with each input, associated with a certain sensory input from environment or internal state of the agent. The control system is a linear system, which is functioning similarly to a feed-forward neural network with no hidden layer. To calculate the output vector ***O*** of values, the input vector ***I*** should be multiplied by a matrix of weights ***W***. Values of ***W*** are integers in the range $[-W_{max}, W_{max}]$.

$$O_j = \sum_i w_{ij} I_i \,. \tag{1}$$

At each time step, the agent performs the action associated with the maximum output value. Correspondence between outputs and actions, and how changes of internal resource depend on actions are summarized in the Table 1.

Table 1

O	**action**	**change of internal resource *r****
O_0	to rest	$\Delta r = -k_0$
O_1	to turn to the left	$\Delta r = -k_1$
O_2	to turn to the right	$\Delta r = -k_2$
O_3	to consume resource	$\Delta r = k_3$
O_4	to move	$\Delta r = -k_4$
O_5	to divide	$\Delta r = -k_5$
O_6	to fight (randomly chosen agent)	$\Delta r = -k_6 + 2k_6$, if internal resource of victim $r_n \geq 2k_6$, $\Delta r = -k_6 + r_n$, in the opposite case

*for all simulations coefficients k_i were set according to the following equations: $k_2 = 2k_1$, $k_4 = k_5 = 2k_2$, $k_6 = 25k_4$, coefficient k_3 was a parameter.

The input vector ***I*** is filled with information about presence of resource and other agents in the field of vision, level of internal resource and Euclidean distance between marker vectors (see below) of agents in the current cell. Full list of input variables and their definitions are presented in the Table 2.

Table 2

Input variable	Value
I_1	k;
I_2, I_3, I_4, I_5	k if there is resource bundle in the current cell; 0 in the opposite case;
I_6, I_7, I_8, I_9	cN_c, where c is constant, N_c is a number of agents in the given cell of the field of agent's vision;
I_{10}	r;
I_{11}	$r_{\max} - r$, where $r_{\max}$ is maximal possible value of internal resource capacity;
I_{12}	$\sqrt{\sum_i (\overline{m}_i - m_i)^2}$, where $\overline{m}$ is a centroid of agents' markers at the current cell;
I_{13}	$\frac{k \cdot \sqrt{\sum_i (m_i^p - m_i)^2}}{2M_{\max}}$, where $\mathbf{m}^p$ is a marker of partner to interact.

Note: for all simulations coefficient k was constant and equal to $k = r_{\max}$.

The weights of the control system are coded in the genome of the agent.

The genome of the agent $\boldsymbol{S}$ consists of three chromosomes $\boldsymbol{S} = (\boldsymbol{B}, \boldsymbol{W}, \boldsymbol{M})$. The first chromosome is the bit string which codes the presence or absence of individual sensory inputs and actions; the second one is the vector of integers which codes the weights of the control system transformation and the third chromosome, also vector of integers, codes the kinship marker of the agent.

If the agent executes the action "divide", its offspring appears. The genome of the offspring is constructed with the aid of the following genetic algorithm:

1. for every gene corresponding to the weight of the control system, add a small random integer value uniformly distributed on the interval $[-p_w, p_w]$, where p_w is mutation intensity;
2. with a small probability p_b, change each bit for the presence of sensory input or action;
3. for every gene corresponding to the kinship marker, add a small random integer value uniformly distributed on the interval $[-p_m, -0.8p_m] \cup [p_m, 0.8p_m]$, where p_m is the mutation intensity of the marker.

2. SIMULATION RESULTS

The simulation was run with a world of 30 x 30 cells and an initial population of 200. To speed up the program execution, the weights were assigned integer values in the range [-1000,1000] and mutation intensity p_w was set to 30.

For all simulations every agent of initial population had the same genome and therefore the same strategy of behavior. This initial strategy was to move toward the resource and consume it. In the situation of absence of the resource patch in the field of vision agent executed divide action. Weights of neural network for an agent of initial population are shown in Table 3.

Table 3

		action		
		O_3 (to consume resource)	O_4 (to move forward)	O_5 (to divide)
input variable	I_1 (bias)	0	0	50
	I_2 (resource at the same cell as the agent)	150	0	0
	I_3 (resource at the next cell in the "forward" direction)	0	100	0

Note. Components of input and output variables which are not included in the table were absent in the structure of the neural network of agents of initial population.

We have performed two series of simulations with the model. They differ in amount of resources in a patch and frequency of patch appearance. For the fist series frequency of resource appearance was ten times greater than for the second, but amount of resources in a patch was ten times smaller than for the second. So, for both cases total amount of resources which could be collected by agent during given period of time was equal, but probability (and, hence, predictability) of obtaining a single portion of resource for the first series was ten times greater than for the second.

Results of simulations are shown in Table 4.

Table 4

	case 1	case 2	case 3	average
high predictability of resources				
Frequency of fight actions in the population	0,000686	0,000807	0,000791	**0,000761**
Frequency of fighting strategies in the population	0,119	0,176	0,172	**0,156**
low predictability of resources				
Frequency of fight actions in the population	0,00234	0,00267	0,00274	**0,00258**
Frequency of fighting strategies in the population	0,617	0,672	0,625	**0,638**

As we see, aggressive behavior of the agents ("warfare") developed sooner or later within all our simulations. However within the context of high resource predictability aggressive agents ("warlike communities") remained in small minority, whereas the frequency of warfare turned out within such context to be a few times lower than the one observed in the context of highly unpredictable resource fluctuation. Note, that in the latter context the proportion of aggressive agents ("warlike communities") always grew significantly over 50%.

3. CROSS-CULTURAL TESTS, DISCUSSION AND CONCLUSIONS

The main testable prediction generated by our model can be formulated as follows: the higher is the resource unpredictability, the higher frequency of warfare we should expect.

When we started collecting cross-cultural data for the test, we soon found out that this test has been already performed. This was actually done by the Embers who showed that resource problems, particularly those created by unpredictable weather or pest disasters strongly predict warfare frequency (C.R. Ember & M. Ember 1990; 1992; see also M. Ember 1982; Shankman 1991; for direct archaeological evidence on unpredictable resource fluctuations as a major factor of warfare frequency see, e.g., Bong 2000; Lekson 2002); what is more, the correlation between the presence of unpredictable natural disasters destroying food supplies and warfare frequency has turned out to be stronger than the one attested for more than a dozen various warfare frequency factors tested by the Embers. Needless to mention that the correlation found by the Embers is entirely in the direction predicted by our model.

However, the Embers' tests need a few significant qualifications. To start with, the Embers (1992a) seem to believe that unpredictable natural disasters destroying food supplies is a major predictor of warfare frequency not only for the stateless cultures, but also for the states. We have the strongest possible doubts about this. And in no way we would like to interpret the results of our model simulations presented above as predicting that we should find a significant correlation between the presence of unpredictable natural disasters destroying food supplies and warfare frequency for the states. Let us explain why.

First of all, complex social systems would normally have more or less developed subsystems permitting them to get through unpredictable natural disasters without critical damages pressing them to wage war against their neighbors in order to acquire resources necessary to secure their survival. For example, if a certain region is affected by an unpredictable natural disaster. And this is relevant not only for industrial complex systems, but also for many preindustrial ones. Let us consider for example the following case:

> "In the autumn and winter of 1743–44, a major drought afflicted an extensive portion of the North China core, resulting in a virtually complete crop failure. The famine-relief effort mounted by the court and carried out

> by ranked bureaucrats was… stunningly effective. Ever-normal and community granaries were generally found to be well stocked, and the huge resources of grain in Tongzhou and other depots were transported in time to key points throughout the stricken area. Networks of centers were quickly set up to distribute grain and cash, and soup kitchens were organized in every city to which refugees fled. In the following spring, seed grain and even oxen were distributed to afflicted farming households. As a result of this remarkable organizational and logistic feat, starvation was largely averted, and what might have been a major economic dislocation had negligible effect on the region's economic growth" (Skinner 1985:283).

Of course, the counter-disaster subsystems in China (and East Asia in general) were somehow more sophisticated than in most other complex agrarian systems. Note, however, that the overwhelming majority of supercomplex agrarian (let alone industrial) systems still possessed some of such subsystems at least in the form of more or less developed markets. For example, within more or less developed market systems merchants are bound to store considerable deposits of food bought in affluent years (when the prices are low) just to sell them out in lean years (when, by definition the prices are high). In addition to this, within such systems in case of natural disasters affecting some region the food resources are almost bound to be moved in very large quantities to this region (where the food prices would be very high) from regions not affected by such disasters (where food prices would be low). In addition to this, complex agrarian systems would possess additional counter-disaster subsystems in form of food deposits stored by various landlords, who would tend to use them in lean years mostly in quite egoistic way in order to indent peasants (however, still helping them to survive through such years). And so on. Hence, we believe that the model presented above simply cannot be used to simulate the impact of unpredictable natural disasters on warfare frequency in complex social systems, just because in order to do this the model should take into account the effect of the functioning of numerous counter-disaster subsystems, which are present within supercomplex systems.

In general, we believe that the causes of warfare among stateless cultures are rather different from the ones between states. On the one hand, we failed to find a single case of a concrete interstate war which could be accounted for by unpredictable natural disasters destroying food supplies or their threat. On the other hand, one has to keep in mind essential differences between warfare in stateless and state cultures. For an independent community to wage war against its neighbors could be the only realistic way to survive in the context of unpredictable natural disaster (especially, against the background of absent trade) to a considerable extent because its relative military potential should not be undermined to a critical extent, as it would not be likely to possess any developed military infrastructure which could be affected by such disasters, and in any case the neighboring communities would be likely to be affected by them to a similar extent. For states experiencing such disasters a similar decision would be rather irrational, as they would be likely to possess a more or less developed military infrastructure bound to be strongly affected by such disasters. On the other hand, they would possess nonmilitary means to counter natural disasters (like the ones described above). Thus an option more expected of the states within such a context should be rather to avoid any wars before the negative effects of a natural disaster are overcome.

Hence, we expected the correlation between the threat of natural disasters and warfare frequency to be negative. For the "purity of experiment" while performing the test we observed all the conditions put forward by the Embers (1992): we omitted from the sample partly or completely pacified societies (C. R. Ember & M. Ember 1992:248–249). We have also observed the Embers' data reliability demands: "To minimize random error in the measurements… we do not generally use a resolved rating if the initial ratings are not the same or close. Operationally, when we say that the initial ratings of warfare frequency (by two or occasionally three different coders) were close, we are referring to one of three situations. First, the initial ratings did not disagree by more than 1 point on a 5-point ordinal scale. Second, if the initial ratings disagreed by more than 1 point, they did not straddle the boundary between low and high frequency of war; the boundary for us, which was predictive of various things in past studies (M. Ember and C. R. Ember 1971; C. R. Ember 1975, 1978), is warfare at least once every 2 years (high) versus less often (low). And third, one of the first two coders said 'don't know' and the third coder's rating was close (as defined above) to the other initial coder's numerical rating. For the coding of resource problems, which were measured on 4-point scales, close ratings are essentially the same as for warfare, with the following changes. First, the boundary was between 1 (no problem) and 2 or more (some problem or more serious problems). Second, because we think the boundary here may be more important than the difference between ratings of 2 and 3 or between 3 and 4, we decided that if two coders disagreed by only 1 point, but the different ratings were on opposite sides of the boundary, we did not consider the ratings close" (C. R. Ember & M. Ember 1992:247–248). In addition to this the Embers define stateless societies in the following way: "Nonstate societies are those coded by Murdock and Provost (1973) as other than 3 or 4 on their Scale 9; in such cases the local community is politically autonomous or there is just one level of administration above the community" (C. R. Ember & M. Ember 1992:249). We performed our test for the rest of the sample; hence, actually our subsample includes not only states, but also complex chiefdoms. The test was performed using the Embers' dataset published in: C. R. Ember & M. Ember 1992b; 1995.

Our test has confirmed our expectations. What we did not really expect is that this correlation would be so strong: Rho = – 0.77; p = 0.02.

Thus, it appears that unpredictable natural disasters destroying food supplies tend to produce rather different impacts on warfare frequency in pre-state *vs.* state societies. Both our model simulations and cross-cultural tests suggest resource unpredictability as a major warfare factor in pre-state societies, but not state ones.

4. NOTE

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