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The Sustainability of Wealth among Nomads: An Agent-Based Approach

J. Daniel Rogers,[1,*] *Claudio Cioffi-Revilla*[2] and
Samantha Jo Linford[3]

Introduction

One of the core objectives of social science in general, and of archaeology in particular, is to explain the emergence and development of complex social systems—i.e., social systems with status inequality and government by non-kin-based authority. In this chapter, we implement an empirically calibrated, spatial agent-based model (ABM) as a tool for studying why and how wealth differentials and associated social inequalities are generated and sustained over multiple generations. We also describe the theoretical foundation, formal strategies, and examples of the mathematical and computational approaches needed to develop complex ABMs.

Recent research on inequality and the sustainability of wealth among mobile pastoralists (nomads) has challenged older interpretations. Earlier ethnographic and historical research emphasized the egalitarian nature of pastoralism and the inability to sustain wealth due to environmental vulnerability and marginalization within developing nation-states. In the 1990s, basic interpretations of egalitarianism were reevaluated to

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[1] Department of Anthropology, NHB 112, Smithsonian Institution, Washington, DC 20013.
  Email: rogersd@si.edu
[2] Center for Social Complexity and Department of Computational Social Science, George Mason University, Fairfax, VA 22030.
  Email: ccioffi@gmu.edu
[3] Department of Anthropology, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064.
  Email: linford.samantha@gmail.com
* Corresponding author

incorporate a broader understanding of differences based on gender, age, skills, and prestige, whether or not within a stratified or ranked social context (Flanagan 1989). For pastoral nomads, observations of environmental and cultural marginality were tied to the perception that social organization was primarily tribal, relatively egalitarian, and organized around less formal social hierarchies. Borgerhoff Mulder et al. (2009, 2010: 37) combined new theoretical hypotheses and ethnographic data to document mechanisms for intergenerational wealth transmission, effectively contradicting earlier egalitarian theories. Related studies have also reanalyzed cross-cultural interpretations of the sustainability of wealth differences among hunter-gatherers and other small-scale societies (Bowles et al. 2010, Charles and Hurst 2003). These newer studies hold two principal implications for the long-term study of social change: first, the mechanisms of wealth maintenance provide general insights into how social inequalities were sustained and transformed over time in the emergence of complex social systems; secondly, pastoral-based pathways to social complexity both expand and complicate theories on the origins of early states and empires.

> **Definition 1 (Pastoralist Wealth *W*; Borgerhoff et al. 2010: 37).** Aggregation of material wealth (*X*), relational wealth (*Y*), and embodied wealth (*Z*), where *material wealth* includes herds and accumulated goods such as jewelry, tents, domestic tools, and other property; *relational wealth* is represented by the symbolic and social capital of obligations and prestige that families accumulate by spending other forms of wealth; and *embodied wealth* is the accumulated knowledge of everything from grazing conditions on different landscapes to regional politics. Formally, the norm of pastoralist wealth can be defined as
>
> $$\|W\| = (X^{*2} + Y^{*2} + Z^{*2})^{1/2},$$

where X^*, Y^*, and Z^* are standardized positive values (e.g., strictly positive z-scores) of each wealth component.

This chapter explores two basic questions affecting wealth transmission:

1. *What is the role of different degrees of social controls in the maintenance of all forms of wealth?*
2. *How vulnerable is wealth to external weather events?*

Our empirical frame of reference for this study is herders living in Mongolia in a social environment dominated by groups structured on kinship and other social ties. Within the model there are no large-scale political systems controlling local actions, beyond that of the lineage/clan observed in the simplest chiefdoms. Conflict is not part of the model. The social context of the model is similar to the period of initial social complexity around the beginning of the Bronze Age in eastern Inner Asia (ca. 3000 B.C.E.), prior to the formation of early states and empires (Rogers 2012).

The history of pastoralism in Inner Asia and elsewhere clearly documents emergent and sustained wealth and social inequalities, deeply enmeshed in the formation of complex societies (Honeychurch 2015). Prior to 200 B.C.E., in the antecedent Bronze and Early Iron Ages (ca. 3000 to 200 B.C.E.), archaeological evidence exists for hereditary leadership and substantial wealth differentials in societies generally described as complex or super chiefdoms (Frachetti 2008, Kradin 2006). The burial mounds of Central Asia (*kurgans*) and Mongolia (*khirigsuur*) provide the principal evidence for

substantial wealth accumulation by central elites, and presumably the institutionalized intergenerational transmission of wealth among ruling lineages.

Theoretical Framework:
Inequality and Origins of Social Complexity

Formally, we use the following definitions of inequality, sustainability, social complexity, and related concepts.

> **Definition 2 (Wealth Inequality *G*).** Uneven distribution of wealth (material, relational, or embodied) in a given society. Operationally, *G* is defined by the Gini coefficient:

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |w_i - w_j|}{2 \, n^2 \mu}, \tag{1}$$

> where $x_i = \|W\|$ (as in Definition 1) denotes the wealth of the *ith* household, *n* is the number of households, and μ is the mean household wealth (Dorfman 1979).

Interestingly, wealth inequality and the Gini coefficient are related to the Pareto power-law of wealth distribution and its scaling exponent by the equation

$$G = \frac{1}{2b - 3}, \tag{2}$$

where *b* is the scaling or Pareto exponent (Cioffi-Revilla 2014: 165, Kleiber and Kotz 2003: 35). Wealth distribution for households is log-normal, not Paretian. Note that equation 2 is also a scaling law. Conversely,

$$b = \frac{1}{2G} + \frac{3}{2}, \tag{3}$$

which goes to complex infinity as $G \rightarrow 0$ (perfect equality). Empirical values of *G* therefore yield power-law equivalent values of *b* and vice versa, based on equations 2 and 3.

> **Definition 3 (Wealth Sustainability).** Ability of an individual or household to acquire and retain wealth across generations; trans-generational acquisition and duration of wealth. Operationally, wealth sustainability is measured in terms of time duration *T* measured between the initial acquisition of wealth at some time τ_0 and loss of wealth at some later time τ'.

Note that wealth sustainability is a probabilistic compound event, based on acquisition and retention of assets (tangible or intangible) as sequential and jointly necessary conditions (Cioffi-Revilla 2014: 177), not a simple deterministic outcome. As such, it is subject to a set of formal principles of social complexity.

Theoretically, we assume that *T* is a continuous random variable (c.r.v.) with a set of observed realizations $\{t_1, t_2, t_3, ..., t_m\} \in T$ defined by probability functions for density $p(t)$, cumulative density $\Phi(t)$, intensity (hazard rate) $H(t)$, and complementary cumulative density $S(t)$, among the most common probability functions associated with *T*. Wealth duration *T* is discrete in the simulation.

> **Definition 4 (Social Complexity).** Extent to which a given society is governed through non-kin-based relations of authority. Ordinal levels of social complexity include kin-based societies (ground state or level 0), simple chiefdom (local leaders

exercise authority), complex chiefdom (regional leaders and local confederates), state (specialized institutions or public administration), and empire (multinational society). A recent overview of data, measurement, and formal theories of the emergence of initial social complexity is provided in Cioffi-Revilla (2014: chs. 5 and 7). The formation of institutionalized hierarchies of authority is typically the social context in which leadership strategies take shape as a result of canonical processes involving, for example, collective action (Cioffi-Revilla 2005, Rogers and Cioffi-Revilla 2009).

Computational Methodology

Agent-based models are increasingly used in all fields of science to explore complex interactions (Kohler and van der Leeuw 2007, Takadama et al. 2010). Computational agent-based modeling methodology consists of the following main six phases of development (from motivation to analysis). The simulation model is called Households World, abbreviated as HHW, as summarized below. Detailed information on design, coding strategies, and algorithms are available in earlier publications (Cioffi-Revilla et al. 2007, Cioffi-Revilla et al. 2010, Rogers et al. 2012).

1. *Motivation:* The core purpose of the study aimed at answering the research questions stated in the Introduction section of this chapter, on the effects of social control, extreme weather events, and social strategies on initial emergence and sustainability of wealth inequality in pre-state nomadic societies of Inner Asia (namely Mongolia and surrounding regions).

2. *Design:* HHW is designed to replicate a broad range of behaviors pertaining to pastoralist households living in a kinship structured social and economic landscape referenced to that of Inner Asia during the Early Bronze Age. HHW includes pastoralist households and their herds, situated in a biophysical landscape affected by weather. The landscape is endowed with biomass for herds to subsist. The overall dynamics are as follows: Weather affects biomass vegetation, which affects herding throughout the annual seasons, which, in turn, affects the movement of households across the steppe. In time, households' herds change in size and location as households congregate in camps as they undergo nomadic migrations in interaction with their herds.

3. *Implementation:* HHW was implemented in 2010, using the MASON toolkit, version 10. The model is written in Java, with graphic facilities to portray multivariable time series, histograms, and maps of the Inner Asia region. Agent decision-making was implemented using ethnographic data from written sources and field observations in Mongolia.

4. *Verification:* HHW was verified using standard procedures for spatial computational ABMs (Cioffi-Revilla 2010: 242, 297), including code walkthrough, unit testing, profiling, debugging, multiple long runs, and parameter sweeps, among others. The current version operates without any known bugs.

5. *Validation:* Several procedures were utilized to test HHW's validity. They included pattern-matching on histograms and related quantitative and qualitative distributions, time-series data, and movement-time relations in model output

data, among others. For example, HHW generates log-normal household wealth distributions similar to those known from ethnographic and historical data (Erdenebaatar 2009, Flores Ettinger and Linford 2013).

6. *Analysis:* Three experiments were conducted, focusing on the effects of (1) social control, (2) marriage strategies, and (3) extreme weather events on initial emergence and sustainability of wealth inequality.

In HHW, households belong to lineages and clans, households have friends, they remember their ancestors, and they have children who marry and begin new households. Households usually obey kinship norms and clan rules, and each day they evaluate the landscape and take their herds out to graze. They tend to camp with friends and relatives in a group similar to the *khot aul* as seen historically and in modern Mongolian pastoralism (Bold 1996). HHW has two socially direct forms of wealth transmission: intergenerational (marriage payment) and direct assistance to kin households in financial trouble (bailout). Here, we ran the simulation for a period of 500 yr. The first 135 yr of the simulation is a calibration phase during which population continues to grow. Effectively, the relatively stable time span of the simulation represents the yr from 135 to 500—the equivalent of over 18 generations.

This study utilizes the concept of a Standard Stocking Unit (SSU) for the purpose of comparability in herd numbers (Humphrey and Sneath 1999: 77). Herd dynamics, including birth, growth, consumption, and death rates are derived from a variety of rangeland studies, including results from the Kherlen Bayaan-Ulaan Grassland Research Center, and ethnographic sources (Begzsuren et al. 2004, Cribb 1991, Redding 1981).

Households and herds 'live' on specific landscapes. This study utilized the Egiin Gol landscape (Honeychurch and Amartuvshin 2007), consisting of a 100 x 100 km area in north central Mongolia (NW corner is at 49°56' N and 102°46' E). Households cannot leave the landscape and there is no trade, social, or political interaction beyond the boundaries. Topography and ground cover vegetation are modeled at a scale of 1 sq km. Vegetation variability is based on the Normalized Difference Vegetation Index (NDVI) calculated from a five yr (1995–2000) mean of contemporary biomass (Hansen et al. 1998, 2000). Monthly NDVI rasters are based on atmosphere corrected bands in 500 m resolution. Aggregate biomass is rendered in 14 land cover types with exponential regressions calculated to produce approximations of edible biomass. Biomass coefficients are based on Kawamura et al. (2005) and verified through a variety of rangeland research in Mongolia (Bedunah et al. 2006, Batbuyan 1997).

For better or worse, weather happens. A widely recognized challenge for pastoralists is the vulnerability of herds to extreme weather (but also disease, predators, and theft). In HHW, weather is reflected through the impact of seasonal changes, winter storms called *dzud*, and droughts. These weather patterns and events affect vegetation abundance and growth rates, and therefore the availability of pasture. An approximated frequency and duration of *dzuds* and droughts was derived from 20th century weather and livestock statistics along with descriptive accounts from specific years and storms (National Statistical Office 2001, 2005: 173, Batima et al. 2008: 77, Begzsuren et al. 2004: 792). With the functional time span of the simulation set at 365 yrs (yr 135 to 500) it was estimated that 67 noteworthy weather events were likely to have occurred. Event timing was randomized within the appropriate seasons over the 365 year span.

Experiments and Results

Three simulation experiments were conducted to answer the central question—what are the factors that most affect wealth maintenance over the course of generations? Considering the length of time involved, the relative longevity of kinship lineages was the best measure of wealth maintenance. Three specific measures were used: longevity of individual lineages T, mean longevity of all lineages, and mean herd wealth for individual w_h and aggregated lineage groups w_a.

Experiment 1: Effects of Social Control. Comparisons were conducted between runs of the simulation, first with a higher degree of centrally controlled residence and kinship rules, followed by runs in which individual households and local group camps independently chose where and when to move and with whom to associate. The central question in this experiment asks: how does central control of kinship and mobility affect wealth sustainability? In a variety of real world and modeling studies, the maintenance of mobility is recognized as necessary for success of individual pastoralist families (Barnard and Wendrich 2008, Fernández-Giménez et al. 2012, Galvin et al. 2008, Kerven et al. 2006, Rogers et al. 2012). Greater mobility should improve the success of individual families, but this depends on the local environment.

Results of Experiment 1 are illustrated in Figs. 1a and b, showing human population dynamics with (2a) and without (2b) centrally controlled social rules. Figures 2a and b (run 81) describes the corresponding herd population dynamics. At the start of the simulation, human populations are small and continue to grow for several generations. Both sets of simulation runs show that at approximately 50,000 d (yr 135), the rate of population growth declines as the landscape nears capacity. The first severe weather events were introduced in both simulation sets at 93,126 d (256 yr). Comparing Figs. 1 and 2 shows that allowing lineage leadership to increase control resulted in significantly denser population than when households and camps are more independent (Fig. 2). Also, mean number of animals per lineage was lower when leadership control increased. However, mean household wealth over the entire 500 yr is similar under either lineage-level social control (mean = 273 animals) or local autonomy configurations (mean = 269 animals). The basic differences between the two simulations are summarized in Table 1.

The overall success of lineages was very different under the two levels of centralized control. Figure 3a and b shows the differences. In Fig. 3a, relatively restrictive social controls significantly limit the longevity of lineages. From the point at which the landscape was fully populated (approximately 140 yr [50k d]) to the end of the simulation (500 yr [180,060 d]), no lineage survived. By contrast, the absence of centralized control shown in Fig. 3b shows the much greater longevity of lineages. Of 151 lineages at time 140 yr there were 14 (9%) surviving until 500 yr. This is a small proportion, but still remarkable given the length of time involved. The mean herd wealth of the households in the 14 long-lived lineages is compared to those that did not survive in Table 2. This table also shows Gini coefficients calculated for the two groups. Long-lived lineages were wealthier at the beginning and end of the sequence, although the Gini coefficient shows that individual households were much less wealthy by the end of the sequence.

Experiment 2: Effects of Bailout and Marriage Strategies. Within the model there are only two properties that are unquestionably directed towards the maintenance and transmission of material wealth—bailout and marriage payment. Bailout is the sharing of a small number of animals for subsistence purposes if kin households fall below the
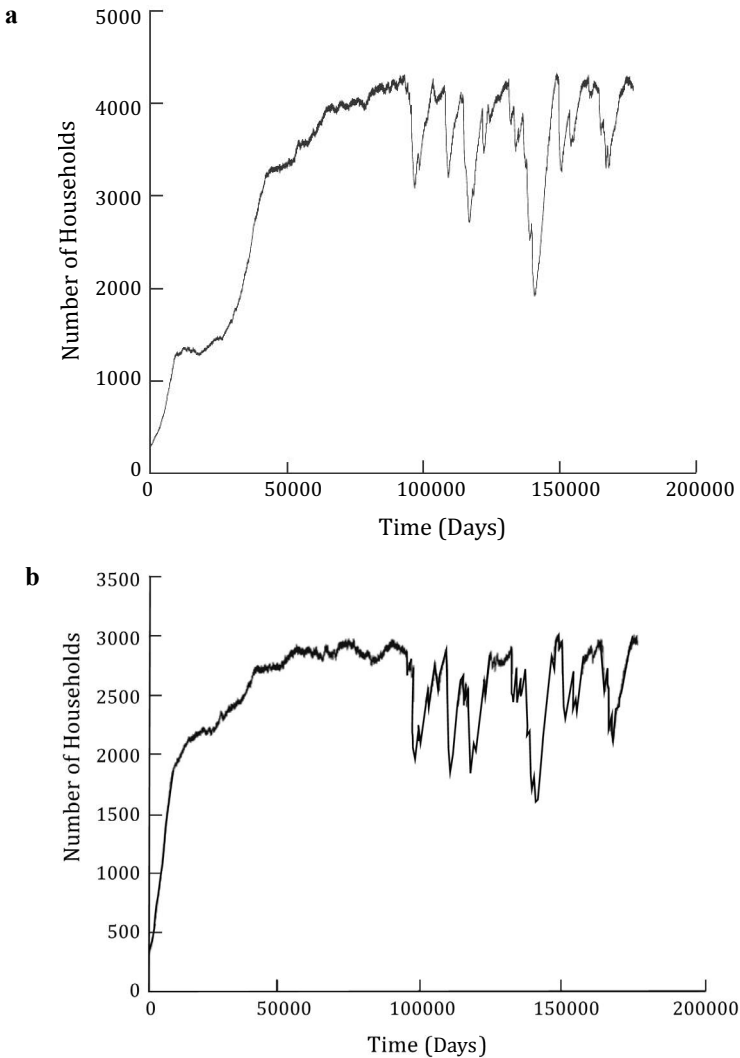
Fig. 1. (a) Human population levels under centrally controlled social rules; (b) human population levels with independent households (Run 80 series).

60 animal sustainability level at any point during the year. Anthropologically there are multiple kinds of marriage payments, including bridewealth, dowry, bride-service, gift exchange, token payments, and sister exchange (Goody 1973). In the simulation, no distinction is made between different forms of exchange; marriage payment is defined in a general sense as the transfer of herd animals from either of the parent households to the newly established household.

Whether parent households give more or less to an offspring household should affect the sustainability of lineages. In Experiment 1 the simulation was run with a 30% transfer of herd animals from one parent household to the daughter household.

a

b
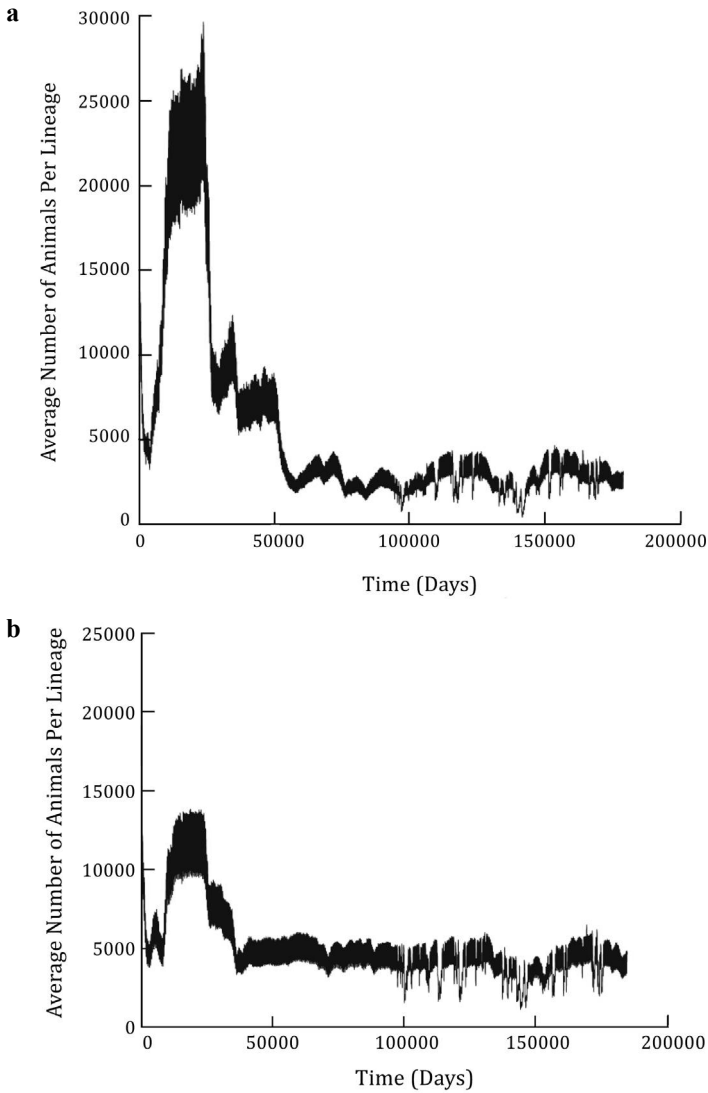
Fig. 2. (a) Herd population levels under centrally controlled social rules; (b) herd population levels under independent households (Run 81 series).

Table 1. Summary of results for two versions of simulation, one with centralized social controls implemented and one with local autonomy.

	Centralized Control	**Autonomous Households**
Human Population	High	Low
Herd Population	High	Low
Household Wealth	Moderate	Moderate
No. of Lineages	High	Low
Mean Herd Size per Lineage	Low	High
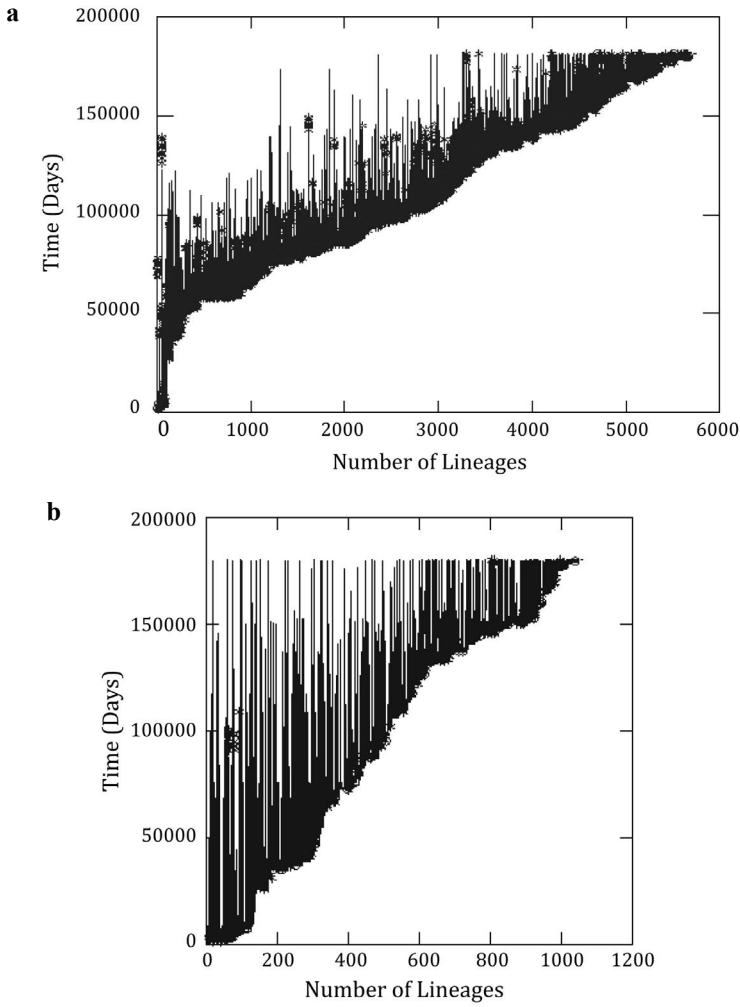
Fig. 3. (a) Lineage longevity under centrally controlled social rules (Run 80 series); (b) lineage longevity under independent households (Run 81 series).

Table 2. Statistics comparing the Longevity Lineages against the shorter lived lineages (Run 81 series).

Time (days)	Calculations:	Longevity Group (14 Lineages)	Other Group (137 Lineages)
Beginning: 49900	Mean herd wealth:	7818	4677
	t-value comparison:	0.0007	
	Gini Coefficient:	0.3755	0.2454
End: 180060	Mean herd wealth:	5695	4306
	t-value comparison	0.0247	
	Gini coefficient:	0.1623	0.2883

Additional runs of the simulation were conducted with the transfer rate reduced to 15%, but not less than the minimum survival level of 60 animals. Additionally, the effects of bailout versus marriage payment on lineage longevity were also compared. Runs of the simulation were conducted with the bailout function turned off and the marriage payment transfer rate set to 30% and with the converse, bailout turned on and marriage payment set to 0.00%.

Results of Experiment 2 show that both bailout and marriage payments had a very significant impact on the longevity of lineages. Eliminating either the bailout or marriage payment options resulted in no lineages surviving to the end of the simulation and an actual reduction in the number of lineages (Run 88 series). If the bailout was maintained, and the marriage payment reduced to 15%, rarely did any lineage survive to the end of the simulation. Within the parameters of the simulation, both marriage payment and bailout are necessary for long-term lineage survivability.

Experiment 3: Effects of Extreme Weather. Herd wealth is especially vulnerable to extreme weather. The simulation does not incorporate conflict, political shifts, or the economics of regional markets, but weather events are certainly a part of the environment module. Ethnographic studies have shown that households with less wealth in Inner Asia fare poorer in extreme weather events than their wealthier neighbors (Cribb 1991: 32, Fernández-Giménez et al. 2012: 7). An analysis was conducted on a series of four events in a specific run of the simulation (Run 82). In yr 262 (96987 d) a late spring snowstorm killed a large percentage of herds, resulting in an initial decline of 267 households (Fig. 4). Additional storms further reduced the number of households, with an eventual total loss of 710. Population levels did not totally recover for 39 yr (>14000 d).

To analyze the results from Experiment 3, the top wealth quartile was compared with the bottom quartile, before and after the series of weather events. In the wealthiest quartile 24 of 43 lineages survive the events and maintained their wealth. In the bottom quartile 24 of 42 lineages survived, 20 of which actually become wealthier. While 56% of the wealthiest lineages were able to maintain their position, it was unexpected that
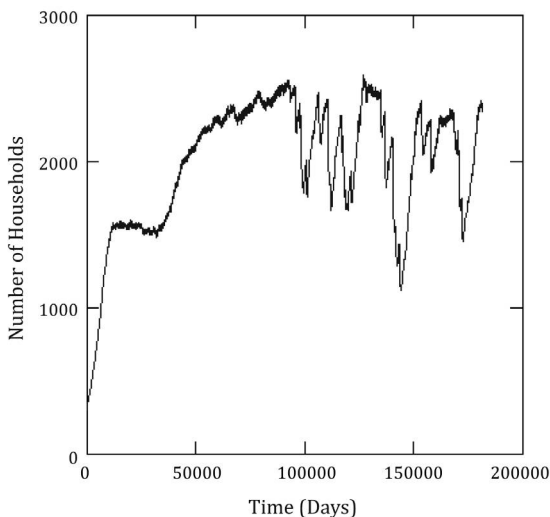

Fig. 4. Household population dynamics and the effects of a series of weather events (Run 82).

almost the same percentage (57%) of poor households also survived, and grew their wealth. Extreme weather events did not spell doom for the poor lineages and may even have opened up opportunities for herd growth in the less populated landscape.

Discussion

Simulation Results

Over time, kinship affiliations within a clan/lineage may become so attenuated that relationships are no longer recognized and the social group splits and new lineages emerge. This is far more likely to happen when one or more lineage households die out without producing daughter households. The timing of new lineage emergence is documented in the simulation (Fig. 3). When strict biological kinship affiliation is used single lineages rarely exist over the course of several hundred years. Logically, it is the exception to this pattern that illustrates the unexpected success of lineages as seen in Experiment 1. In the HHW model, contemporary Mongolian pastoralist kinship organization was used as the starting point, as illustrated in Fig. 5. The Mongolian information is based on interviews conducted with herder families in the Egiin Gol region of northern Mongolia (Erdenebaatar 2009). In Mongolia, kinship affiliation is normally not recognized beyond three generations vertically or beyond second cousins horizontally.

Although ethnographic sources for detailed wealth data in Inner Asia are rare, it is useful to compare one example with the simulation results. Vreeland (1957) conducted interviews with Khalkha Mongols living in the United States, but originally from the Narobanchin territory of Inner Mongolia (northern China). Although this is certainly secondary information, Vreeland accumulated enough wealth data to allow construction of the histogram in Fig. 6a. The Narobanchin pastoralist data shows a very common
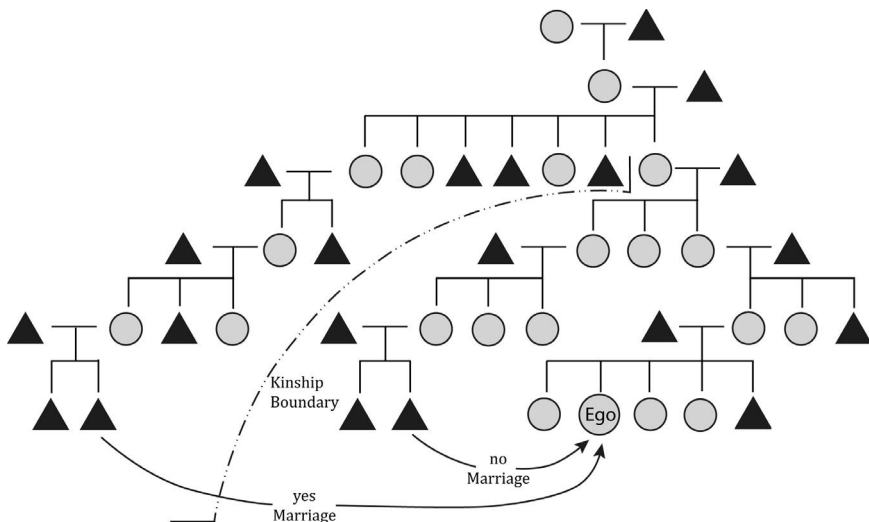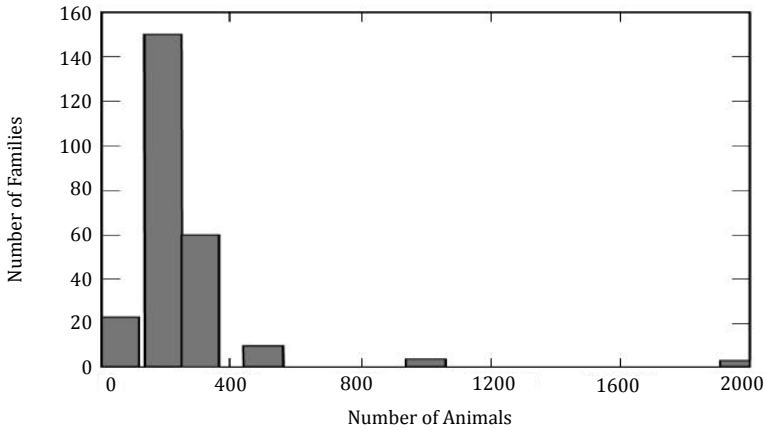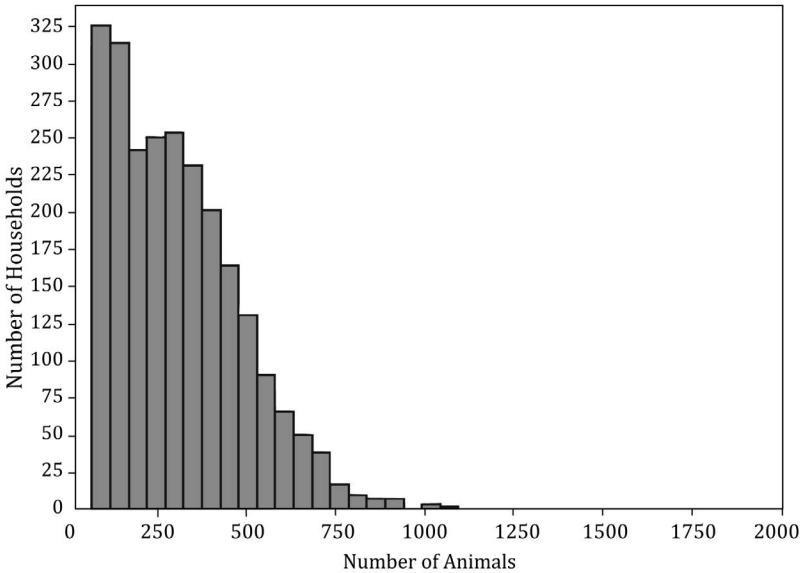

Fig. 5. Exogamy model of contemporary Mongolian pastoralist kinship organization from the Egiin Gol region (based on draft illustration by William Honeychurch and Diimaajayn Erdenebaatar).

a

b

Fig. 6. (a) Reconstruction of the Narobanchin region household wealth profile based on 1950s ethnographic interviews; (b) a simulated household wealth profile (Run 90). The two bar charts have different scales because of the differences in the sources of information.

wealth distribution, with many very poor households, a few intermediate, and a very small number of wealthy—the classic many-some-rare pattern of the Pareto power-law (Cioffi-Revilla 2014: 161–168). Figure 6b illustrates the comparability of the simulation data in household wealth distributions based on a specific summer day in simulation Run 90. The simulation data has a large number of poor households, although none below 60 animals since this was the survivability threshold. Depending on exactly when a 'snapshot' of the wealth distribution in the simulation is taken, there may rarely be a few households with as many as 3,000 animals.

In the simulation, survivability of the wealthiest and the poorest quartiles was nearly the same. This is an unexpected result when compared to the ethnographic data. There are two reasons that account for this difference. First, the ethnographic data reports nuances of economic and social status and success is measured on an ordinal dichotomous scale of doing "better" or "worse". The simulation, however, uses only the crude measure of household and lineage survivability and does not include increasingly common disaster assistance that may come from outside the region. Secondly, the simulation is explicitly based only on material wealth; relational and embodied wealth are implied, but are not programmed characteristics of wealthy households. Clearly, in the real world wealthy families use social connections to their advantage.

Poor households may be more vulnerable to a specific event. However, viewed from the perspective of generational time scales and lineage survival, poorer lineages did survive in the simulation and were even able to increase their wealth. There is a practical limit to the size of herds being cared for by a single family (Vreeland 1957: 35–37). If wealthy households are near this limit (3,000 SSUs in this study) they have little room for growth, whereas poor households still have a labor surplus that permits growth, assuming sufficient grazing. Declining population in a region would undoubtedly open up mobility and new grazing opportunities for the remaining families. There is no empirical data that would allow direct comparison of long-term household survivability.

Broader Theoretical Implications

One of the most difficult aspects of simulation modeling is also its core advantage—it is truly dynamic. Time series data can be collected at scales ranging from days to millennia and from individual families to entire social groups. Rarely if ever is there access to such detailed empirical data. The richness of the simulated data makes scale recognition an unavoidable priority. For instance, should results be collected in the aggregate; if not, then where in the constantly changing passage of days and years? Herd wealth for any particular lineage fluctuates day by day, more so month by month, and year by year. Because of this variability, results are generally collected in the aggregate, but with a focus on time scales not available ethnographically (e.g., Irons 1994, Vainshtein 1980).

In situations where clans/lineages may be explicitly endogamous or exogamous, it is very unlikely that such social roles would continue in an unbroken chain for more than about 120 yr, assuming each generation is 20 yr long. These social characteristics exist in HHW and this is why lineages seldom persist for more than 100–150 yr. This is not to say that in the real world kinship never has great time depth, only that the mechanisms of fictive kinship become a factor. Royal and other elite lineages often represent an exception to the typical depth of ancestry recognition. In Mongolia for instance, ancestral ties to Chinggis Khan's (d. 1227 C.E.) lineage still play a social role and were an even more powerful connection to privilege and status in Mongolia before the communist revolution of 1921.

In 20th century Mongolia, wealthier families had more mobility options and were able to take advantage of the best grazing (Fernández-Giménez 1997, Vladimirtsov 1934). These families could afford the costs of moves and their more extensive social networks provided information and reciprocal opportunities. Poorer families could not easily afford the cost of moving and their social connections were more limited. In a recent major snow disaster in Mongolia, Fernández-Giménez et al. (2012: 7) note that

"Poor households lost a significantly higher proportion of their livestock compared to mid-level and wealthy herders....", consistent with global evidence on the positive correlation between poverty and disaster consequences. Herd losses have both short and long-term consequences for the family. It reduces the household's earning potential and consumption practices, affecting the nutritional status of the family, especially women and children. Social networks and obligations are also affected if a family becomes too poor to provide the proper gifts and honor reciprocal social expectations (Siurua and Swift 2002, Templer et al. 1993).

The maintenance of wealth across generations is a key aspect of how institutionalized inequality is developed and maintained (see Smith et al. 2010: 92). The existence of recognized elites is a key reminder that there is more to longevity of lineages than wealth on the hoof. Recognized privilege can outlive material wealth and is often the key to reestablishing fortunes. This can often be seen in dramatic fashion when a defeated royal house reemerges generations later to lead a new hegemony. Privilege does not entirely depend on recognized categories of elite group membership. Concepts like heterarchy recognize that there are socially accepted but officially unrecognized networks of leadership that may emerge from the personal abilities of individuals, such as oppositional social and political groups, subaltern groups, crime syndicates, and many others (Crumley 1995, Guha and Spivak 1988).

The institutionalization of status and the implication of greater access to wealth are likewise foundational in the complex history of early states and empires in Inner Asia. In particular Sneath questions the dichotomy of the state versus the non-state within the Inner Asian steppe, bolstering the argument that pastoralists, particularly within Mongolia, are not egalitarian (2007). This argument is highly debated among scholars of Inner Asian history and archaeology, for example Golden (2010) and Kradin and Skrynnikova (2009) heavily critique the assumption of a headless state in Mongolia. Sneath (2007: 3) argues that close examination of historical texts provides proof of the intergenerational transmission of wealth and privilege. Nineteenth-century social theory declared a distinction between the territorialized and stratified state societies and nomadic, egalitarian non-state societies. Egalitarian non-state societies became associated with 'primitive' or 'tribal' societies representing an inverted image to the modern state throughout the twentieth century. Levchine (1840), for instance, observed that the tribal model of kinship groups coming together to form larger aggregates is counter to what actually happened within the Kirghiz nation. The Kazakh polity was instead formed as administrative divisions created through a hierarchy of political administration. The formation of the polity was furthered by the emphasis on patrilineal descent groups used to structure and order society, but they were not the foundation of the process.

An example from the Ming Dynasty (1368 to 1644 C.E.) provides another instance of political strategy counter to prevailing cultural evolutionary thinking. After the fall of Mongol rule in China, patrilineal descent was used as the foundation of the taxation system. This actually forced groups to organize along kinship lines to fulfill tax obligations, rather than along the lines of their existing organization as politically segmented groups. This is an example of the state creating kin groups, rather than kin groups as precursors to the state. Further examples exist from the early 20th century under the influence of Soviet nation building (e.g., Munkh-Erdene 2006). Through

historical records and accounts it can be seen how pastoralists within Inner Asia are part of a functioning aristocracy and not simply egalitarian as has often been assumed.

Conclusions

The nature of wealth transmission and inequality among mobile pastoralists is far more complex than characterized in the experiments here. Salzman, for instance, describes the political and social structure of mobile pastoralists in the Middle East and their relationship to the state (2004: 65–66). The complexities of the situation come less from internal social relations than from external political and power differentials. The simulation purposefully does not model political hierarchies beyond the lineage, nor external trade or migration, but instead seeks to focus on fundamental social and environmental relationships at the local scale.

In addition to the relationship between sustained wealth (economic advantage) and inequality there are several other sources of power used by elites in ranked societies like those being modeled here. Leadership strategies for maintaining control include genealogical seniority, supernatural authority, fictive kinship, force, sacred and long-distance knowledge, and political expertise. Ultimately, it is not just the accumulation of wealth or its sustainability over time, but how resources are translated and justified in the social web of privilege. Wealth alone is insufficient as an explanation for institutionalized inequality. However, the correlation between material wealth and forms of privilege is very strong.

In the experiments above, three aspects related to the transmission of wealth across generations were examined using the agent-based model. In Experiment 1, it was found that relatively independent households allowed greater longevity of lineages, compared to lineages with centralized control. Independent households have greater mobility which allows for better survivability in extreme weather events and generally better access to grazing. Experiment 2 dealt directly with intergenerational transfer of wealth and kinship-based sharing. Both marriage payments and bailouts in times of need were extremely important to lineage longevity. Experiment 3 examined the role of wealth in surviving extreme weather events. Surprisingly, it was found that wealthy and poor lineages suffered almost equally. Ethnographically, it is well known that poor households do less well in herd loss disasters. In the simulation both wealthy and poor lineages contain both wealthy and poor households. If the focus is on lineage survival then sharing among relatives allows survival of the social unit (e.g., Cooper 1993, 1995). More research is needed to clarify this result. However, in ethnographic findings wealthy households exercise their relational and embodied wealth to sustain their advantage. Those two features of wealth are less prominent in the agent-based model, but could be implemented in future versions.

Certain lineages grew and sustained their wealth for generations, through two simple mechanisms—marriage payment and sharing within lineages and local camps in times of crisis (bailout). A third ever present factor within the simulation was luck of access to preferred pasture. As might be expected, in some cases the actions of lineage leaders helped and sometimes their actions hindered group success. Ethnographically, the benefits of wealth are mobilized to enhance success. In the simulation the benefits of wealth work in even more subtle ways to solidify emergent patterns of grazing access. The three mechanisms of wealth differentiation provide an explanatory foundation for

how social inequalities emerged and were sustained. Pastoralists have generally been considered marginal in the development of states, empires, and the earliest civilizations of the world. However, recent reanalysis of ethnographic data, and now computational modeling, have shown that simple methods of wealth transfer can sustain lineages over very long periods of time. These results support what we know from historical research including the existence of aristocratic lineages and centralized authority among pastoralists of Inner Asia.

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