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Risk-Pooling and Herd Survival: An Agent-Based Model of a Maasai Gift-Giving System

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Abstract We use agent-based modeling to study *osotua*, a gift giving system used by the Maasai of East Africa. Osotua's literal meaning is "umbilical cord," but it is used metaphorically to refer to a specific type of gift-giving relationship. Osotua relationships are characterized by respect, responsibility and restraint. Osotua partners ask each other for help only if they are in need and provide help only when asked and only if they are able. We hypothesize that under the ecologically volatile conditions in which Maasai pastoralists have traditionally lived, such a system is particularly suited to risk pooling. Here we explore whether osotua increases the viability of herds by comparing herd survivorship and stability under osotua rules to a) no exchange and b) probabilistic rules for requesting and giving livestock. Results from this model suggest that this gift-giving system can dramatically increase herd longevity through a limited pooling of risk.

Keywords Risk-pooling · Reciprocity · Cooperation · Norms · Pastoralism · Maasai

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Introduction

One of anthropology's earliest and most striking findings was that gift-giving norms are common around the world, important to many subsistence economies, and vary a great deal from place to place (Mauss 1990). One of the most common features of such systems, and one that contrasts sharply with the no-strings-attached gift-giving norm common in Western society (Cronk 1989), is the notion of delayed reciprocity. Very often, gifts are given with some expectation that they will be reciprocated at some point in the future. In such systems, gifts are used to bind people together and to create and maintain relationships. Some of the earliest work on non-Western gift-giving systems was among the so-called potlatch systems common among the peoples of the northwest coast of North America (Boas 1966; Rosman and Rubel 1971). Although potlatching began on a small scale, it grew tremendously in the nineteenth century when trade goods were introduced and when warfare was no longer available as a route to high status. Potlatch gifts became a substitute for warfare, with enemies giving one another very large gifts and then expecting even larger gifts in return in the future. In highland New Guinea, a similar system arose for similar reasons. An existing gift-giving system, called *moka*, grew tremendously when warfare was ended and trade goods introduced. Like potlatch gifts, moka gifts became large and competitive, with enemies exchanging ever-larger gifts over many years (Strathern 1971). Elsewhere, many smaller scale and more benign gift-giving systems have been documented. Among the best studied is *hxaro*, a gift-giving system among Ju/'hoansi hunter-gatherers of south-western Africa. Individuals have many hxaro partners, with whom they exchange small gifts from time to time. In times of trouble, hxaro partners can rely upon each other to provide food and water, so that hxaro networks form a kind of social safety net (Lee 1993; Wiessner 1977, 2002).

This study focuses on *osotua*, a gift-giving norm documented ethnographically among Maasai and other Maa-speaking pastoralists of East Africa. Like the hxaro, potlatch, and moka systems, the osotua system involves the transfer of wealth, but it also differs from those systems in important respects. Specifically, although osotua partners have a reciprocal commitment to help one another if asked to do so, their gifts need not be reciprocal. Rather than being a system of reciprocal gift-giving, osotua is better understood as a system of limited risk-pooling.

Osotua's literal meaning is "umbilical cord." If economic anthropologist Steve Gudeman (1986) is right that people everywhere understand their societies' economies through central metaphors, then osotua may be regarded as the central metaphor of Maasai ethnoeconomics. Osotua's centrality to Maasai life was noticed by Christian missionaries, who evoked the idea of the Bible as a bond between God and people by translating "testament" as "osotua." Despite the fame of the Maasai and the important role that osotua plays in Maasai economic life, osotua has received little attention from ethnographers. Most mentions of osotua in the existing ethnographic literature on Maa-speaking peoples are limited to brief descriptions of osotua partners (called *isotuatin*) as bond friends, stock-sharing partners, and stock friends (e.g., Spencer 1965, pp.27, 59; Spencer 1988, p.39). Although isotuatin may provide each other with gifts and services of many kinds, the emphasis in these translations on livestock reflects their importance in the economy. Hollis (1905, pp.289, 321–322) translates osotua as "peace," but in the sense of a peace treaty or peaceful bond between former enemies rather than a general state of peacefulness (*eseriani*). Jacobs (1965, p. 210) makes the important observation that because osotua in its literal sense refers only to a *human* umbilical cord, its metaphorical use emphasizes the humanness of such relationships (according to Jacobs, a nonhuman umbilical cord is called *osarikoma*).

To learn more about osotua, Cronk (2007) used both qualitative and quantitative methods to explore the norm's features and the behaviors associated with it. The project was conducted in 2005 in the Mukogodo region of Kenya (Cronk 2004).[1] The qualitative aspect of the project consisted of semi-structured interviews and informal re-interviews with ten men ranging in age from 25 to 73. The interviewees displayed a very high degree of consensus regarding the major features of osotua relationships. 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. Gifts given in response to such requests are given freely (*pesho*) and from the heart (*ltau*) but, like the requests, are limited to what is actually needed. (see also Perlove 1987, p.169). Because the economy is based on livestock, many osotua gifts take that form, but virtually any good or service may serve as an osotua gift. Once osotua is established, it is pervasive in the sense that one cannot get away from it. Osotua is also eternal. Once established, it cannot be destroyed, even if the individuals who established the relationship die. In that case, it is passed on to their children (see also Spencer 1965, p.59). Osotua does not follow a schedule but persists 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. Not all gift-giving involves or results in osotua. For example, some gift-giving results instead in debt (*sile*). Osotua and debt are not at all the same. While isotuatin have an obligation to help each other in time of need, this is not at all the same as the debt one has when one has been lent something and must pay it back (see also Spencer 1965, p.27, and Perlove 1987, p.169). Going along with the idea that osotua gifts do not repay debt, osotua gifts are not payments at all, and it is 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.

One interviewee illustrated many of osotua's main features with a story about his own family. Some decades ago, his ancestor Kimbai was killed by two men from an enemy group. One of Kimbai's killers then removed his warrior's belt (*ntore*) and wore it as a trophy. After the fight, the killers visited a man from another local group and asked him for food, lodging, and medicine to treat their wounds. Unbeknownst to the visitors, their host and Kimbai were isotuatin. That man's wife recognized Kimbai's belt and deduced that the visitors had killed him. She and her husband slaughtered a sheep for fat to feed the visitors, poisoned the fat, which killed the two visitors, and thus avenged Kimbai's death. This revenge killing was a form of osotua gift back to the dead Kimbai and, by extension, to his survivors. The belt was then returned to

[1] The ethnic landscape in the Mukogodo region is complex. In 1971, Mukogodo community leaders successfully petitioned the Kenyan government to refer to them as Maasai, although more specific ethnic identities (e.g., Mukogodo, Mumonyot, Digirri, Ilng'wesi, and LeUaso) remain important locally. Because Cronk's work on the osotua norm involved interviewees and game-players from throughout the region, we refer to them collectively as Maasai. For more information about the history of ethnic identities in the Mukogodo area, see Cronk (2004).

Kimbai's grandfather, and the bond of osotua has continued between the two families.

Interviewees disagreed on only one point: Whether anything could end or "cut" (*adung'*) osotua. Eight said that nothing could end an osotua relationship. One said that a war could end an osotua relationship. Another said that a lie, whether told to elicit a gift (or a larger gift than actually needed) or in response to a request from an osotua partner, would end the relationship. However, he also made clear that such behavior was unthinkable. Osotua partners are expected to request only what they need and to give what is needed (though no more than that) if they are able to do so.

To explore the osotua norm's impact on behavior, Cronk (2007) 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. 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. The other half were played with a single additional framing sentence: "This is an osotua game." That minimal framing resulted in several contrasts between osotua-framed games and unframed games. In keeping with the emphasis in osotua relationships on restraint, respect, and responsibility, amounts given by both players as well as the amounts that first players expected to receive in return were all lower in the framed than in the unframed games. In games played without osotua framing, a positive correlation was found between amounts given and amounts expected in return, suggesting that players were invoking such common principles of exchange as trust, investment, and tit-for-tat reciprocity. In the osotua-framed games, in contrast, no relationship was found between amounts given and amounts expected in return. In osotua-framed games, but not in unframed games, amounts given by the first player and proportional amounts returned by the second player were *negatively* correlated, suggesting that the osotua framing shifts game play away from the logic of investment and towards the mutual obligation of osotua partners to respond to one another's genuine needs, but only with what is genuinely needed.

In a related study, Cronk and Wasielewski (2008) explored the impact of the osotua norm on the trust game behavior of American subjects with only minimal exposure to the concept. Seventy subjects read a short description of Maasai culture and the osotua concept and then played a trust game that was presented to them with no further framing. Another 70 subjects read the same description of Maasai culture and osotua and then played a game labeled "The osotua game." To get a baseline regarding how American subjects play the trust game, yet another 70 subjects read a text about meteorology and then played trust games presented to them with no further framing. The American subjects' behavior replicated in almost every way the behavior of the Kenyan subjects, with lower amounts being given and expected in return in the osotua-framed games than in the games played after reading about the Maasai but with no further framing. This result suggests that even unfamiliar social norms can have rapid and strong effects on behavior. It also indicates that the description of the osotua norm provided to the subjects, which was essentially the same as the description given here, was accurate and detailed enough to result in behaviors that corresponded closely with those seen in Kenyan subjects who had learned about the osotua norm simply by growing up as Maasai.

Although Maa-speaking peoples now engage in a wide variety of economic activities, Maa-speaking has long been closely associated with pastoralism, i.e., with subsistence based on herds of cattle, sheep, goats, and, in drier areas, camels. Livestock have two features that may be keys to understanding the osotua gift-giving norm. First, livestock are a form of wealth that is visible to the entire community. Unlike money, livestock cannot be secreted away. 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 and Tooby 1992), the public nature of livestock wealth makes osotua one system in which cheating is unlikely to be a major concern. Second, 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 and Hjort 1976). Any pastoralist would do well to find ways to reduce his or her exposure to risk.

There are various ways to deal with risk, including risk retention, risk avoidance, risk reduction and risk transfer (Dorfman 2007). *Risk retention*, which consists of accepting risk and absorbing any resulting losses, is what institutions do when they self-insure and what others do when they store resources in anticipation of future losses. Pastoralists engage in risk retention when they maintain herds larger than they need for subsistence, as a hedge against such losses (see, e.g., Naess and Bårdsen 2010). Such a strategy is difficult for the same reasons that risk is so great: Drought, disease, and theft make the maintenance of large herds difficult. *Risk avoidance* involves the reduction of dependence on high variability outcomes. Pastoralists may do this by reducing their reliance upon herds and practicing other forms of subsistence, such as hunting and raising of crops, as well (for an East African case study of risk avoidance, see Little *et al.* 2001). Among Maasai, however, such a strategy has a social cost because pastoralism is more respected than raising crops and hunting (Galaty 1982). Another potential disadvantage of risk avoidance is the fact that options with high risk often carry a larger anticipated reward so avoiding risk often entails giving up the potential for high payoffs. *Risk reduction* includes efforts to lower the probability of loss, or alternatively, to reduce the size of losses. Pastoralists' tactics for risk reduction include spreading stock into different ecological areas (Dahl and Hjort 1976, p.114) and, in much the same way that capitalist investors reduce risk by buying bonds as well as stocks, diversifying livestock holdings among species that vary in terms of their ability to survive droughts (King *et al*. 1984; Mace and Houston 1989; Mace 1990, 1993). Finally, *risk transfer* is the exchange of risk from one individual or group to another. One common way to transfer risk is to pool it, i.e., to agree to take on some of another party's risk in exchange for their willingness to take on some of one's own risk (Cashdan 1985; Wiessner 1982). This increases the likelihood that parties to the risk-pooling agreement will suffer losses but decreases the severity of those losses. Among hunter-gatherers, risk pooling may be achieved by having members of a group forage independently and then equally divide their acquisitions (Winterhalder 1986). Among pastoralists, livestock exchange, which can be frequent and substantial enough to significantly affect herd composition, may serve as a way of pooling risk (Bollig 1998, 2006; De Vries *et al*. 2006; Flannery *et al*. 1989; McCabe 1990). Although droughts and diseases may hit large areas simultaneously, one aid to risk pooling among pastoralists is the fact that such disasters do not necessarily hit all herds with equal severity. For example, when drought and disease struck livestock herds owned by Pokot in western Kenya in 1991 and 1992, some herders lost about 50% of their cattle, while others lost only a few head. Losses among goat herds were similarly variable, with some herds dropping by as much as 30% while one actually grew by 11% (Bollig 1998:145). We hypothesize that the osotua rule pools risk and increases herders' abilities to maintain viable herds while also limiting osotua partners' exposure to each other's risk by limiting the amounts transferred to what is truly needed and what the donor can truly afford to give.

Methods

A variety of modeling approaches have been used to investigate questions about human cooperation, including analytical models and simulations. Agent-based models are a class of simulations in which agents are modeled as entities with particular characteristics and decision rules who interact with one another and with their local environments. They are particularly well-suited for investigating the viability of cooperation when individuals have various predispositions and decision rules that they use to interact with one another and/or their local environments. In addition, agent-based modeling is coming to be used more widely within anthropology to investigate a variety of questions about interactions between individuals and their physical and social environments (e.g., van der Leeuw and Kohler 2007, Lansing *et al*. 2009). For example, agent-based models in anthropology are becoming increasingly common as evidenced by a recent edited volume on the topic (van der Leeuw and Kohler 2007) and work integrating agent-based modeling with a variety of other anthropological methods (e.g., Lansing *et al*. 2009). These models contribute to our understanding of the ways in which individuals' behavioral dispositions and characteristics lead to aggregate changes to the physical and social landscape which they inhabit.

Here we use an agent-based model of the Maasai pastoral system to investigate whether the gift-giving norms associated with osotua give rise to limited risk pooling. As with any other modeling endeavor, it is necessary to simplify various features of the system in order to make the model tractable and, perhaps more importantly, so as to not obfuscate the central underlying relationships that are its focus. In order to make our model of the Maasai pastoral system as realistic as possible, our values and assumptions about herd dynamics were based on existing scholarship (Dahl and Hjort 1976). We used this model to investigate whether the osotua rule increased overall herd survivorship and decreased the variability of survivorship within dyads compared to situations in which no livestock was exchanged and situations in which livestock was exchanged probabilistically.

Using Netlogo software, we modeled a population of two actors, each with a herd of finite size (see Fig. 1 for model overview and Appendix A for full model description). Each actor—representing a household of approximately six individuals—began with a herd of 70 cattle, and during each time period each actor's herd grew or shrank at a rate normally distributed around a mean of 3.4%, a typical annual growth rate for cattle herds in this region of East Africa (Dahl and Hjort 1976). Herd size was capped at 600, also a realistic maximum herd size for a household of this size. There was also a chance during each period that each herd would suffer a loss through drought or disease. The likelihood of such a loss and its severity were normally distributed around 31.6% and 6.97%, respectively. These figures are consistent with the severity of actual herd losses from multi-year droughts among East African pastoralists

(Dahl and Hjort 1976). Based on estimates of a family's caloric needs and cattle productivity in the dry season, we set 64 as the minimum size of a viable herd (structure of the model is captured by Fig. 1 and more detailed information can be found in the model description Appendix).

We then simulated several rules for interactions between individuals. First, we ran simulations in which no transfer of cattle occurred, providing a baseline for comparison with runs in which transfer of cattle did occur. In runs where transfer of cattle did occur, individuals each had one of two asking rules (probabilistic or osotua) and one of two giving rules (probabilisitic or osotua). This allowed us to compare the viability of the osotua rule in comparison to probabilistic rules and situations with no exchange.

We formalized the osotua rules as follows:

1. **Osotua asking rule:** Individuals ask their partner for cattle only if their current holdings are below the asking threshold (the minimum herd size of 64).
2. **Osotua giving rule:** Individuals give what is asked, but not so much as to put cattle holdings below the giving threshold (also the minimum herd size of 64).

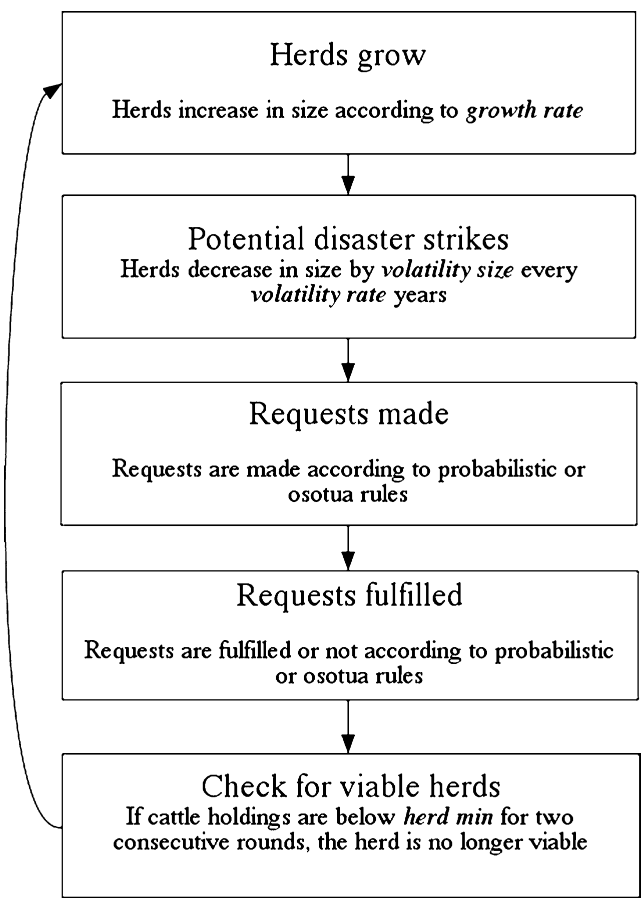

Fig. 1 Overview of model schedule. More detailed schedule provided in Appendix

Probabilistic rules are implemented as follows:

1. **Probabilistic asking rule:** Individuals ask their partner for cattle at a rate equivalent to the average osotua asking rate (.33) observed in the models run with both osotua asking and giving rules, and ask for a number of cattle that is equivalent to the mean of that given in the osotua runs (12 cattle).
2. **Probabilistic giving rule:** When asked, individuals give a proportion of cattle equivalent to the average mean proportion given in the models run with both osotua asking and giving rules (.29).

These rules were combined in different ways to produce five versions of the model:

1. No exchange
2. Osotua asking and giving rules
3. Probabilistic asking and giving
4. Probabilistic asking and osotua giving
5. Osotua asking and probabilistic giving

Consider a typical simulated interaction in the osotua asking and osotua giving scenario (version 2). The first time period begins with both herders having 70 cattle. During this time period, herds grow to 72 and 71 cattle and no 'disaster' strikes. Both individuals stay above the viability threshold of 64, so they do not make any requests. In period two, herds grow but there is also a 'disaster' which affects the first herd, which shrinks to 61, but not the second, which grows to 73. Because the first herder now has a herd below the viability threshold of 64, he requests three cattle from the second herder, just enough to bring his herd back to the minimum viable size (consistent with the osotua norm of restraint). Because the second herder is able to fulfill this request without, himself, dropping below the minimum viable herd size, he transfers three animals to the first herder, bringing their respective totals to 64 and 70.

Results

We investigated herd longevity to test the viability of herds under each of the asking and giving rules. Figure 2 shows survivorship curves for herds under each of the five conditions. Herd duration was not normally distributed; Kruskal-Wallis nonparametric ANOVA shows differences between the conditions (χ^2=1102.224; p=0). According to nonparametric post-hoc comparisons (Siegel and Castellan 1988) the median herd duration under osotua exchange was different from that under all other conditions. The full osotua model increases median herd longevity compared to the no-exchange model, raising the median herd duration from 11 iterations to 18 iterations (Table 1). The other conditions either had no effect on the median herd duration, or in the case of osotua request and probabilistic response, lowered the median herd duration.

In order to explore whether osotua rules increased risk pooling, we explored whether the outcomes for partners were correlated under each of the five conditions. Figures 3 and 4 show the relationship between the durations of the partners' herds under no exchange and osotua exchange conditions, respectively. There is no relationship between the two players' herd durations in the no exchange condition, but under osotua exchange, there is a significant correlation (Spearman's ρρ=0.141, $p=0$). There is also a correlation when requests are probabilistic and responses are driven by osotua rules, but the median herd duration in that condition was lower than when there was no exchange. There is no relationship under the other conditions. All statistical analysis and visualization completed using R (R Development Core Team 2008).

Discussion

When agents used both osotua giving and asking rules, herd longevity was greater than with any other combination of decision rules, indicating that osotua rules improve herd longevity over the alternatives of no exchange and probabilistic exchange. The longevity of the two agents' herds were more closely correlated in the osotua model than in any of the other models, indicating that osotua's effect on herd longevity was due to risk-pooling. When agents follow the osotua giving rule, they give if asked and if they are able to do so. At the same time, the osotua asking rule creates a constraint on asking (only when needed) which prevents exploitation. When used in tandem, this improves the average herd longevity within partnerships and decreases the variability of longevity within partnerships, essentially tying together the fates of the two osotua partners.

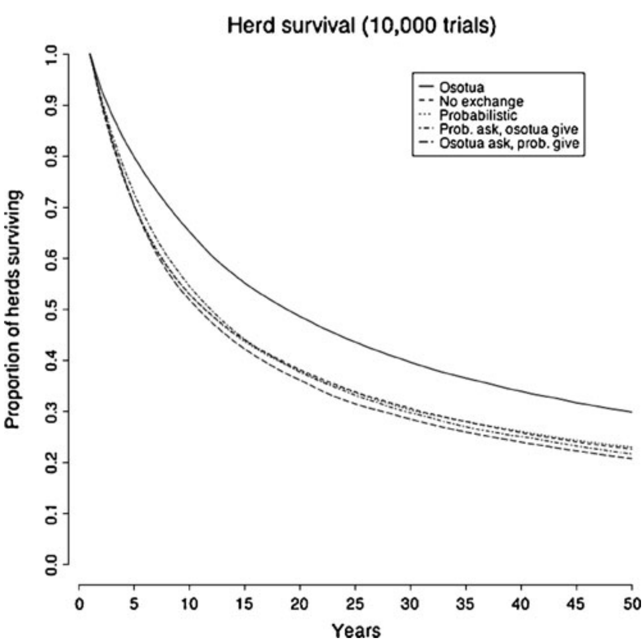

Fig. 2 Survivorship of herds in each condition. Average herd duration in the osotua exchange condition is significantly longer than in any other condition (see Table 1)

What is happening in the full osotua model is made clearer by comparisons with the other four models. Two of the other models (probabilistic asking and giving; probabilistic asking with giving following the osotua pattern) did neither better nor worse than the model with no exchange at all. The other model (asking according to the osotua rule with probabilistic giving) actually did worse than the model with no exchange. This appears to be due to the fact that requests are always made by needy individuals, but they are not always responded to as they would be under the osotua giving rule.

Our models indicate that a system of livestock exchange based on the rules of the osotua system helps herders maintain viable herds for longer than they would if they were entirely on their own or if they exchanged livestock equivalent probabilistic rules. Osotua exchanges achieve this affect through risk pooling, a form of risk transfer. Maasai pastoralists thus engaged in a variety of types of risk management. By maintaining large herds, they practiced risk retention. By diversifying their livestock holdings, Maasai pastoralists engaged in risk reduction. Maasai efforts to avoid the risks of pastoralism by also engaging in other forms of subsistence were discouraged by their strongly held pure pastoralist ideal, but the ethnographic record shows that many Maasai and other Maa-speaking groups have engaged in hunting, farming, and even fishing in addition to raising livestock. The relative importance of these different ways of managing risk is unclear and probably varied from group to group depending on their overall wealth, the availability of non-pastoralists resources (e.g., arable land, wild game, and fish), and other circumstances. The importance of the osotua norm in Maasai culture and the seriousness with which osotua relationships are treated suggests that risk pooling was essential to the success of the Maasai economy. In future work we plan to investigate how these dyadic dynamics scale up in networks of interacting actors who inhabit environments that may vary. The results of the present model demonstrate that agent-based models can be useful for exploring gift-giving dynamics such as osotua at the dyadic level. However, they also may be used to explore more complex dynamics within the osotua system and other ethnographically documented gift-giving systems.

Our model is similar to one used by Flannery *et al.* (1989) to study the impact of a system of gift-giving called *suñay* on herd survival among llama herders in the Peruvian Andes. Formally, the suñay system is rather different from osotua, but in actual practice the two may resemble each other quite a bit. For example, in suñay gifts of livestock are supposed

Table 1 Median herd durations

Exchange condition	Median herd duration (iterations)
No exchange	11
Probablistic exchange	11
Probablistic request, osotua response	11
Osotua request, probabilistic response	10[a]
Osotua exchange	18[b]

[a] median significantly different from no exchange model at $p < .05$; [b] median significantly different from no exchange model at $p < .001$

to be given not in response to requests but rather by the host of an annual ceremony at which llamas are decorated who is grateful for the help provided by those attending the ceremony. However, Flannery *et al.* report that, in reality, suñay gifts are often planned in advance in light of information passed through intermediaries regarding the needs of those attending the ceremony—a practice not unlike requests based on need in the osotua system. Flannery *et al.'s* model of suñay is also similar to our model of osotua in that requests for gifts occurred when an individual's herd dropped below a threshold of viability. As with our models, they found that the addition of a gift-giving system helped herds remain above that threshold for longer than they did without such a system. The similarities of these two systems and the fact that they

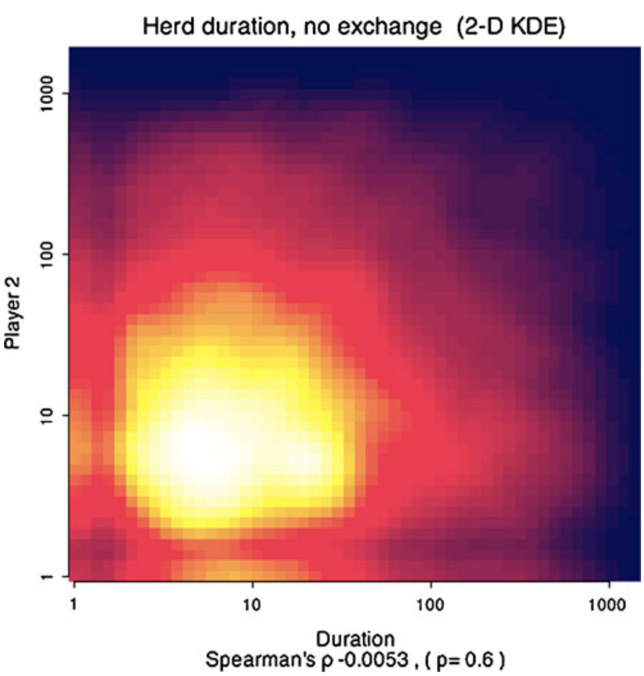

Fig. 3 Kernel density estimate plot of Player 1 and Player 2 herd duration in the no-exchange condition (log-log axes). White/yellow regions indicate more common conditions (n=10000, Spearman's Rho: -0.0053, p=0.6)

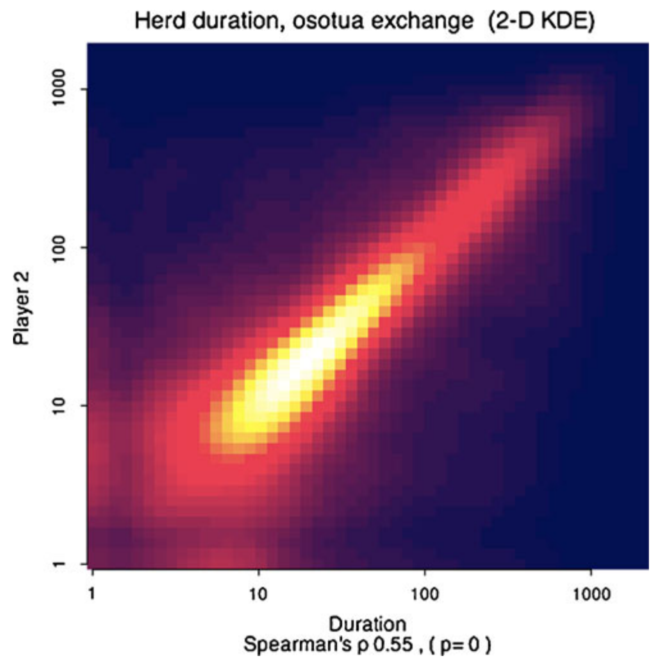

Fig. 4 Kernel density estimate plot of Player 1 and Player 2 herd duration when both players use osotua rules (log-log axes). White/yellow regions indicate more common conditions (n=10000, Spearman's Rho: 0.55, $p \approx 0$)

both occur in pastoralist societies suggests that the volatility associated with pastoralism may have led to the independent development of similar institutions to deal with the problem of risk management.

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Appendix: Model Description

The model description offered below follows the standardized ODD protocol for describing individual and agent based models (Grimm and Railsback 2005; Grimm *et al.* 2006).

Purpose

Here we use an agent-based model of the Maasai pastoral system to investigate whether the gift-giving norms associated with osotua give rise to limited risk pooling. This model allows us to investigate whether the osotua rule

Table 2 Overview of state variables associated with each type of entity

Entity	State variable	Description
Global	Annual growth rate	Amount by which herds grow each year
	Volatility rate	Likelihood of a negative event (e.g., drought)
	Volatility size	Decrease in herd size resulting from negative event
	Minimum herd size	The minimum viable herd size
	Maximum herd size	The maximum herd that can be maintained
Agents	Herd size	Number of cattle in agent's herd
	Asking threshold	In Osotua model, the threshold below which agents ask for cattle
	Giving threshold	In Osotua model, the threshold below which agents will no longer give cattle
	Asking rate	In probabilistic model, the rate at which agents ask
	Giving rate	In probabilistic model, the rate at which agents give
	Proportion given	In probabilistic model, the proportion of asked amount that agents give

increased overall herd survivorship and decreased the variability of survivorship within dyads.

State Variables and Scales

In this model time is represented discretely. Space is not explicitly modeled. Herd growth dynamics and volatility are implemented with global variables while the herd size and giving/asking rules are agent variables (Table 2). During each time period, agents execute the commands described in the schedule.

Process Overview and Scheduling

This model proceeds in discrete time steps, and entities execute procedures according to the following ordering:

1. For each actor, herds change in size:
   - Herds increase in size according to *growth rate*
   - Herds decrease in size by *volatility size* every *volatility rate* years
   - If *herd size* is above *herd max* it is set to *herd max*
   - *Herd size* is rounded to nearest integer
2. Requests are made:
   - If no exchange, no requests are made
   - If asking is probablistic, requests made according to *asking rate*
   - If giving is osotua, requests are made if *herd size* is below *herd min*
3. Requests are fulfilled
   - If no exchange, no requests are made
   - If asking is probablistic, requests fullfilled according to *giving rate* and *giving proportion*
   - If giving is osotua, requests are made if *herd size* is above *herd min*
4. Actors removed from the population if two consecutive rounds occur where cattle holdings are below *herd min*.
5. *Age* of actors incremented by 1

Table 3 Initial and default values for all variables

Entity	State variable	Initial/Default Value	Units
Global	Annual growth rate	3.4 (SD: 2.53)	% current herd
	Volatility rate	10	% per year
	Volatility size	30 (SD: 10)	% of current herd
	Minimum herd size	64	Number cattle
	Maximum herd size	600	Number cattle
Agents	Herd size	70	Number cattle
	Asking threshold	64 (Osotua only)	Number cattle
	Giving threshold	64 (Osotua only)	Number cattle
	Asking rate	33 (Probabilistic only)	Number cattle
	Giving rate	100 (Probabilistic only)	Number cattle
	Proportion given	.29 (Probabilistic only)	Proportion

Design Concepts

Emergence In this model, risk pooling emerges from interactions between agents.

Prediction Agents in this model lack the ability to predict outcomes of future environmental variability or future social interactions. They do not integrate information across time periods.

Sensing Agents receive requests from their interaction partners and are able to examine their own resource holdings before fulfilling requests.

Interaction Agents interact by making and fulfilling requests for cattle.

Stochasticity Herd growth and environmental volatility both have stochastic components.

Observation Reported data are averaged from 10,000 runs for each of the five conditions. Simulations were run until both agents were removed from the population (i.e., dropped below the viability threshold for more than 2 consecutive time periods).

Initialization

All runs were initialized according to default parameters in Table 3.

Input

In order to make our model of the Maasai pastoral system as realistic as possible, the following parameter values and assumptions about herd dynamics were based on existing scholarship (Dahl and Hjort 1976).

Growth Rate We used a 3.4% growth rate with an SD of 2.53 based on Dahl and Hjort's (1976, p. 66) estimate the growth rate in "normal" conditions to be 3.4%, with a maximum possible growth rate of roughly 11% and a minimum of approximately −6% (in the diminishing herds example). Dahl and Hjort estimates of these numbers are based on both empirical evidence and analytical modeling.

Herd Size Initial herd sizes in our model were 70, with a minimum of 64 and a maximum of 600. These values were derived from Dahl and Hjort (1976, p. 178) who state that a herd of 64 cattle is sufficient to sustain a reference family. Herd sizes described in the text range from 60–100 cows and herds larger than 600 are not considered viable (Dahl and Hjort 1976, p. 158).

Volatility We used a volatility rate of .1, meaning that on average a disaster (e.g., drought or disease) occurred every 10 years. In our model, this disaster reduced the cattle herd by 30% on average, with a SD of 10%. Dahl and Hjort (1976, pp. 114–130) note that these disasters occur approximately every 10–12 years based on empirical data, and that the population decline (during disasters that occur every 10 years) should not be more than approximately 28%, based on analytical models.

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