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Transition of social organisations driven by gift relationships

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Anthropologists have observed that gifts bring goods to the recipient and honour to the donor in many human societies. The totality of such social relationships constitutes a network. Social networks characterise different types of social organisations including bands of small kin groups, tribal unions of families, and hierarchically organised chiefdoms. However, the factors and mechanisms that cause the transition between these types have hardly been explained. Here, we focus on gifts as the driving force for such changes. We build the model by idealising gift interactions and simulating the consequent social changes due to long-term massive interactions. In the model, people give their wealth to each other, produce wealth, and reciprocate for the gift. Gifts and reciprocation strengthen relationships. Through simulation, we demonstrate that, as the frequency and scale of gifts increase, economic and social disparities successively arise. Simultaneously, network structures shift from bands to tribes and then, chiefdoms. Statistical analysis using the Standard Cross-Cultural Sample, a global ethnographic database, empirically verifies the theoretical results. The constructive simulation study, as presented here, explains how people's interactions shape various social structures in response to environmental conditions. It provides the basic mechanistic explanation for social evolution and integrates microscopic and macroscopic theories in social sciences.

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Introduction

Gifts establish social relationships through the transference of goods in many societies. Anthropologists have observed three obligations of the gift: to give, to receive, and to reciprocate (Mauss, 1923). Particularly, reciprocity unites people, whereas those who fail to reciprocate lose their reputations and become subordinate to donors. For instance, chiefs and big men in Polynesian and Native American communities exchange assets such as livestock or ornaments in this way at nuptials, funerals, war compensation, trade, and various rituals. By reciprocating appropriately (sometimes with amplification), one's reputation is maintained (Malinowski, 1922; Mauss, 1923; Strathern, 1971). Other researchers, in contrast, emphasise that some gifts are donated to seek acknowledgement without expecting reciprocity (Moriyama, 2021). Food sharing in hunter-gatherer societies generally belongs to such gifts. Those who give their food will improve their reputation but do not oblige reciprocity to the recipients (Bliege Bird et al., 2018; Kitanishi, 1998; Ready and Power, 2018). In any case, the gift strengthens the social relationships between the donor and recipient, including cooperation, dominance, and subordination (Komter, 2007; Mauss, 1923). In this paper, we mainly consider ceremonial gifts directed to specific individuals that require amplified reciprocity.

The totality of social relationships constitutes the network (Leach, 1982; Wasserman et al., 1994). Different social organisation structures exist for such networks. Human beings generally form kinship systems based on genealogical and marital relationships due to developed kin recognition (Chapais, 2009; Lévi-Strauss, 1949; Planer, 2021; Rand and Nowak, 2013). As the population density and the frequency of conflicts with external enemies increase, the structure shifts from bands united by kinship to tribes united by cultural belief such as siblinghood, to chiefdoms composed of role-divided groups, and then to states with legitimate monopolies of power (Service, 1962). The increase in economic and social disparities accompanies these transitions. Other researchers have emphasised the increase in productivity, surplus, or frequency of war to explain the emergence of complex social organisations, disparities, and the division of labour (Bataille, 1949; Carneiro, 1970; Marx, 1911; Turchin and Gavrilets, 2009). However, the origins of such structures have been unclear.

In this paper, we focus on gift relationships that cause changes in microscopic interpersonal relations as the driving force to shape the macroscopic structure of social organisations. Therefore, we model gift transactions. People give their wealth to someone else, produce wealth, and reciprocate for the gifts they have received. When reciprocity succeeds, an equal cooperative relation is established. However, when it fails, the recipient would repay the debt and be subordinate to the donor. By simulating the model, we demonstrate the emergence of various social organisations. We show that social structure shifts from bands to tribes and then to chiefdoms, depending on the frequency of the gifts and the interest rate for reciprocity. Furthermore, we demonstrate that, as gift transactions are more frequent, economic disparity followed by social disparity arises. Thus, we bridge the gift theory of microscopic interpersonal relationships and the theory of macroscopic social structures. This will provide a so-called 'mechanism-based explanation' to reveal the micro-macro relation and historical causality (Ylikoski et al., 2012). Here, we are interested in the social consequences of the gift interactions described above rather than the origins of such interactions. Thus, we explore theoretically possible patterns of social organisations driven by gift interactions, assuming that people give, receive, and reciprocate as observed in the field.

To test the validity of the theoretical results, we compare them to the statistical analysis of a global ethnographic database of premodern societies called the standard cross-cultural sample (SCCS) (Kirby et al., 2016; Murdock and White, 1969). The SCCS contains 186 societies, considered culturally and linguistically independent of each other (even if some correlations exist due to shared ancestry in the strict sense (Minocher et al., 2019)). The data allow us to quantitatively analyse cultural adaptations to environments (Bernard, 2017; Marsh, 1967). Subsequently, we empirically unveil the successive rise of economic and social disparities as the frequency and scale of gifts increase. By combining theoretical simulation and statistical analysis, we produce logically coherent and empirically valid scenarios on the evolution of each social organisation.

The remainder of this paper is organised as follows: In the next section, we introduce a basic model of the gift relationship and demonstrate the emergence of economic and social disparities. Following this, we extend the model to include generation alternations to consider kin relationships and demonstrate the transition of social organisations from bands to tribes and chiefdoms. Next, by analysing the SCCS, the theoretical results are verified. Finally, we discuss the significance of this method, which combines theoretical models with anthropological theories and empirical data analysis, to explore social phenomena.

Basic model

Overview of the model. First, as a preparation, we introduce a basic model for the development of economic and social relations by gifts within a single generation. In the model, we represent society as a network of people. The nodes represent individuals, and the directed edges represent their social relations. Each node i has its own wealth w_i . In each time step, each node i gives its wealth as a gift to node j with probability p_{ij} , which is the weight of edge directed from i to j . Then, each node produces wealth. The production is proportional to $1 + \log(1 + w)$, considering the law of diminishing returns (Gibson and Gurmur, 2011; Malthus, 1798; Ricardo, 1891). After production, each node reciprocates for the gift. Here, one must return $1 + r$ times the amount received in the initial gift. When one can reciprocate appropriately, the deal ends. However, inappropriate reciprocity will leave a 'debt' that will be repaid based on the subsequent production. Until the repayment is completed, those repaying cannot make new gifts (but can receive new gifts and have more debts).¹ Here, we assume that each node gives its entire wealth as an initial gift. This means that the donor imposes a repayment obligation proportional to the amount of the wealth rather than losing the entire wealth by giving. It, however, can be relaxed. If one gives a fraction p of wealth, this is represented in the present model by changing the effective interest rate to pr since the obligated interest for the recipient is prw_i . Hence, the results are qualitatively unchanged even when each node gives some percentage, rather than all, of its wealth as an initial gift.

Note that 'wealth' here refers to any assets in the broad sense. It can include money, livestock, ornaments, and, in extreme cases, people. The interest rate r and the productivity function $1 + \log(1 + w)$ depend on the kinds of and situation for the gift. Generally, r tends to be positive in ceremonial gifts made by chiefs (Mauss, 1923). In the Kula exchange in Trobriand Islands, r equals 0, that is, equivalents are exchanged (Malinowski, 1922), whereas it is about 1, that is, reciprocity should be doubled, in the Moka exchange in Hargenens in Papua New Guinea (Strathern, 1971). It can be negative (without expecting reciprocity) in daily life such as food sharing (Bliege Bird et al., 2018; Kitanishi, 1998; Ready and Power, 2018). Here,

however, we consider the cases with $r \geq 0$ to discuss the evolution of disparities. Production of livestock increases with its amount, whereas having ornaments may not directly increase productivity. Still, giving and receiving ornaments can increase one's social reputation, which will increase production due to larger social supports (Malinowski, 1922). However, simulation results with the constant productivity function 1 (without the term $\log(1+w)$) give qualitatively the same results as shown in Fig. S1. Hence, we neglect dependence on the productivity function for simplicity.

To represent the change in social relationships caused by gifts, we assume that the edge weight p_{ij} increases by η each time the wealth is transferred from node i to j whether as a gift, reciprocation, or repayment. The more frequently one gives to a person, the greater the motivation to make a gift to that person in the future. Let us consider the consequences of the gift from i to j . Appropriate reciprocation results in $p_{ij} \approx p_{ji} > \eta$, that is, i and j are in an equal cooperative relationship. However, repaying the debts over several steps from j to i will lead to $p_{ji} > p_{ij}$, that is, i has an advantage over j . We call $c_i = \sum_j p_{ji}$, the sum of edge weights directed towards i , as the connectivity of i , which represents i 's social status. Note that the edge weights are normalised so that $\sum_j p_{ij} = 1$, the sum of edge weights directed from i , after the change in their values due to the gift, fixes the sum of the gift probability to 1.

In the simulation, the initial edge weights are set equal to $1/N$, where N is the number of nodes. Similarly, each node has a wealth of 1.0 in the initial state. The parameters are summarised in Table 1

Algorithm of the model. Changes in i 's wealth Δw_i and the edge weight Δp_{ij} from i to j are expressed as follows. In the following equation, we use a random variable ζ_{ij} that takes 1 with probability p_{ij} and 0 otherwise. $\zeta_{ij} = 1$ indicates that i gives j a gift.

$$\Delta w_i = \frac{1 + \log(1 + \sum_j w_j \zeta_{ji})}{100} + r(w_i - \sum_j w_j \zeta_{ji}), \quad (1)$$

$$\Delta p_{ij} = \eta(\zeta_{ij} + \zeta_{ji}), \quad (2)$$

$$p_{ij} = p_{ij} / \sum_k p_{ik}. \quad (3)$$

Each i chooses a recipient j according to the edge weights. i gives the wealth to j , and i receives wealth from some individuals (maybe none). i 's production is determined by the amount of wealth i received. The denominator of productivity was set to 100 to prevent wealth from exploding. i will receive interest for a gift made and pay it for a gift received (Eq. (1)). The edge weights change due to the interaction. p_{ij} increases due to either i 's gift to j or i 's reciprocation for j 's gift as expressed in Eq. (2). Here, we described the case without debts for simplicity. There can be

wealth and edge weights change due to debt repayment. Finally, the edge weights are normalised (Eq. (3)).

Emergence of disparity. Simulations are performed for 1000 time steps, that is, 1000 cycles of gift, production, and reciprocation procedures. With time, people's wealth and network structures change. By analysing the distributions of wealth and connectivity, we observe an increase in economic and social disparities. Figure 1A shows the temporal change of the Gini coefficients for wealth and connectivity. Gini coefficient for wealth G_w is given by $G_w = \sum_{i=1}^N \sum_{j=1}^N |w_i - w_j| / (2N \sum_{i=1}^N w_i)$, which shows the extent of the inequality (the same applies to that of connectivity G_c).

Since gift transactions involve amplified reciprocation as long as $r > 0$, the economic disparity increases as more gifts are exchanged. When economic disparity is sufficiently large, the appropriate reciprocation becomes difficult. Then, unidirectional social relationships are established through the repayment of 'debts'. As shown in Fig. 1A, B), the increase in economic disparity precedes social disparity. Furthermore, the social disparity increases when more people cannot reciprocate appropriately. In this simulation, G_w reaches close to 1, which indicates that all assets in society are monopolised in the end. This seems too large compared to empirical cases. The Gini coefficient of wealth is about 0.2 for hunter-gatherer and horticultural societies and about 0.5 for pastoralist and agrarian societies (Smith et al., 2010). Here, however, we note that the monopoly of ornaments, for example, does not mean that of all living goods. Since 'wealth' in our model represents the goods that are offered as gifts, the Gini coefficients for such kinds of goods can be larger than that of the overall wealth.

In Fig. 1C, we plot the average duration of individuals' statuses by changing the interest rate r . We focus on three statuses, that is, 'free' (blue), 'repaying' (green), and 'rich' (orange). 'Free' indicates that people are not in the repayment process, 'repaying' indicates that they are in that process, and 'rich' indicates that they are in the top 5% of the wealthy individuals in society. We calculate the average steps for which people sustain these statuses. The graph suggests that as r gets larger the 'repaying' people are less likely to finish repayment, indicating a larger disparity. However, 'free' or 'rich' people are also likely to lose their positions. Hence, the stability of the high status is greatest for a slightly positive r value.

Figure S2 shows the temporal change of the network structures. As time passes, the networks are denser, and the edges are concentrated towards a few people. Consequently, we observe the emergence of social disparity and a hierarchical organisation, as in the chiefdom, in this model. However, when the number of gift interactions is small, the network is sparse and exhibits no specific structure, unlike the band. The literature suggests the importance of both kinship and reciprocal transactions in establishing social relationships (Apicella et al., 2012; Hill et al., 2011; Planer, 2021; Rand and Nowak, 2013; Service, 1962; Thomas et al., 2018; von Rueden et al., 2019). Therefore, we need to implement the reproduction process to include kin relationships to explain the transition of social organisations from bands to tribes and then, chiefdoms.

Full model

Model. In this section, we introduce the reproduction process to the basic model. First, we assigned a lifetime l_i to each i following the Poisson distribution with a mean of l , which represents the average number of gifts one makes in a lifetime. When l_i steps have passed since i 's birth, i reproduces children. Children inherit an equal division of their parent's wealth and the edge weights directed towards the parent. When individual i has N_i children, the wealth of the children would be w_i/N_i and the edge weight

Table 1 Parameters used in the model.

Sign	Explanation	Value
N	(Initial) number of individuals in society	100
η	Increment of edge weight by transaction	0.03
r	Interest rate for reciprocation	0.1
N_s	Number of societies in the model	50
l	Average number of gifts in a lifetime	Variable

In the results described below, parameter values are fixed to those shown in the table unless the value is explicitly described. The last two parameters only appear in the full model.

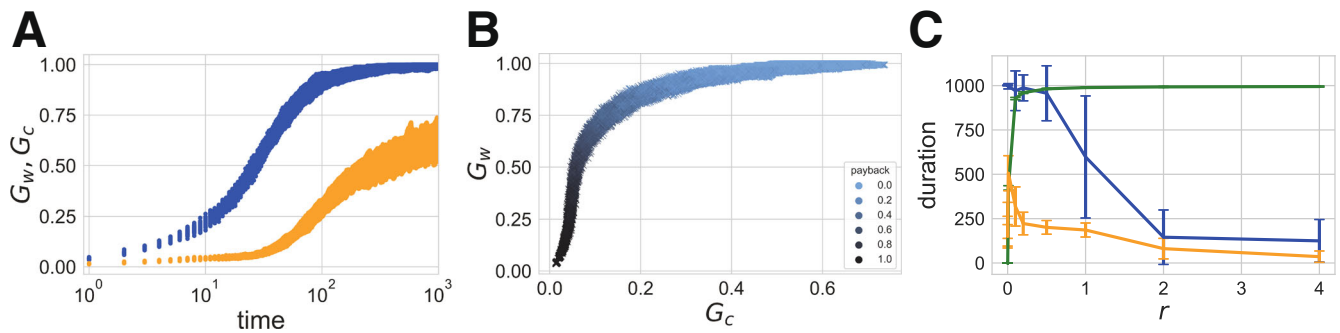


Fig. 1 Simulation result of the basic model. **A** Temporal change of Gini coefficients for wealth (blue) and connectivity (orange). The graph presents the results of 100 trials. **B** Scatter plots of Gini coefficients at each time step. The marker colour indicates the percentage of appropriate reciprocation made for the gift at that time. The lighter colour shows that fewer gifts are reciprocated. **C** The average duration of individuals being 'free' (blue), 'repaying' (green), and 'rich' (orange), depending on the interest rate for reciprocation r . Error bars show the standard deviations of 100 trials. 'Free' indicates that people are not in the process of repayment, 'repaying' indicates that they are in that process, and 'rich' indicates that they are in the top 5% of wealthy individuals in society. r equals 0.1 in **A** and **B**.

from individual j to the children would be p_{ji}/N_i . Subsequently, to model the kin relationship, siblings are connected by the edge with 3η of the weight. Note that this value is not important. For example, we can obtain essentially identical results by setting this value as 5η or 10η (see Figs. S3 and S4.).

Here, since the number of children in families is positively correlated with their wealth in pre-industrial societies (Gibson and Gurmu, 2011; Nettle and Pollet, 2008), we assume that the number of children for individual i follows the Poisson distribution with a mean of $1 + \log(1 + w_i)$. However, simulation results are almost qualitatively independent of the specific forms. For example, assuming that the number of children follows the Poisson distribution with a constant mean (independent of wealth), essentially the same results are obtained (see Fig. S5.).

The number of individuals in society will change through reproduction. In actual situations, large societies eventually divide (Service, 1962). In this model, if the population of each society doubles the initial value N , we assume that it splits into two. At this time, connections with those who have split into different societies are removed and connectivity is renormalised to keep the sum of edge weights directed from each node to 1. In the model, N_s societies exist. When a society splits into two, another society is removed from the system at random to keep the number of societies to N_s . This process can be interpreted as an invasion, imitation, or coarse-grained description of a growing system. Therefore, societies that grow faster replace others, resulting in society-level evolution. This multilevel evolution of families and societies follows the hierarchical Moran process, which is generally applied to the evolution of group-level structures in hierarchical systems (Itao and Kaneko, 2020, 2021, 2022; Takeuchi et al., 2017; Traulsen and Nowak, 2006).

For this full model, we arrange the above algorithm of the basic model as follows. Each person has a lifetime l_i following the Poisson distribution with a mean l . The denominator of productivity would be l_i instead of 100 in Eq. (1) to keep the average productivity in a generation fixed. Then, after l_i steps pass, i bears children following the Poisson distribution with a mean $1 + \log(1 + w_i)$. Then, each child inherits the parent's wealth and edge weights by dividing them equally. The proportion of inherited wealth, namely s , varies from society to society. Cross-cultural research has revealed the link between intergenerational wealth transmission and wealth inequality (Mulder et al., 2009). In the following simulation, s equals 1, that is, all parent's wealth is distributed to children. Figures S6 and S7 show the result with $s = 0$ and 0.5. Although larger r and l

are needed for the evolution of disparities under smaller s , they give qualitatively the same results.

The value of the frequency of gifts l depends on the kinds of and situation for gifts. For example, the number of gifts upon marriage is proportional to the number of children in the family and on the order of 1–10. The gifts of ornaments among chiefs are made once every few years, indicating a similar order (Malinowski, 1922). This can be much larger for the daily exchange of goods. However, l is up to 300 in our simulation due to computational cost. Still, results with larger l can be estimated from the current results as we explain later.

Transition of social organisations. We performed the simulation for 50 l steps by changing the interest rate r and the frequency of gift l . In the basic model above, economic and social disparities increase over time. However, they now converged to certain values depending on r and l (see Fig. S8). Figure 2 shows the network structures and the distributions of wealth and connectivity of individuals in societies in the last 5 l steps. When l is small, we observe small clusters of nodes that are densely connected within the cluster and sparsely connected to the rest of the nodes. Clusters are formed by shared ancestry, that is, kinship within several generations. The gift interactions bring sparse connections among clusters. At this time, the inequalities in wealth and connectivity are weak. As l increases, the clusters are larger and the connection among them is denser. Furthermore, a strong inequality in wealth appears. Then, when l is sufficiently large, the edges are concentrated on several 'free' people who are not in the repayment process (blue nodes). The network is hierarchically organised with a chain of unidirectional edges. Both inequalities in wealth and connectivity are now strong. The distributions of wealth and connectivity show the power-law tail for the larger side. Such fat tails indicate strong disparities. Moreover, Fig. 2B suggests that the power exponent α decreases as l increases, indicating a fatter tail for the larger side and a further development of disparities.

Figure 3A, B reveals that economic disparity arises before social disparity, as in the basic model.² Moreover, for small values of l , the disparities and other relevant quantities for $r > 0$ approach those observed for $r = 0$, before sharply deviating from them. This suggests that as disparities emerge, the economic and social states move to a different phase. Economic changes occur first, supposedly when the increase in production due to the acquisition of wealth is no longer sufficient to cover the interest for reciprocation. This is followed by social change, which is

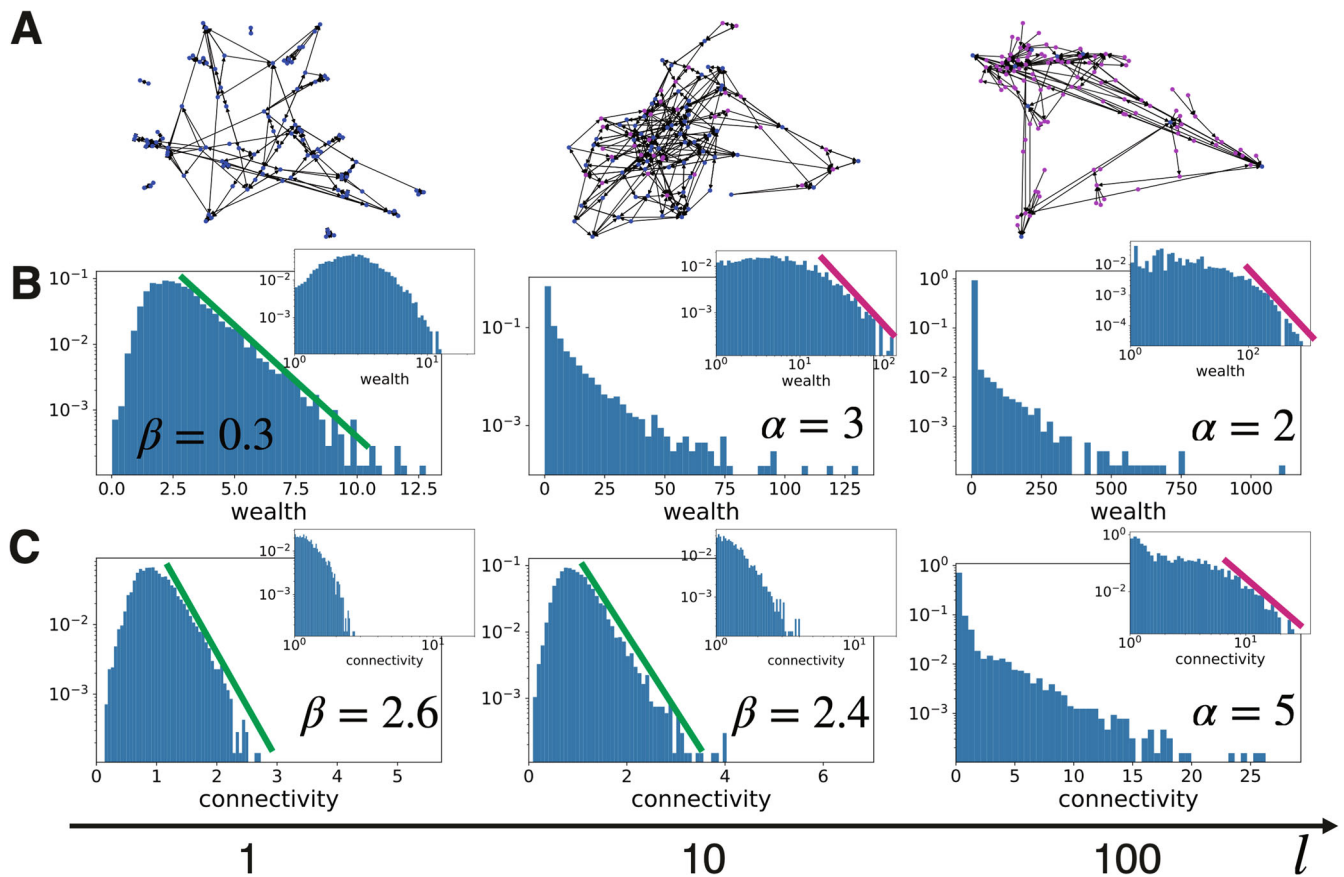


Fig. 2 Dependence of network structure, wealth distribution, and connectivity distribution on the frequency of the gift l . **A** Network structure in the final state. Edges with weights larger than η are shown. Red nodes represent 'repaying'—those who are in the repayment process. Blue nodes represent 'free'—those who are not in that process. **B** The frequency distribution of wealth. **C** The frequency distribution of connectivity, that is, the sum of the weights of edges directed to each node. Insets are log-log plots of the frequency distributions. The green line is the exponential fitting of the distribution $\exp(-\beta x)$, whereas the pink lines are power-law fitting $x^{-\alpha}$. The estimated values of α and β are shown in the figure. The figures show the typical result for each of the three 'phases' described below. The coefficients of variation (SD/mean) of α and β values are below 0.2. Considering the small deviations, the presented examples are deemed to represent the results for each l .

supposed to occur when most gifts are no longer reciprocated and unidirectional social relations develop. Note that we have demonstrated the temporally successive emergence of economic and social disparities in the basic model. Here, however, we demonstrate their emergence as an adaptation to the different environmental parameter values r and l . Then, we obtain the phase diagram of the disparities by examining whether each Gini coefficient is significantly larger than that for $r=0$ by using 100 samples of simulations for each parameter value, as shown in Fig. 3C. Here, we identified the emergence of disparity if the difference is larger than three times the standard deviation. Parameter regions for no disparities, economic disparity alone, and both disparities are shown in purple, yellow, and green, respectively, as distinct phases. The diagram shows that larger r and l values accelerate the evolution of disparities. Figure 3 indicates that increases in r and l generally have the same effect on the result. Thus, even though the maximum value of l is set to 300 in our simulation, results with a larger l can be estimated from those with larger r .

We then investigate the characteristics of emergent networks. Here, we focus on the degree of clustering, that is, the cliquishness of a typical neighbourhood, and the degree of hierarchy, which is the asymmetric connectivity of different levels (Wasserman et al., 1994). The average clustering coefficient c is measured by calculating the average percentage of the connection between each node's neighbours (Watts and Strogatz, 1998). Flow hierarchy

degree h is measured by calculating the percentage of edges that are not included in any cycle, which indicates the extent of persistent directionality in continuing flows (Luo and Magee, 2011).

Figure 3D, E shows the dependence of clustering coefficient c and hierarchy degree h on the frequency of gifts l and interest rate r . As l is larger, implying gift transactions are more frequent, c is smaller and h is larger. The trend for c is almost independent of the interest rate r , but h is dependent on it. Precisely, the increase in h accompanies that of G_c . Hence, a hierarchical social organisation emerges as a qualitative change in the system, accompanied by social disparity.

Kinship-based connection unites people who are genealogically close to each other and creates clusters. As social relationships expand through gifts, kinship-based ties fade and people are linked to any other person in society, making the network less clustered. Then, when debts are incurred frequently, a few rich people solely build novel relations. Those who cannot reciprocate are forced to repay and strengthen the relationship directed to the donor of the gift. Then, the hierarchy emerges in the network. People who receive repayment from many people are increasingly wealthy, which allows them to make gifts to many others (in fact, the correlation between wealth and connectivity is large only when societies are hierarchically organised, as shown in Fig. 3F). As a result, those with large connectivity further enhance it. Hence, network development follows the so-called 'preferential attachment', which is known to result in the power-law tail of

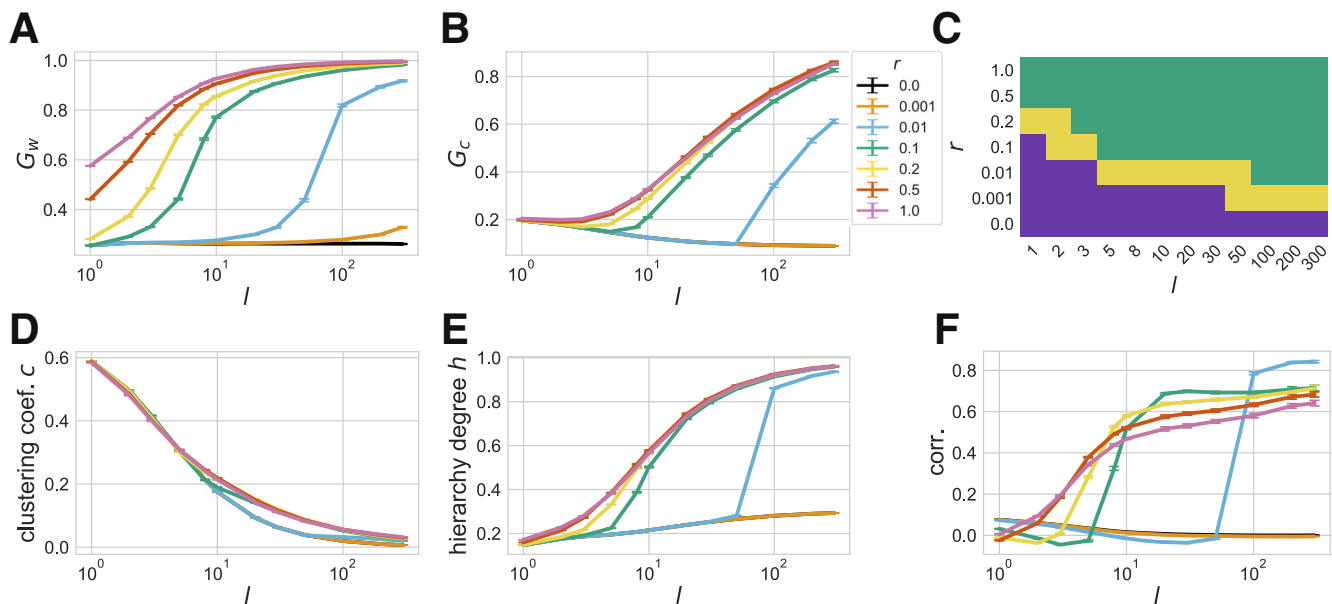


Fig. 3 Dependence of the disparities and network characteristics on interest rate r and the frequency of gifts l . Error bars show the standard deviations of 100 trials. **A** Gini coefficient for wealth G_w . **B** Gini coefficient for connectivity G_c . **C** Phase diagram of disparities. Phases of no disparities (purple), economic disparity alone (yellow), and economic and social disparities (green) are shown. **D** Average clustering coefficient c , that is, the cliquishness of a typical neighbourhood. **E** Flow hierarchy degree h , which is the persistent directionality in continuing flows. **F** The correlation coefficient of wealth and connectivity. Different line colours correspond to different interest rates r .

connectivity (Barabási and Albert, 1999; Dorogovtsev et al., 2000; Krapivsky et al., 2000). Figure 2C shows the power-law tail in the distribution of connectivity for larger l .

Figures S9 and S10 show the dependence of simulation results on population size N and the increment of edge weight by transaction η . The result with $N = 30$ was almost the same as in Fig. 3. The result with $\eta = 0.03$ was qualitatively the same. However, the region for both disparities (green) narrows and the hierarchy degree is smaller because the connectivity changes weakly if η is small.

In the simulation so far, we have assumed that people give their entire wealth as a gift and that children divide inheritances equally. In real societies, however, the size of the gift and the distribution of the inheritance can differ (Colleran, 2014; Gibson and Gurmu, 2011; Harrell, 1997; Malinowski, 1922; Strathern, 1971; Todd, 1999, 2011). Therefore, we perform the simulation of an extended model in which the percentage of wealth to be donated and the inequality in inheritance evolve over generations. Here, we assume that these strategy parameters are transmitted from parents to children with slight variation through ‘mutation’ (Cavalli-Sforza and Feldman, 1981; Creanza et al., 2017). As shown in Fig. S11, people will spend most of their wealth on gifts when l is sufficiently large. Furthermore, an equal inheritance evolves for small l and an exclusive inheritance evolves for large l , which is consistent with empirical research (Service, 1962). Note that the results regarding the emergence of disparities or transitions in network structures are qualitatively robust against this modification.

Empirical data analysis

We empirically test our theoretical results on the successive rise of economic and social disparities and the transition of social organisations along with the increase in the degree of the gift (determined by its frequency and the interest rate) by using the SCCS database (Kirby et al., 2016; Murdock and White, 1969). First, we estimate the degree of the gift for each society using

variables related to the frequency of events that accompany the gift-like transaction as follows: *Compensation Demands*, *Taxation Paid to the Community*, *Degree of Marriage Celebration*, *Market Exchange within the Local Community*, *Tribute/Taxation/Expropriation*. As explained in the supplementary information, these variables measure the frequency and the size of gifts or exchanges, which gives a rough measure of r and l . Compensation demands and marriage celebrations are known to be initiators of reciprocal gifts (Leach, 1954; Lévi-Strauss, 1949; Mauss, 1923; Strathern, 1971). Other variables measure the amount of wealth flow within a community. Then, we estimate the economic and social disparities by *Number of Rich People*, *Number of Poor*, *Number of Dispossessed* and *Administrative Hierarchy*, *Social Stratification*, *Removal of Leaders Who Are Incompetent or Disliked*, respectively. We normalise the values of each variable to set the mean 0 and the variance 1. We also change the sign, if necessary, so that the higher values correspond to higher degrees. For some societies, data for some variables are lacking. For the estimation, we average the available values. Then, we normalise each measure so that the minimum is 0 and the maximum is 1. These measures are rather qualitative compared to the measures used for the simulation, such as the Gini coefficients. However, considering the limitations in the available data, these measures are adopted to roughly estimate their relationships and examine the validity of the theoretical results.

By calculating the correlation between the SCCS variables and the estimated gift degree, we investigate cultural and environmental characteristics that can be related to the frequency of gifts and the interest rate. Table 2 shows the variables with high correlations with the gift degree. The gift degree is suggested to be larger in societies with higher population density or richer resources. It is also likely to be larger in herding societies and smaller in hunting societies. Differences depending on subsistence patterns may be due to differences in the type of wealth. As we have mentioned, we use ‘wealth’ in the broadest sense, and the parameter values of the interest rate r and the frequency of gift l can depend on the type of wealth. They are large for societies

Table 2 Correlation between SCCS variables and the estimated gift degree (excerpt).	
Variable	Corr.
Resource base	0.63
Societal complexity	0.62
Adults herd small animals	0.62
Metalworking	0.59
Population density	0.58
Levels of political hierarchy	0.56
Children hunt with adults	−0.54
Political role differentiation	0.53
See Table S1 for further information.	

exchanging livestock, as they are easily transported and grow quickly. Additionally, our analysis suggests that as the gift degree is larger, societies are more hierarchically organised and people are more specialised.

Figure 4 shows the empirical relationships of economic and social disparities with the gift degree. Consistent with the theoretical results in Figs. 1 and 2, both disparities increase with the gift degree. Furthermore, we also confirm that the increase in economic disparity precedes that in social disparity.

Unfortunately, the data on network features themselves are not available for cross-cultural comparison. Still, several ethnographic studies provide such data (Apicella et al., 2012; Ready and Power, 2018; Schnegg, 2006, 2015). The degree distribution of social networks is exponential (or Poissonian) when reciprocal relationships are dominant, whereas it follows a power-law when strong economic disparities are observed, as consistent with our model (Schnegg, 2006, 2015). Furthermore, the above correlation analysis is consistent with the emergence of a hierarchical organisation under larger gift degrees, which is predicted by the model. Research on social organisations suggests that societies shift from band to tribe and then, chiefdom as population density or the frequency of war increases (Service, 1962). Since a denser population and larger necessity of cooperation for war provide more opportunities for people to interact, this is consistent with our theoretical results.

Ethnographic reports suggest that the increase in tradable goods (often due to contact with Westerners) enables a more frequent exchange of gifts with largely amplified reciprocation. At this time, many people cannot maintain high status, while at the same time, great chiefs appear with economic and social dominance (Mauss, 1923; Strathern, 1971). This corresponds to the instability of statuses for a larger interest rate r and a hierarchical organisation for a larger r and frequency of the gift l in our model.

Discussion

By simulating the model of gift transactions, we demonstrated the emergence of disparities and the transition of social organisations. We found that societies shift among the three ‘phases’ as the gift degree, determined by its frequency and the appropriate interest rate for reciprocation, increases. When it is small, the kinship-based connection is dominant. People are equal, and society is composed of many small clusters of kin. As the gift degree is large, that is, gift transactions with amplified reciprocation occur frequently, economic disparity arises as a result of amplified reciprocation for the gift. Furthermore, people become more densely connected, and larger clusters corresponding to tribes appear. Then, as the gift degree is so large that many people fail to reciprocate, social disparity arises due to the asymmetrical relationships caused by debt repayment. Societies are now hierarchically organised so that great chiefs appear with economic and social

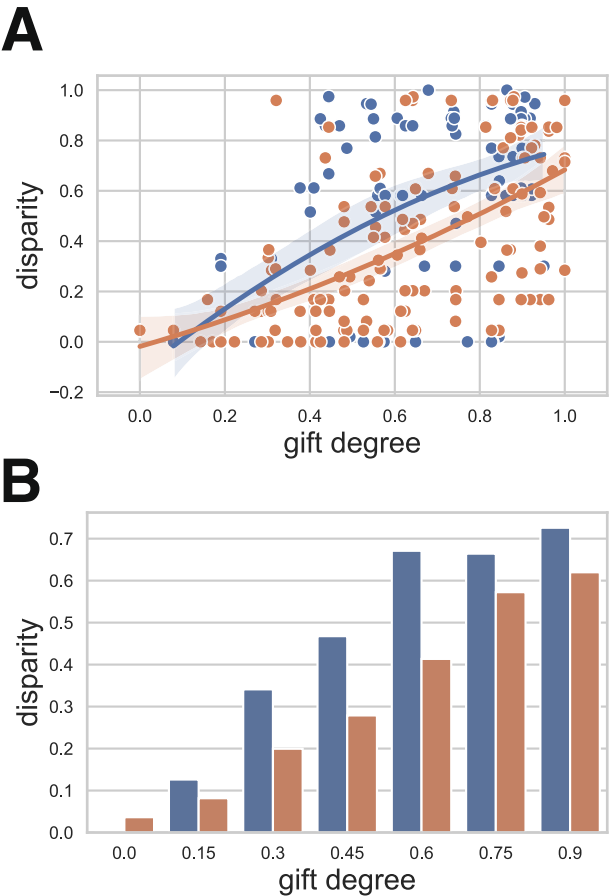


Fig. 4 Empirical relations between the gift degree and economic/social disparities. **A** Scatter plots of the relationships of economic (blue) and social (orange) disparities to the gift degree. The lines show a regression model of order 2 along with 95% confidence intervals. **B** Histogram corresponding to scatter plots.

dominance. These theoretical results are verified empirically through data analysis of the SCCS database. We confirmed that as the gift degree increases, the economic and social disparities successively arise and societies are hierarchically organised.

The gift transactions we have discussed here are a means of managing social relationships through the transference of wealth, not of optimising economic profit (Mauss, 1923). Polanyi proposed reciprocity, centralised redistribution, and market exchange as basic modes of economic activity and stressed that economic activities are inseparable from political and social interactions (Polanyi, 1957). In our model, in the band and tribal phases, most gifts are reciprocated appropriately, suggesting that reciprocity is the main mode. In the chiefdom phase, however, many individuals are in the repayment process for a few rich individuals. A constant flow of tribute from the great majority to the chiefs indicates the emergence of centralised redistribution. Such interrelationships between economic and social acts should be considered to elucidate the social significance of gift-giving.

Cultural anthropologists interpret marriage metaphorically as a ‘gift (or exchange) of mates’ to emphasise that it brings social relationships to the kin groups of both partners, including alliance and dominance, comparable to the gift of goods (Leach, 1982; Lévi-Strauss, 1949). This, along with the genealogical relationship, has been considered the basic principle upon which human beings build kinship relationships (Leach, 1982; Planer, 2021). Theoretical studies on kinship systems have demonstrated that these relationships can organise societies (Itao and Kaneko, 2020, 2022).

Increased population density and surplus production will accelerate the interactions between people, including the gift (Bataille, 1949; Service, 1962). Previous research suggests that the social network shrinks with the loss of surplus food (von Rueden et al., 2019). Our data analysis shows that the population density and richness of resources are positively correlated with the frequency of gifts. Hence, the increase in population and productivity could accelerate gift transactions, leading to the transition of social organisation from kinship systems. Note that our data analysis only shows the correlation. The above causality is suggested by the model but not empirically shown.

Our theoretical results suggest that, as the gift degree increases, economic disparity, followed by social disparity, arises. Economic disparity results from the amplified reciprocation for the gift. When it grows so large that most people cannot reciprocate, unidirectional relationships are established, resulting in the emergence of social disparity and a hierarchical organisation. At this time, the development of social networks follows preferential attachment, and the power-law tail appears in the distribution of connectivity. The empirical results are consistent with this sequential emergence of disparities and hierarchical social organisation as the gift degree increases.

Furthermore, by comparing our results with the work by Service, we note the correspondence between the phases in our model and his stages (Service, 1962). In his discussion, the band is characterised by small kin groups. In our model, the first phase is characterised by strongly clustered kin groups without economic or social disparities. The tribe is characterised by a large union of families with social equality. Our second phase is characterised by moderately clustered large groups with economic but no social disparities. Finally, the chiefdom is characterised by the hierarchical organisation of role-divided groups with both economic and social disparities. Our third phase is also characterised by a hierarchical network and both disparities.

Thus, our model describes the following rough but logically coherent scenario for the development of human history: early in human history, only the above mentioned ‘gift of mates’ existed. Kinship structures were the dominant social organisations. Then, the gift interactions increase due to the generation of surplus through agriculture or pastoralism, the improvement of transportation, and the increase in population density. Consequently, social relationships expand and social organisation shifts to tribes and then to chiefdoms. Additionally, people are specialised and a hierarchical organisation emerges. Here, we do not simply assume that surplus products can feed non-producers and enable a division of labour, but we see surplus as the driving force that promotes gifts, causing specialisation and social stratification. Previous studies have emphasised the increase in the surplus, productivity, population density, and warfare (Bataille, 1949; Marx, 1911; Service, 1962). However, it has been unclear how and why such factors cause social change. To solve such problems, it would be effective to perform simulations using a simple model, as we have presented here, to demonstrate such changes and provide a mechanistic explanation.

Here, it should be examined whether the gift is the main factor influencing people’s social relationships. Anthropologists have repeatedly observed societies in which gifts work as an important factor, especially in pre-industrial societies (Komter, 2007; Malinowski, 1922; Mauss, 1923). It is possible, however, that other factors may be more appropriate as driving factors of social changes, but this can only be evaluated by comparing our model to models built with a focus on other factors to determine which one of them better explains reality.

The present study has some limitations. In the study, we do not explain why people behave as described in the model.

Signalling theory explains that gift-giving is a high-cost display of the donors’ competence and generosity to enhance their reputation (Bliege Bird et al., 2018). Theoretical work needs to be conducted to elucidate the evolutionary origins of gift-giving and the determinants of the parameter values of r and l in each specific region. Additionally, Service has proposed that phases of state with a legitimate monopoly of social power and industrial societies with a complex interdependent network of specialised groups appear after chiefdom (Service, 1962). Although the monopoly of wealth and network connectivity may be demonstrated in our model, we should consider other factors to discuss law enforcement or the balance of power between society and elites to reveal the evolution of states (Acemoglu and Robinson, 2019; Fukuyama, 2011). Sociologists have discussed that changes in attitude towards exchange and wealth precede the emergence of industrial societies (Bataille, 1949; Weber, 1930). Hence, our model should be expanded to include these changes.

Our empirical data analysis also has some limitations. The estimation of the gift degree and the economic and social disparities may seem arbitrary. To measure these variables directly, it will be necessary to collaborate with field research. Currently, we could only analyse the correlations between ethnographic variables and the gift degree. Phylogenetic comparative analysis is also necessary to control statistical non-independence due to shared ancestry (Minocher et al., 2019). Additionally, because of the lack of chronological data, we could not analyse causal relationships between the gift degree and disparities or social organisations.

Social structures are shaped through interactions among people over many generations. In this paper, we have theoretically demonstrated the formation of macroscopic social structures through microscopic interpersonal relations. We have built the model by idealising the behaviour of people reported by anthropologists. Then, we examined the logical coherence of macroscopic phenomena if one assumes that many people behave in that way. We found the emergence of social organisations consistent with empirical observation and revealed their micro-foundations. By combining theoretical simulations of a simple constructive model and empirical data analysis, we have integrated the theory of interpersonal gift relationships and that of social organisations. Theoretical studies, as shown here, produce explanatory scenarios by referring to empirical studies and propose relevant variables to be measured in the field. Empirical studies in the field describe notable phenomena and enable the measurement of variables to test theories. This collaboration of theoretical and empirical studies will contribute to the discussion on the emergence of complex social structures and the unveiling of universal features in the social sciences.

Data availability

Source codes for the model can be found here: <https://github.com/Kenjiliao/gift.git>.

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Notes

- 1 In the Moka exchange, those who are unable to reciprocate are called rubbish men (Strathern, 1971). They lose their reputation and cannot make a fair deal by the time the reciprocation is completed. There, recipients do not reciprocate sequentially. However, we have modelled as above to express the relationship between late reciprocation and a poor reputation.

- 2 This successive emergence of the power-law tail in the wealth and connectivity distribution recalls the embedding of power-law in the abundance of chemicals to that in reaction network connectivity (Furusawa and Kaneko, 2006).

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Author contributions

KI and KK designed the model; KI conducted the simulations; KI and KK analysed the data; and KI and KK wrote the paper.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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