Original Article

Need-based transfers on a network: a model of risk-pooling in ecologically volatile environments

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ABSTRACT

Need-based transfers are a widespread form of human cooperation across cultures that enhance survival in marginal environments. Examples include central place food sharing among foragers and stock friendships among pastoralists. Previous models have demonstrated that such systems lead to higher rates of herd survival under volatile ecological conditions, such as those experienced by the Maasai of East Africa. The Maasai use a need-based transfer system called osotua that leads to risk pooling. Here we implement osotua-style asking and giving rules on a network in order to understand which network features promote herd survival. We find that (1) greater network size increases herd survival when individuals selectively ask their wealthiest partner for livestock but not when they ask a partner at random, (2) greater network connectedness improves herd survival regardless of whether individuals ask their wealthiest partner or ask a partner at random, (3) greater network heterogeneity leads to higher herd survival with selective asking of wealthy partners and decreases herd survival for random asking. In general, selective asking of wealthy partners is associated with higher rates of herd survival. We also examined the features of survival networks in order to understand the characteristics of the networks that result from 50 simulated years of osotua-style sharing under ecologically volatile conditions and the elimination of individuals who do not stay above sustainability threshold. These results will help inform further fieldwork on the need-based transfer systems and increase our understanding of features of sharing networks that enable risk pooling. Simple decentralized sharing rules can be highly effective for pooling risk, suggesting that complex cultural institutions may not be necessary for expansion into ecologically marginal environments.

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1. Introduction

Natural disasters, disease, theft, and a wide variety of other events constitute common but inherently unpredictable threats to human wellbeing and survival. In a word, they create risk. Risk has been defined in a variety of ways, but in human behavioral ecology it refers to "unpredictable variation in an outcome with consequences that matter" (Winterhalder, 2007:433). The problem of how to effectively manage risk is therefore a recurrent pressure shaping the evolution of human behavior and cultural institutions, including those surrounding resource transfer and cooperation. Humans are remarkable for their ability to adapt not only to the environment in which they originally evolved but also to a wide variety of marginal, ecologically volatile environments around the world. One of the keys to our ancestors' success in this regard may have been their ability to effectively deal with the risks and uncertainties associated with such environments through systems of resource transfer.

People throughout history and around the world have developed a variety of strategies for dealing with risk. Four common risk management strategies are risk retention, risk avoidance, risk reduction, and risk transfer (Dorfman, 2007). Risk retention consists of accepting risk and absorbing any resulting losses. When people store resources in anticipation of future shortages and when institutions self-insure, they are engaging in risk retention. Risk avoidance involves the reduction of one's dependence on high variability outcomes. For example, working for a steady, reliable paycheck rather than as a freelancer is a way of avoiding risk. Risk reduction includes efforts to lower the probability of loss, or, alternatively, to reduce the size of losses. Investors reduce risk by buying bonds as well as stocks. Finally, risk transfer is the exchange of risk from one individual or group to another. Buying an insurance policy is one common way to transfer risk. This article concerns another common type of risk transfer: risk pooling, also known as risk sharing (e.g., Barr & Genicot, 2008; Fafchamps & Lund, 2003). Risk pooling refers to agreements to take on some of another party's risk in exchange for their willingness to take on some of one's own (Cashdan, 1985; Wiessner, 1982).

Risk transfer (including risk pooling) is the only one of these four risk management strategies that necessarily involves cooperation. Typically, risk pooling arrangements entail a commitment to helping a risk-pooling partner when that partner is in need and one is able to help. Because the donor's response to the recipient's need is the defining feature of such systems, we refer to them as systems of risk-pooling through *need-based transfers*.

In the context of foragers, need-based transfers bear some resemblance to the concepts of tolerated theft (Blurton Jones, 1984, 1987; see also Isaac, 1978; Jaeggi & van Schaik, 2011) and demand sharing (Peterson, 1993) in that all three involve transfers from those who are at least temporarily resource-rich to those who are in need. In tolerated theft and demand sharing, one shares in order to avoid the costs associated with defending resources. Those costs may sometimes include gaining a reputation for being stingy. In contrast, within need-based transfers like the osotua system which we modeled here, there are potential benefits to creating and maintain relationships with partners on whom one can depend if one is in need in the future. Need-based transfer systems such as osotua can help to mitigate the risks associated with living in marginal or unpredictable ecological conditions (Aktipis, Cronk, & De Aguiar, 2011). In some ways, need-based transfers can be considered a larger category of resource transfers that include tolerated theft and demand sharing as well as resource transfers that occur as part of the osotua system and related systems. These types of resource transfers fall on a continuum from highly coercive (e.g., theft or extortion) to voluntary transfers (e.g., osotua transfers or charitable gifts). We use the term 'need-based transfers' in this paper to mean voluntary need-based transfers that can serve a risk pooling function.

Risk pooling through need-based transfer arrangements increase the likelihood that both parties will suffer losses while decreasing the severity of those losses. In situations where losses tend to be both severe and unpredictable, accepting a predictable but relatively small cost while avoiding large, unpredictable ones can be a beneficial tradeoff for all concerned. Among hunter-gatherers, for example, big game is a resource that is usually acquired unpredictably. This means that many would-be hunters actually come home empty-handed much of the time. If they had to rely solely upon their own foraging efforts, they would either starve or abandon big game hunting in favor of more reliable, predictable food sources, such as plants, honey, and small game. A solution to this problem practiced by hunter-gathering peoples around the world is to pool risk by having the members of a group forage independently followed by an equitable division of what they have acquired (Cashdan, 1985; Gurven, Allen-Arave, Hill, & Hurtado, 2000; Gurven & Hill, 2009; Gurven, Hill, & Jakugi, 2004; Price, 1962, 1975; Wiessner, 1982; Winterhalder, 1986, 1990; Woodburn, 1998). Although food sharing results in risk pooling through the pooling of resources, risk can be pooled even when those who own resources retain control of them. Consider, for example, the hxaro gift-giving system of the Ju/hoansi of Namibia and Botswana (Wiessner, 1977, 1982, 2002). Hxaro gifts, which are typically small items such as beads and arrowheads, are essentially tokens used to establish and maintain relationships that allow hxaro partners to call upon each other when in dire need of food or water. The hxaro system thus creates a risk-pooling network beyond just the local groups within which large game is routinely shared.

Need-based transfers that lead to risk-pooling also occur in food-producing societies. In one simulation of such a system among early twentieth century Hopi, Hegmon (1989) showed that such sharing enhances survival most when households share with those in need only after having first met their own needs rather than by pooling all food harvested. Similarly, many pastoralists also commonly pool risk not by pooling resources but rather by transferring limited numbers of livestock to those in need (Almagor, 1978; Bollig, 1998, 2006; De Vries, Leslie, & McCabe, 2006; Dyson-Hudson, 1966; Flannery, Marcus, & Reynolds, 1989; Gerkey, 2010; Gulliver, 1955; McCabe, 1990; Potkanski, 1999). With a few exceptions (e.g., Bollig, 1998, 2006), such systems have been documented only qualitatively, with a focus mainly on the rules and expectations that govern

them, with scant attention being paid to such quantifiable matters as numbers of stock-friendships maintained or numbers of head transferred. Along with our previous simulation described below (Aktipis et al., 2011), this article is a first step in a broader effort to understand such systems by using computer simulations to generate predictions that we and our collaborators will in the future test at field sites.

As a model of adaptive decision-making by pastoralists in the face of risk, our work follows in a long tradition of such models. These include Mace's models of Gabbra decision-making regarding herd management and birth scheduling (Mace, 1993, 1996; Mace & Houston, 1989), (Flannery et al.'s (1989) computer simulation of herd dynamics among Andean pastoralists, and De Vries et al.'s (2006) simulation of the impact of livestock acquisition patterns on herd demography. Our contribution to this tradition is in the use of computer simulations to examine pastoralists' decisions about whether to ask for or give livestock to one another.

The inspiration for our model comes primarily from our understanding of a system of risk-pooling through need-based transfers among Maa-speaking pastoralists in East Africa such as the Maasai and Samburu, which they refer to by their word for umbilical cord: osotua. Osotua relationships are started in many ways, but they usually begin with a request for a gift or a favor. Such requests arise from genuine need and are limited to the amount actually needed. Osotua does not follow a schedule, and it will not go away even if much time passes between gifts. Although osotua involves a reciprocal obligation to help if asked to do so, actual osotua gifts are not necessarily reciprocal or even roughly equal over long periods of time. The flow of goods and services in a particular relationship might be mostly or entirely one-way, if that is where the need is greatest. Maasai interviewees state very clearly that osotua gifts neither create nor repay debt, that osotua gifts are not payments at all, and that it is therefore inappropriate to use the verb to pay (alak) when referring to them. Osotua imbues respect (enkanyit), restraint, and a sense of responsibility in a way that non-osotua economic relationships do not. In the words of one interviewee, keiroshi: It is heavy.

To learn more about osotua, Cronk (Cronk, 2007; Cronk & Wasielewski, 2008) used the osotua norm to frame Trust Games played by Maasai. In the Trust Game, two players, who are anonymous to each other, are given an initial endowment. The first player can then give none, some, or all of his endowment to the second player. The experimenter triples that amount and then passes it on to the second player. Thus, the second player has an endowment that consists not only of the amount provided initially by the experimenter but also the amount given by the first player, multiplied by three. The second player can then give some, none, or all of the funds in his control to the first player. A total of 50 games were played. All players were given standard instructions, in Maa, on how to play the Trust Game. Half of the games were played with no framing beyond the instructions themselves and the other half were told "This is an osotua game." The osotua framing led to lower amounts given and lower amount expected (compared to the unframed game). In addition, osotua framing led to a negative correlation between the amounts given and received, in contrast to a positive correlation in the unframed games. One possible interpretation of this is that second players in the framed games may have seen low amounts given as a signal of need on the part of the first player. These findings suggest that the osotua framing shifts game play away from the logic of investment, debt, and repayment and towards the logic of risk-pooling through need-based transfers: Osotua partners have a mutual obligation to respond to one another's genuine needs, but only with what is genuinely needed.

Osotua and other risk-pooling systems among pastoralists may be facilitated by certain characteristics of livestock themselves. First, livestock are a volatile form of wealth. Although herds have the capacity to grow, they can also be rapidly, severely, and unpredictably reduced by diseases, droughts, and theft (Bollig, 1998; Dahl & Hjort, 1976). Any pastoralist would do well to find ways to reduce his or her exposure to risk. One way to understand the relationship between livestock and osotua relationships is to see them as different kinds of "wealth":

Fig. 1. A Maasai man posing with his favorite goats.

livestock are "material wealth" and osotua relationships are "relational wealth" (Borgerhoff Mulder & Beheim, 2011). Both types of wealth may range from very stable to very volatile. While livestock are a volatile form of material wealth, osotua relationships are designed to be an extremely stable type of relational wealth. Binding the latter to the former helps mitigate the former's volatility.

Second, livestock are a form of wealth that is visible to the entire community (Fig. 1). Unlike money, livestock cannot be secreted away. Although the lending of livestock among herders means that a glance at a herd-owners' pens at the end of the day will not yield a perfect estimate of his wealth, such lending involves too small a portion of herds to throw such estimates off by very much. If a man has lots of livestock in his pens at sundown, then he is very unlikely to be poor; if he has few livestock in his pens at sundown, then he is very unlikely to be rich. It is therefore easy to see whether an individual is in good or poor economic condition and thus whether they are being truthful about their need for additional livestock and their ability provide livestock to others. Although the avoidance of cheating and cheaters is an important theme in the study of cooperation (e.g., Cosmides & Tooby, 2005), the public nature of livestock wealth makes osotua one system in which cheating by feigning poverty is unlikely to be a major concern.

To explore the role that osotua relationships play in the management of risk among Maa-speaking pastoralists, Aktipis et al. (2011) developed an agent-based model involving simulated pairs of osotua partners. Herd survival was defined in terms of the agents' success at keeping their herds above a critical threshold that we derived from the literature on herd demography and household food needs among East African pastoralists (Dahl & Hjort, 1976). Agents with herds that dropped below the threshold for two consecutive rounds were removed from the simulations, along with their herds (see Fig. 3). This is consistent with the pattern seen among the Maasai in which impoverished families become relegated to a denigrated and shunned social category called il-torrobo (Cronk, 2004; Galaty, 1982). Although il-torrobo typically engage in such non-pastoralist pursuits as hunting, gathering, and bee-keeping in order to stay alive, they do not abandon whatever few animals they might still own.

Exchange between partners based on the rules of osotua relationships led to better herd survival than simulations with no exchange or with exchange based on probabilistic rules. Correlations between partners' herd survival rates were also stronger in simulations with exchanges based on the osotua rules, indicating that osotua exchange partners were indeed achieving their higher rates of survival through increased risk pooling. Aktipis et al. (in prep.) have extended this agent-based model by comparing the performance of players following the rules of osotua exchange (i.e., risk-pooling) to partners following the logic of account-keeping reciprocity. As with the previous simulation, partners whose behavior is guided by the rules of need-based transfers do better than those whose behavior is guided by the rules of reciprocity in the strict sense of balance, account-keeping, and tit-for-tat. In this paper, we extend this research in a new direction by looking at need-based transfers in the context of social networks. We also compare two types of need-based transfer rules, one of random asking among individuals in a network of partners and another of selective asking of the wealthiest partner. It is currently not known which specific rules individuals use for deciding who to ask for help within the osotua system and similar need-based transfer systems. We explore these variations of the rules within different social networks in order to guide subsequent fieldwork and experiments with human subjects.

2. Model and methods

2.1. Network generation

To create a baseline for comparison, we begin by studying the average herd survival in homogeneous osotua gift-giving networks. By homogeneous we mean that all individuals in the network have the same number of osotua partners. As the diagram in Fig. 2 shows, each vertex represents an individual and each pair of osotua partners is connected by an edge. We will use N to represent the network sizes i.e. the number of individuals (vertices) in a network. We will use k to represent the average degree, i.e. the average number of osotua partners per individual. Because the osotua partnerships are bidirectional, to guarantee the symmetry of the network, the values of k are limited to even numbers. For example, in Fig. 2(A) each node i, $(1 \le i \le N)$ has degree four $(d_i = 4)$ and is connected to two of its closest neighbors from both sides.

The network dynamics of a heterogeneous network was studied using Watts–Strogatz random networks (Watts & Strogatz, 1998). The Watts and Strogatz networks provide a simple algorithm for generating networks that have systematically varying levels of heterogeneity. Each random network is generated by randomly rewiring a fraction (β) of the edges of a homogeneous network. To keep the average degree of the network k unchanged, adding or deleting edges is not allowed in this process. As shown in Fig. 2(B) and (C), as β increases, the number of edges to be rewritten increases proportionally which increases the randomness of the network. Consequently, β can be used to quantitatively measure the randomness of a heterogeneous network.

2.2. Implementation of osotua gift-giving on a network

To be consistent with the previous study on osotua gift-giving in pairs (Aktipis et al., 2011), we formalized the osotua rules on a network as follows:

1. Osotua asking rule Individuals make a request for cattle only if their current holdings are below the asking threshold (the minimum herd size of 64). Each individual is allowed to make only one request per year.
2. Osotua giving rule Individuals give what is asked, but not so much as to put cattle holdings below their own giving threshold (also the minimum herd size of 64). If asked, an individual may give multiple gifts.
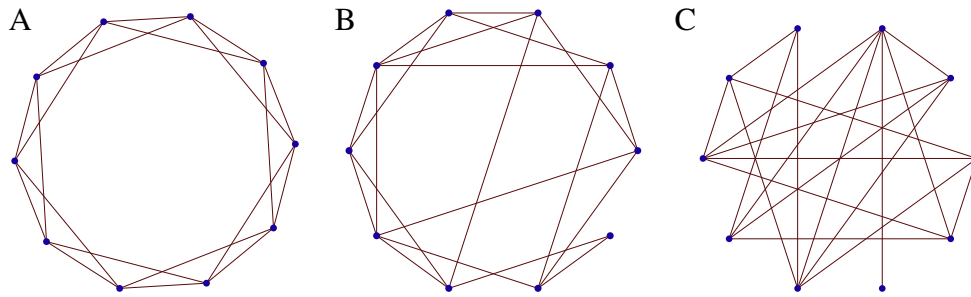
Fig. 2. (A) A homogeneous (non-random) network with parameters: $N = 10, k = 4, \beta = 0$, (B) a Watts–Strogatz (heterogeneous) network with $\beta = 0.2$, and (C) a Watts–Strogatz network with $\beta = 1$.

3. Asking order If multiple individuals make requests, requests are processed one at a time based on a randomly selected order.
4. Asking strategy:
   (a) Random asking Assuming that individuals do not have information on their partners' herd sizes, individuals make a request to one of their osotua partners with equal probability.
   (b) Selective asking Assuming that individuals have information on their partners' herd sizes, individuals pick the wealthiest among all their osotua partners to make a request. When two or more of an individual's partners have the same maximum herd size, he will make a request to only one of them with equal probability.

2.3. Simulation

Herd survival in osotua networks was simulated using Matlab. As shown in Fig. 3, each simulation consists of five phases: Initialization, Random growth, Disasters, Osotua request, Osotua response, and Vitality check. The default network size in all simulations is $N = 100$ vertices and the average degree is $k = 4$, unless otherwise specified. In the simulations, the herd size $H_i^{(n)}$ of each individual i ($1 \leq i \leq N$) at year n, is updated at the end of year n simultaneously and is tracked until $n = 50$. For every network topology, simulations are repeated 10000 times and the average values are reported.

2.3.1. Initialization

Each network topology is specified by an $N \times N$ adjacency matrix $A = \{a_{ij}\}$. Because the osotua obligation is reciprocal, the osotua network is undirected, i.e., if node i is an osotua partner to node j then $a_{ij} = a_{ji} = 1$. Consequently, the adjacency matrix A is a symmetric matrix with row sum k. Note that for a homogeneous network, A has permutation symmetry (each node is identical) and additional symmetries depending on the structure of the edges of the network. To generate a Watts–Strogatz network with a given β, we randomly pick $\frac{\beta Nk}{2}$ edges, disconnect one end and reconnect the link to a different randomly picked node. To implement this, $\frac{\beta Nk}{2}$ pairs of subscripts (i, j) are randomly selected from $\{(i, j) | A(i, j) = 1\}$ with equal probability. Then, a $\hat{j} \neq j$ is randomly selected to replace j for each pair. The new adjacency matrix $\hat{A}$ will lose the permutation symmetry but the row sums are kept unchanged.

For both homogeneous and random network, initial herd sizes are set to

$$H_i^{(0)} = 70, \quad 1 \leq i \leq N \tag{1}$$

for all individuals at the beginning of each simulation.

2.3.2. Random growth

Each year, an individual herd i grows at a random rate $g_i^{(n)}$ that is sampled from a Gaussian distribution. Consistent with Aktipis et al.

(2011), the growth rate distribution is given by

$$g_i^{(n)} \sim \mathcal{N}\left(3.4\%, (2.53\%)^2\right) \quad 1 \leq i \leq N, \ 1 \leq n \leq 50 \tag{2}$$

i.e. the growth rate averages at 3.4% with a standard deviation of 2.53%, a typical annual growth rate for cattle herds in this region of East Africa (Dahl & Hjort, 1976). Consequently, before taking disasters into account, the herd size for individual i at the end of year n should be

$$\widetilde{H}_i^{(n)} = H_i^{(n-1)} + H_i^{(n-1)} g_i^{(n)}, \quad 1 \leq i \leq N. \tag{3}$$

With a very small probability the Gaussian distribution will give us negative numbers, which we recognize them as negative growth. This is consistent with the fact that herds can decrease not only due to catastrophes such as drought, disease, and theft, but also simply because in some years deaths may slightly exceed births.

2.3.3. Disasters

The sequence of disasters is assumed to be generated by Poisson processes: the time until the next disaster strikes is exponentially distributed with mean 10%. Each individual herd is considered independent and
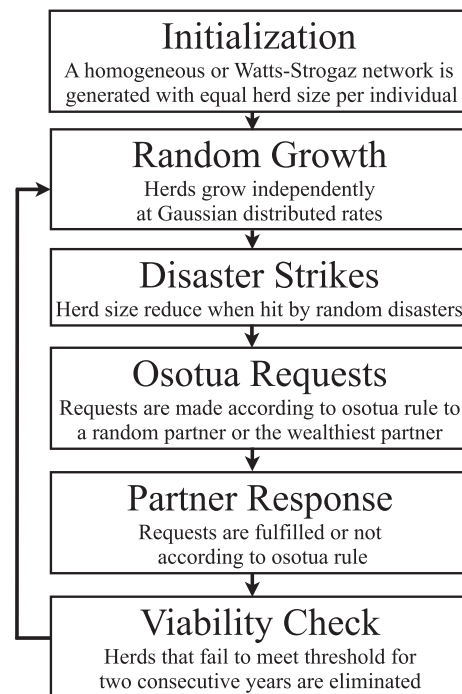

Fig. 3. Flow chart of steps in simulation of osotua gift giving on a homogeneous or Watts–Strogatz network.

is assigned a disaster calendar at the beginning of a simulation which is a series of exponentially distributed random numbers indicating gaps between disasters. If year n is a disaster year for individual i, a random number $l_i^{(n)} \sim \mathcal{N}\left(30\%, \; (10\%)^2\right)$ is drawn to decide the percentage of the herd that is lost in this year. At the end of each year, the disaster phase checks every individual's calendar: if it is a disaster year for an individual, then the corresponding loss $\Delta(i, n) = l_i^{(n)} \widetilde{H}_l^{(n)}$ is subtracted from that individual's herd size. In general, after growth and loss

$$\widetilde{\widetilde{H}}_i^{(n)} = \begin{cases} \widetilde{H}_i^{(n)} - \Delta(i, n) & \text{disaster year} \\ \widetilde{H}_i^{(n)} & \text{no disaster year} \end{cases} \quad 1 \leq i \leq N. \tag{4}$$

2.3.4. Osotua request

After accounting for random growth and disaster losses, the program will enumerate the individuals whose herd sizes fall below the sustainability threshold ($\theta = 64$) and randomly generate an order for them to make one request each. Every individual uses the same pre-determined strategy (random asking or selective asking) to make a request to one of his osotua partners, asking for enough to bring his herd size back to the sustainability threshold

$$\alpha_i^{(n)} = \begin{cases} 0 & \left(\widetilde{\widetilde{H}}_i^{(n)} \geq \theta\right) \\ \theta - \widetilde{\widetilde{H}}_i^{(n)} & \left(\widetilde{\widetilde{H}}_i^{(n)} < \theta\right), \end{cases} \tag{5}$$

where $\alpha_i^{(n)}$ is the number of cattle asked by individual i. In each simulation, all individuals use the same asking strategy throughout the entire 50 years. Each individual is allowed to make only one request per year, even if no livestock are received as a result of the request.

2.3.5. Osotua response

Individuals respond to osotua requests one at a time following the order in which they are made. When an individual, j, is asked by individual i, j will respond by giving $\gamma_{j \to i}^{(n)}$ cattle to i where

$$\gamma_{j \to i}^{(n)} = \begin{cases} 0 & \left(\widetilde{\widetilde{H}}_j^{(n)} < \theta\right) \\ \widetilde{\widetilde{H}}_j^{(n)} - \theta & \left(\widetilde{\widetilde{H}}_j^{(n)} < \theta + \alpha_i^{(n)}\right) \\ \alpha_i^{(n)} & \left(\widetilde{\widetilde{H}}_j^{(n)} > \theta + \alpha_i^{(n)}\right). \end{cases} \tag{6}$$

In other words, if j has more cattle than θ he will respond to the request made by i. If j has more than $\theta + \alpha_i^{(n)}$, he will fulfill the request made by giving $\alpha_i^{(n)}$ cattle to i, otherwise j only give all his "extra" (the number that beyond threshold θ) cattle to i.

2.3.6. Viability check

When the osotua phase finishes, the herd sizes are finalized for the current year,

$$H_i^{(n)} = \widetilde{\widetilde{H}}_i^{(n)} + \sum_j \gamma_{j \to i}^{(n)} - \sum_j \gamma_{i \to j}^{(n)}. \tag{7}$$

In the viability check phase the herd size of the current and the previous year is checked. If an individual herd fails to meet the threshold for two consecutive years, i.e. $H_i^{(n)} < \theta$ and $H_i^{(n-1)} < \theta$, the herd (and the individual) will be removed from the simulation by setting $H_i^{(m)} = 0$ for all $m > n$. This modeling assumption is based upon the fact that, among the Maasai, individuals whose herds are below sustainability threshold typically keep their remaining cattle but find other ways to make a living (e.g., hunting, gathering, bee-keeping) outside of the network of herders. The remaining herds will then restart a yearly

cycle with the random growth phase (2.3.2) until the program ends after the fiftieth year.

3. Results

Previous work has shown that osotua gift-giving between two individuals enhances the survival of their herds (Aktipis et al., 2011). We extended this gift-giving strategy to a network in order to explore the effect of network characteristics on herd survival. Here we report the quantitative impact of varying the network size (N), number of connections (k), and network heterogeneity (β). Further, we investigate how the network centrality and individual popularity measures associate with final herd survival (both for the initial networks and survival networks).

3.1. Network size

We study homogeneous ($\beta = 0$) networks exemplified by Fig. 2(A)- and focus on the impact of the size of the network and the connectivity of the network on the average survival rate by the end of the fiftieth year to obtain benchmarks for non-homogeneous network topologies when $\beta \neq 0$, such as shown in Fig. 2(B,C).

To study whether larger network size promotes herd survival, we varied N in homogeneous ($\beta = 0$) networks exemplified by Fig. 2A. N was varied from 5 to 100 while the number of osotua partners per person was maintained at $k = 4$. Fig. 4(A) shows that increasing the network size (N) has no significant effect on herd survivorship when all the participants use a random asking strategy. When a selective asking strategy is used, however, increasing N does enhance herd survival as shown in Fig. 4(B). This effect is most significant when the network size is relatively small ($N \leq 10$). When the size of the network reaches 10, further increases do not improve herd survivorship.

Comparing Fig. 4(A) to (B) we note that, for all network sizes, survivorship is always significantly ($\geq 20\%$) better for a selective asking strategy than for a random asking strategy. This difference can also be observed in the beginning and ending network topology figures shown in Fig. 5.

3.2. Network connectedness

Next, we examine the impact of increasing the number of connections on herd survival, while keeping the size of the network constant at $N = 100$ and using a homogenous network. We double k in each successive simulation from $k = 2$ up to $k = 64$. Again, selective asking is significantly better than random asking at increasing herd survivorship. In addition, Fig. 6 shows that increasing the average node degree promotes herd survival for both asking strategies. Furthermore, when a selective asking strategy is used (Fig. 6B), this effect is more significant than when a random asking strategy is used (Fig. 6A). However, the increase of the survival rate with the increase of the degree saturates: increasing the number of connections (k) above 32 does not improve herd survival, regardless of which asking rule is used.

3.3. Network heterogeneity

3.3.1. Randomness and herd survival

Finally, we examine the effect of network heterogeneity (β) on herd survival while keeping the network size ($N = 100$) and connectedness ($k = 4$) constant. Here, network heterogeneity is the proportion of connections that are randomly rewired, and this is varied from 0.1 to 1. One thousand Watts–Strogatz networks are randomly generated for each β, and simulations of each network through year 50 are repeated 1000 times. The average survival rates are averaged and displayed in Fig. 7, where the effect of heterogeneity parameter β is shown clearly. Network heterogeneity affects herd survival differently depending on the asking strategy: When β is relatively small and a random asking strategy is used (shown by blue dots) increasing network heterogeneity
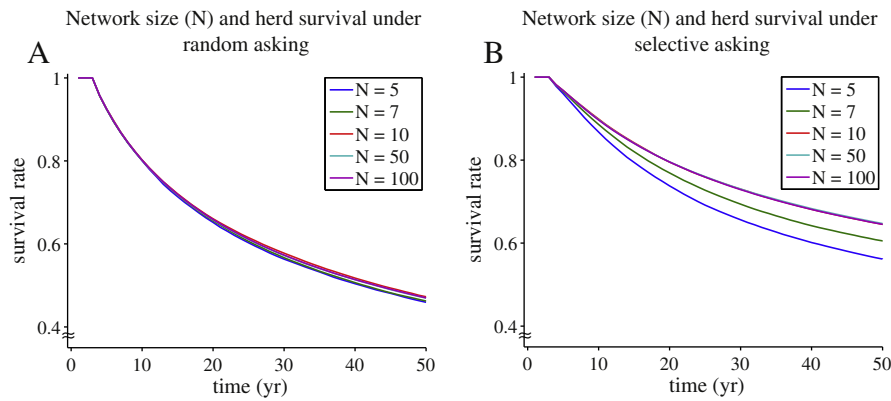
Fig. 4. Varying network size N for a constant number of connections ($k = 4$) and a homogeneous network. (A) When individuals in need randomly ask one of their partners for help, N shows little effect on herd survival. (B) When individuals in need ask their partner with the largest herd, increasing the network size N improves herd survivorship for $N \leq 10$.

harms herd viability. On the other hand, when a selective asking strategy is used (black dots), heterogeneity improves the average network survival rate. These effects diminish when $\beta \geq 0.5$ for random asking and when $\beta \geq 0.7$ for selective asking. The reasons why network heterogeneity influences the network herd viability in two distinct directions will become clear after we see the individual survival dynamics, which is discussed in Section 3.4.

3.4. Degree distribution

Fig. 8 shows that, within a heterogeneous network where the degree (number of connections) of individuals vary, the survival of an *individual's* herd increases with the number of connections. Similar to Fig. 6, this increase saturates at approximately four osotua partners for random asking and approximately twelve for selective asking. Again, when using the selective asking strategy, the increase is more significant. Hence these results indicate that most individuals will have a better chance to survive through 50 years if they increase their number of osotua partners. However, the diminishing improvements in survival as partners are added, as shown in Fig. 8, suggests that there are limits to the degree to which additional partners are worth adding presumably because at some point the increase in herd survivorship one experiences by adding another partner is less than the social costs of doing so.

The different saturation levels for random and selective asking explain why network randomness (β) influences these different strategies in distinct ways as shown in Fig. 7. Heterogeneity of the networks leads to distribution of the initial degrees. As we can see from Fig. 8, the survival rate for random asking saturates at $k = 4$ and hence individuals with degree higher than four all have the same survival rate. Hence the *average* survival rate over the degree distribution of a

heterogeneous network for random asking will be *lower* than for a homogenous network with the same mean degree of $k \geq 4$.

For selective asking the survival rate continues to increase with the degree until $k \approx 12$. Hence for networks with a mean degree less than twelve, the *average* survival rate will be *higher* for heterogeneous networks than for homogeneous ones.

4. Discussion

Risk management is important in all human societies. However, because pastoralists typically live in volatile environments and are often beyond the easy reach of law enforcement, they may be in greater need of decentralized systems for managing risk and responding to shocks compared to people with other methods of subsistence. Although risk-pooling through need-based transfers is just one way to manage risk, it may be particularly well suited to situations in which resources are scarce and other risk management options are limited, as is the case with pastoralists.

This simulation is part of The Human Generosity Project, which aims to understand the nature of human generosity. The HGP investigates the role of need-based transfers in human cooperation through field work at multiple field sites including pastoralist groups in East Africa (Maasai in Kenya/Tanzania and Karimojong in Uganda) and Mongolia, hunter-gatherers (Hadza in Tanzania), subsistence farmers (Ik in Uganda), Fijian fisher-horticulturalists and American cattle ranchers in the Malpai borderlands region of Arizona and New Mexico. This project also includes simulation work focused on modeling need-based transfer systems with various ecological, social and demographic conditions. The findings from this model will guide fieldwork at each of these sites, and findings from the fieldwork will subsequently guide future simulations. The Human Generosity Project will also conduct experiments on
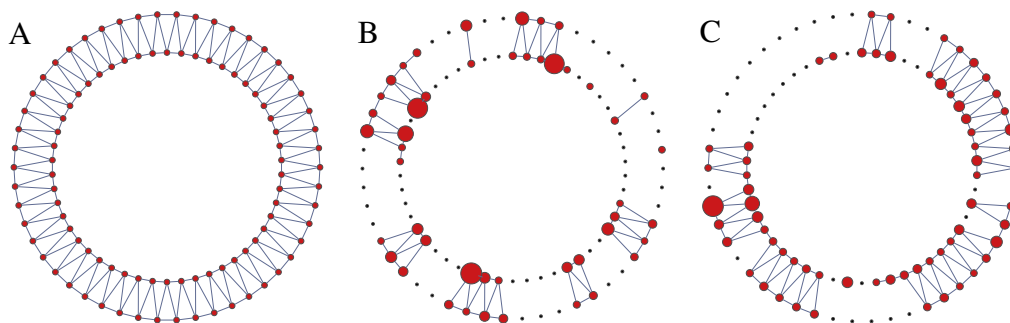

Fig. 5. Topology of the osotua networks. Red circles indicate individuals with surviving herds and the size of the circle indicates their corresponding herd size in year 50. Black dots indicate individuals whose herds have been eliminated from the simulation because they dropped below the viability threshold in two consecutive years. (A) The initial homogeneous osotua network where every individual is the partner of his closest 4 neighbors. (B) A typical topology of the same network in year 50 using a random asking strategy. (C) A typical topology of the same network in year 50 using a selective asking strategy.
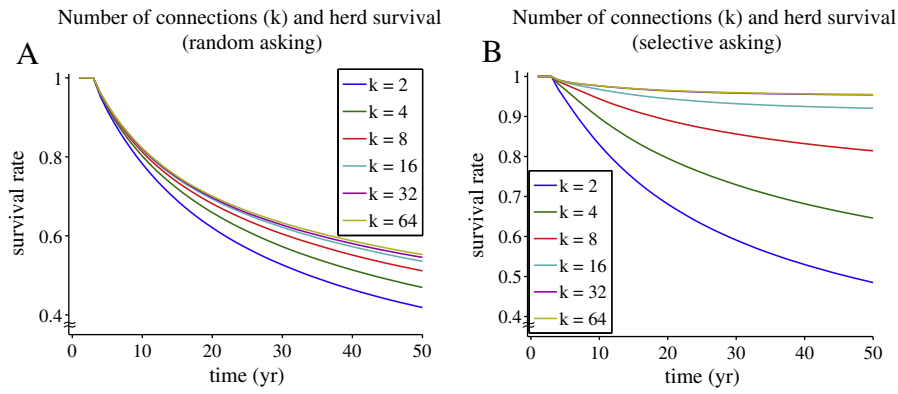
Fig. 6. Herds have higher rates of survival when individuals have more connections *k* for homogenous ($\beta = 0$) networks of size $N = 100$. The marginal benefit to additional connections *k* drops off quickly as k increases. (A) Random asking. (B) Selective asking of the partner with the largest herd.

human subjects to explore the psychological bases for giving and use these findings to also guide fieldwork and future modeling.

Previous computer simulations have shown that the osotua risk pooling system used by Maasai pastoralists improves herd survivorship for dyads of livestock owners (Aktipis et al., 2011). In this article, we modeled that system on a series of simulated networks, varying the overall number of individuals in the network (network size), the number of connections each individual has to other individuals in the network (network connectedness), and whether all individuals in a network have the same (homogenous) or different (heterogenous) number of connections to other individuals in the network. We also varied whether the individuals asked their partners for help at random or in order of their livestock wealth. In virtually all of the simulations, herd survival was improved by selective asking compared to random asking.

The finding that selective asking leads to improvements – sometimes quite dramatic ones – in herd survival compared to random asking may at first seem obvious given that real people do not typically interact with one another at random. However, what this finding demonstrates is that the success of a risk pooling system may be highly dependent upon the accuracy of the participants' knowledge regarding one another's wealth. Pastoralists may have an advantage in this regard because their wealth holdings are essentially public knowledge: it is difficult to hide a grazing cow. In societies where wealth comes in forms that are easier to keep private, it may be more difficult for need-based transfer systems to work, and risk management may need to take other forms. In future fieldwork we plan to compare the viability of need-based transfer systems among pastoral societies and societies in which wealth is more private.

In our model, we found that, given a homogenous network, increases in herd survival diminished when the size of the network got above ten. Also in a homogenous network, increases in herd survival diminished when each individual's number of connections got above 32. In a heterogenous network, however, the increase of an individual's herd survival diminished above the much lower number of 12 connections for selective asking (4 for random asking). The finding that, in homogenous networks, network sizes of more than ten did not lead to significant increases in herd survival shows that risk-pooling networks do not need to be large to be helpful. Small networks are significantly better than none at all, and large ones may not be necessary. This matches a finding regarding the usefulness of sharing among small groups of foragers arrived at analytically rather than through a simulation (Winterhalder, 1990). The findings regarding network connectedness are particularly interesting because they yield predictions that could be easily tested with some additional fieldwork. Given that real world networks are likely to be heterogenous, the finding from the heterogenous network simulation that herd survival diminished when the number of connections reached about 12 is probably a better guide to reality than the finding from the homogenous network that this point was reached at about 32.

Our simulations also suggest that a side effect of risk-pooling arrangements may be to help equalize the distribution of wealth among pastoralists, something that has been suspected for many years
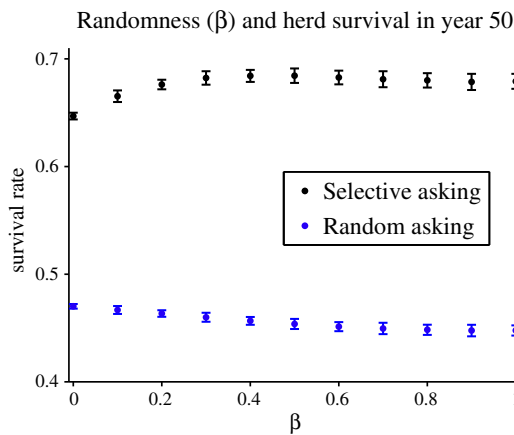

Fig. 7. Average survival rates after 50 years (dots) and their standard deviations (error bars) as a function of network heterogeneity (β). Random asking (blue dots) leads to a decrease in the survival rate as β increases to about 0.5. Selective asking (black dots) leads to an increase in the survival rate as β increases up to about 0.3. The network size remains constant at $N = 100$ and the number of connections is constant at $k = 4$.
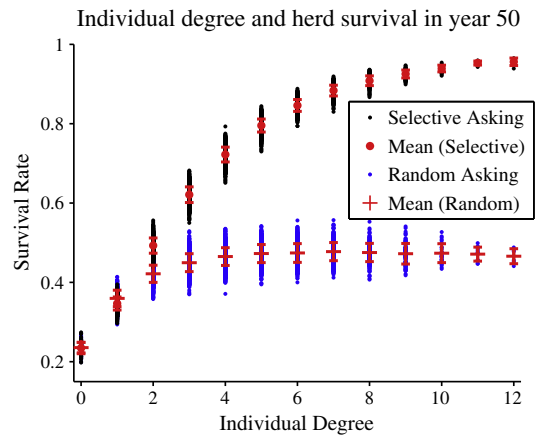

Fig. 8. Individual survival rate as a function of the number of initial osotua partners (degree) for random (blue dots) and selective (black dots) asking. The network size and the average number of connections are constant ($N = 100$, $k = 4$) and $\beta = 0.8$. The data represent averages and standard deviations (red symbols) for 1000 simulation runs for each of 1000 randomly generated topologies.

(e.g., Lewis, 1976:176). The most common way to compare degrees of inequality in the distribution of wealth is the Gini coefficient (Gini, 1912), which varies from zero, when all wealth holdings are equal, to one, when one person controls all the wealth. When agents in our simulations asked their partners for help in order of their wealth holdings, the result was a more equal distribution of wealth than when they asked for help at random, with Gini coefficients of 0.1659 and 0.2168, respectively (see also Fig. 9). Factors that work in the opposite direction include inheritance and a tendency for people in such societies to assort themselves by wealth not only residentially but also in terms of social and economic relationships, including risk-pooling relationships (Borgerhoff Mulder et al., 2010). For example, when risk pooling partners are chosen among the Jie of Uganda and the Turkana of Kenya, "considerations of wealth enter into it, for a man does not wish to ally himself to someone considerably poorer than he is, and from whom, therefore, he may find difficulty in obtaining his due return and a fruitful relationship in general. A wealthy man never finds it difficult to make new bond-friends, but a poor man is usually acceptable only to similarly poor men" (Gulliver, 1955:210). The end result may be greater variation between than within pastoralist wealth strata, as is seen in at least some parts of East Africa (e.g., Cronk, 1990).

In future work we plan to systematically vary the nature of the randomness of disasters and the extent to which disasters are independent or correlated among individuals in a network. In our current model, disasters occur with exponentially distributed frequencies in time and with equal probability for each individual. As a result, there are correlations neither in time nor among neighbors in the networks for the disasters that they experience. This is clearly not the case for many disaster events in reality. Droughts are regional and hence affect neighbors simultaneously. They also tend to occur in multi-year periods. The same is often true for warfare and other types of adverse events that pastoralists experience. In future work we will study the influence of spatiotemporal correlations on the survival rates of risk-pooling networks. A clear and testable empirical implication of this is that herders might do well to seek out risk-pooling partners whose risk profiles differ from their own. It is possible that the topography of East Africa, which includes a great deal of local variability in altitude and hence in climate and rainfall, may make this relatively easy to accomplish. Existing ethnographic accounts of some East African pastoralists provide support for this idea. For example, Pokot men rarely have more than one stock friend in the same place, instead maintaining them in at least six to ten different places (Bollig, 2006:287). Similarly, a Turkana herder will try to maintain bond-friendships in a variety of places to ensure that he has a potential suppor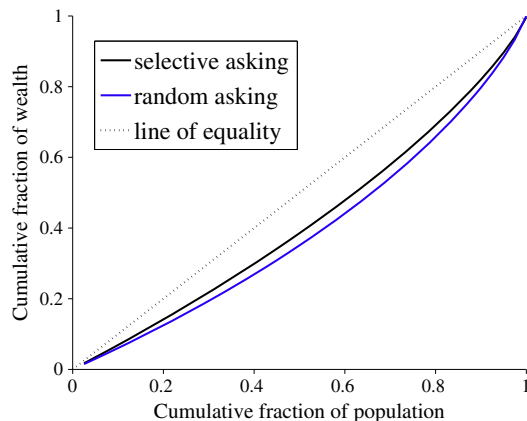ter in most or all of the areas to which, in any year, he might wish to shift if his usual grazing areas happen to be in poor condition (Gulliver, 1955: 212). Pastoralists living in more homogenous environments may have a more difficult time finding partners whose risk profiles differ from their own.

Risk pooling systems like the one explored in this article are often compared to insurance policies (e.g., Gurven et al., 2000). The similarity lies in the fact that both informal risk-pooling networks and insurance companies work by transferring risk from party to party. They also differ in many ways, most notably in terms of how the information and control over the system are distributed. The modern insurance industry is made possible by the ability to accumulate large amounts of data about rare events, which can then be used actuarially to calculate risks and set premiums (Bernstein, 1996; Levy, 2012). Informal risk-pooling systems, in contrast, rely upon knowledge about risk that is distributed among the participants and never formalized or centralized in any way. The contrast is similar to the one between centrally planned and unplanned economies (Hayek, 1945). In the former, the information needed to run the economy is accumulated and centralized, while in the latter it remains dispersed among the individual participants in the economy themselves. The use of distributed information combined with a decentralized system of asking for and transferring cattle may be a relatively efficient and effective informal risk management system when formal insurance may not be viable for actuarial or institutional reasons.

Although this simulation was based primarily on a single ethnographic case, it may have implications for risk-pooling more generally, and particularly wherever environments are volatile enough to create uncertainty about the future availability of resources. Human subjects readily adopt a need-based transfer approach in the laboratory (Cronk & Wasielewski, 2008; Gazzillo, Sopher, Aktipis, & Cronk, 2013), suggesting that this form of cooperation may be part of the human behavioral repertoire. However, it is clear that need-based transfers often manifest as a part of cultural systems that create shared norms of resource transfer such as the Maasai osotua system. The study of need-based transfer systems such as these may therefore lead to important insights about the interactions between the evolutionary forces favoring cooperation and cultural systems that enable coordination through shared expectations (Chwe, 2001; Cronk & Leech, 2013).

Throughout evolutionary history, humans have lived in environments characterized by ecological uncertainty and resource scarcity. The pooling of risk through need-based transfer systems is one way of solving the adaptive problems associated with living in such environments and it is one that is necessarily dependent on the willingness of individuals to enter into trusting and cooperative risk pooling relationships. The results of the present model suggest that risk-pooling networks are particularly effective if individuals have the ability to selectively ask the wealthiest individuals in their networks and that risk pooling networks need to be neither large nor highly interconnected in order to be effective. Together these finding suggest that large and complex social insurance institutions are not necessary in order for humans to pool risk effectively. Simple risk pooling rules such as the osotua systems of the Maasai greatly enhance the ability of humans to survive and thrive in challenging ecological conditions. Need based transfers may therefore be a form of cooperation that is critical for understanding both the evolutionary and cultural adaptations that enabled human expansion into marginal environments.

Acknowledgments

Fig. 9. Lorenz curves showing the cumulative distribution of wealth (measured by the number of cattle owned) as a function of the fraction of the population. The diagonal curve (dotted line) represents a completely uniform wealth distribution. Random asking (blue curve) leads to a more uneven wealth distribution than selective asking.

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