

The Emergence of Inequality and Hierarchy: A Network Explanation

Samuel Bowles
Santa Fe Institute and University of Siena
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Abstract. The emergence of persistent political hierarchy and economic inequality beginning about eleven thousand years ago may be explained in part by the novel equilibrium network structures that post-Pleistocene ecological and economic conditions supported. I explore how changes in the nature of wealth and the division of labor could have induced transitions among three stable network structures: symmetric networks with little political hierarchy or economic inequality, asymmetrical networks with political hierarchy but little economic inequality and asymmetrical networks with both hierarchy and inequality. As in Kets, Iyengar, Sethi and Bowles (2009), the distribution of benefits on these networks is limited by the feasible coalitions that may withdraw from the existing network, where membership in a coalition is restricted to those who are within distance k in the network. A distribution of benefits on a network is stable if no feasible coalition can benefit by deviating from the network. In addition to k , the key determinant in the mapping from economic conditions to the above three equilibrium networks is the extent of intermediation decay in network benefits. Ethnographic and archaeological data from forager, horticultural and herding populations illustrate the model.

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Introduction

The emergence of persistent political hierarchy and economic inequality associated with the domestication of plants and animals beginning about eleven thousand years ago is one of the most important innovations in economic and social structure on record; but it remains a puzzle. A prominent explanation (1) proposed that domestication raised the value of prime land and hence increased the resource circumscription of communities, thereby increasing the cost of exclusion and enhancing the power of those capable of excluding others. I propose a social variant of the circumscription hypothesis: independently of any changes in the resource gradient, changes in the efficient structure of social and economic networks associated with domestication reduced the options of those who would opt out of an unequal distribution of benefits in the network. As a result their bargaining power in the network was reduced. According to this hypothesis changes in the nature of wealth and the division of labor induced transitions among three stable network structures: symmetric networks with little political hierarchy or economic inequality, asymmetrical networks with political hierarchy but little economic inequality and asymmetrical networks with both hierarchy and inequality. The transition is accounted for by the fact that face-to-face exchanges typical of forager populations facilitate coalition formation while the more arms length exchanges of Holocene networks do not.

I distinguish between economic and political inequality in the following way. Political inequality (or hierarchy) is the differential ability of individuals to command others associated with asymmetric network structures. Economic inequality is persistent and heritable or otherwise ascribed differences in the distribution of the joint surplus of a network among its members. Because the ethnographic and archaeological record indicates that political hierarchy may occur in the absence of the economic inequality, explanations that collapse the political and economic dimension of inequality are not sufficient. Examples are models that determine a node's share of the surplus by the node's status as an essential intermediary or how central the node is (2-4).

The need to model both political and economic inequality motivates the use of a new concept of network stability proposed by Kets, Iyengar, Sethi and Bowles (5). A network is stable if there does not exist a coalition of its members who could benefit by forming a new

stable network where a coalition may form only among members not greater than distance k in the network where $k = 1$ indicates immediate neighbors, $k=2$ is neighbors of those neighbors, and so on. In contrast to measures based on centrality, which determine the income of the rich by how well connected they are, in this approach what matters is how well connected the would-be less well off are. Political inequality will matter for economic inequality because essential intermediaries among nodes have bargaining power in the sense that they may commit to a binding take it or leave it offer. The approach thus borrows both from the cooperative game theory approach based on coalitional deviations and the sociological approach that stresses network centrality. Kets et al suggest that this approach may explain the economic sociology of protest associated with factory production in the 19th century by contrast to sharecropping and more dispersed production systems. Here I apply the same model to the Holocene economic and institutional transition.

The next section surveys what is known about the Holocene transition and discusses contemporary empirical examples of the three ideal type networks drawn from ethnographic and archaeological evidence. Section 3 presents a model of Pleistocene and Holocene networks that allow a mapping from economic and environmental conditions to the existence of the above three equilibrium networks and the distribution of payoffs on them. These are a) the membership of permitted deviations from an existing network that may feasibly be coordinated, resulting from the spread of the network in geographical and social space, and b) the presence or absence of intermediation decay in network benefits resulting from the nature of the goods or services flowing through the network. The final section discusses extensions.

The “First Economic Revolution”

Prior to thirty thousand years ago we find little archeological evidence of inequality among the families making up bands of human ancestors. But beginning around 15 thousand years ago, evidence from burials, prestige goods, storage facilities, and residences indicates that in some (but almost certainly not most) human communities durable political hierarchy and economic inequality existed (6). The emergence of social stratification thus long predates the first appearance of states and the effective monopolization of coercion by specialized governmental actors (7, 8). The fact that inequality emerged in an effectively decentralized

environment motivates our turning to non-cooperative network formation models for illumination. Our hypothesis is that the changing structure of equilibrium social networks (and bargaining rules for the distribution of the net benefits of the network) is part of the explanation of this process.

Ethnographic studies have identified three common network structures differentiated by the extent of political and economic inequality. The first and probably originally by far the most common network structure is egalitarian in both the political and economic sense. Networks are dense (with many redundant links) with little inequality in either degree distribution or betweenness. Well-studied examples are the consumption smoothing processes implemented by food-sharing networks among the Ache in Paraguay, the Hiwi in Venezuela and other foragers (9-11). The second network structure is characterized by substantial asymmetry of position and consequent political inequality with very little economic inequality. Examples of this kind of network are the chiefdoms of the North American Iroquois, many Melanesian 'big man' systems, consumption smoothing systems among the nomadic Pokot in Kenya, and pre-European contact distribution systems in highland New Guinea (12-14). These are less dense networks with greater inequality in degree distribution, betweenness, and other measures of structural asymmetry. The final network structure is unequal in both its political and economic dimension as exemplified by the Himba herders in Namibia and many patron client networks in which pronounced star-like network structures coincide with substantial differences in wealth (13).

Studies of these network structures have identified three dimensions of the relevant social interactions. The first is the nature of the goods or services transacted. In the egalitarian networks of the Ache the goods and services that the network transmits are either perishable or require face to face contact. As a result, intermediation decay is substantial: direct links are much more valuable than indirect ones. By contrast, networks that processed goods such as livestock, grain or other well defined non-perishables are characterized by limited intermediation decay. A second difference is the extent to which network members not connected by a direct link in, say, a consumption smoothing network, were nonetheless known to each other and able to communicate and hence to coordinate their actions in shaping a network's evolution. The final difference is the extent and degree of inter-generational heritability of the individual

differences that influence one's network position. A central position in network sharing perishable foods might be the result of an individual's persuasive powers or luck and hence unlikely to be inherited. By contrast when consumption smoothing is managed through the storage of grain or the movement of cattle, substantial levels of accumulation are possible and may persist over generations

Political and Economic Inequality in Pleistocene and Holocene networks.

Setup. Players are located on a network. A network is a pair (N, g) where N is a set of vertices $\{1, \dots, n\}$ and g is an $n \times n$ matrix with $g_{ij} = 1$ indicating that there is a link (edge) between vertices i and j so that i and j are *neighbors*. The number of neighbors of a vertex is its *degree*. The *distance* between two vertices is the length of the shortest path between i and j in g if such a path exists.

We term the *substance* of the network the goods or services that move from node to node including transfers of food or livestock, visitation rights, support in disputes, acquiring information, arranging marriages, and the like. A network may be formed for the purpose of mutual assistance. In any period each household (node) may with some probability be in need, and may receive help from those to which it is connected. The form of the help (the substance of the network) varies across production systems. Household well-being (utility) is increasing and concave in disposable resources, which consist of own resources and help received minus help given. As a result, for a given level of own resources, the marginal utility of resources for households in need exceeds that of households not in need and as a result groups that sustained effective mutual assistance networks enjoyed higher average payoffs.

Without explicitly modeling the mutual assistance process, we simply assume that a household's benefits from participation in a network net of the costs of establishing links, $f(q)$, is increasing and concave in q , the number of nodes to which it is connected directly (in the case that indirect ties do not give assistance) or directly and indirectly (in the case that indirect ties may also assist). Links may be established by mutual consent costing c to each node, and severed unilaterally. A network g^i is said to be accessible from g^j if the members of the deviating coalition required to create g^j are within k distance of one another and at least one member of the deviating coalition gains higher payoffs in g^j while none gain lower. A network is k -stable if no

other network is accessible from it.

Distribution on the network is determined as follows. Essential intermediaries between nodes may commit to a take it or leave it demand for a transfer from the nodes among which the intermediary is essential. This individual is said to have bargaining power. In response, an individual may either accept the demand or sever the link and form an accessible new k -stable network with other members of a feasible coalition.

We thus distinguish between the economic network through which flow goods, mutual aid and the like and the collective action network (with links between those at most k distant in the economic network) that determines the set of possible members that may form a deviating coalition in response to demands by an individual with bargaining power. These distinctions, and some examples are given in Table 1.

	Economic equality	Economic inequality	Economic network
Political equality	Foragers		Complete
Political hierarchy	Enga, Pokot	Himba	Star
Collective action network	Complete	Star	

Table 1. **Economic and Collective Action Networks.** The collective action network is a super network of the economic network so if the latter is complete, the former must also be complete.

Pleistocene forager networks. The substance of Pleistocene networks – perishable goods or promises of welcome in times of need – were such that indirect links were worth less than direct links. The combination of substantial risk exposure due to climatic variation and small group size made it beneficial for each individual to form direct links with most other households. Simplifying, let indirect links be worthless (complete decay) and the Pleistocene forager network g^f be complete, thereby making k irrelevant.

For the case of $n = 4$ in the absence of transfers, each member receives benefits of $f(3) - 3c$. As there are no essential intermediaries in the network, no individual has bargaining power so the egalitarian distribution is an equilibrium. Were (for exogenous reasons) an individual to

have bargaining power, the associated gains would be limited by the deviation opportunities offered by the complete network. Severing one link in response to a demand for a transfer would result in payoffs for the members of the deviating coalition of $f(2) - 2c$, so the maximum transfer any node could demand from another without inducing a deviation is $f(3) - f(2) - c$, which is positive (because it is optimal to form the complete network) and decreasing in the extent of concavity of the benefit function. Assuming that the node with exogenously given bargaining power maximizes its utility subject to the constraint that the other members not deviate, the difference in utility between the node with bargaining power and the rest is thus $4\{f(3) - f(2) - c\}$. Table 2 summarizes these results for Pleistocene networks, and the subsequent analysis of Holocene networks.

[Table 2 here]

Holocene networks. The substance of Holocene networks were storable goods such as grain and livestock that were subject to limited decay so that indirect links had value. This fact, plus the larger number of interacting nodes (due to larger settlement size and more extended exchange) and greater cost of links led made sparse networks socially optimal (joint surplus maximizing), and also stable, conditional on some (possibly non-unique) distribution of value on the network. Simplifying I assume that there is no decay for along paths of length 1 or 2, and complete decay for longer paths. Then for $n > 3$ the joint surplus maximizing Holocene network is a star. Consider two ideal type Holocene networks. Network g^1 is one for which $k=1$ because nodes not directly connected by mutual assistance are not in communication with one another, while g^2 is one for which $k=2$ because conditions of residence or cultural practices allow coordination among nodes at distances greater than 1. To allow comparison with Pleistocene networks we assume that $n = 4$, and that c is not altered by Holocene conditions.

On g^2 the central member of the star has bargaining power. In the absence of transfers the central member receives $f(3) - 3c$, and each peripheral member receives $f(3) - c$ resulting in a center-sponsored star (peripheral nodes gain a larger share of the surplus). Because $k=2$ peripheral nodes may collectively deviate to a 3-line or a 3-clique in response to a transfer demand. In the latter case they receive $f(2) - 2c$ so the maximum the center could demand of each is $f(3) - f(2) + c$ receiving a total payoff of $4f(3) - 3f(2)$ while peripheral members receive $f(2) - 2c$.

But in the absence of transfers among the deviating coalition and assuming that link costs are shared equally, individual payoffs to the deviating coalition would be greater if they formed a line, namely $f(2) - 4c/3$. This option limits feasible transfer demands by the central node to $f(3) - f(2) + c/3$. As a result the central node receives $4f(3) - 3f(2) - 2c$. However in the absence of a pre-commitment to this egalitarian value distribution among the deviators, the central member of the deviators line network could now demand of the others a transfer of $f(2) - f(1) - c/3$. In the absence of differences among the nodes, suppose that each deviating member has equal probability of occupying the center of the line. In this case, the expected payoffs to the deviators from g^2 are the central nodes payoff, namely $3f(2) - 2f(1) - 2c$ times one third, plus two thirds times $(f(1) - c)$, or $f(2) - 4c/3$. This is exactly the payoff to all members of the egalitarian line with so whether the deviating coalition is able to make commitments assuring this result is unimportant. Thus the maximal transfer in this case is $f(3) - f(2) + c/3$, resulting in the central node's payoff of $4f(3) - 3f(2) - 2c$.

Peripheral members of network g^1 have payoffs of $f(3) - c$ in the absence of transfers and autarchy payoffs of $f(0) = 0$ should they deviate. As a result the center will receive $f(3) - 3c + 3\{f(3) - c\} = 4f(3) - 6c$, which is the entire value of the network, and the peripheral nodes zero.

Results. The networks in Table 2 are ordered by the magnitude of the difference between the richest and the others, ranging from zero for the Pleistocene network (without asymmetry) to the entire value of the network for the Holocene network with $k=1$. The final column gives the gini coefficient for the distribution of network benefits associated with the 5 networks (for a logarithmic utility function and $c = 0.2$).

For networks intermediate between the two extremes in Table 1 the payoffs to the central node depend on the size of the network (4 in this case) and the slope of the benefit function because that determines the value of possessing bargaining power, while the payoffs to the peripheral nodes depend on the level of benefits afforded by the deviation network of reduced size. Thus in a larger network the node with bargaining power may demand transfers of a larger number of peripheral members, but the transfer from each is less as a result of the concavity of the benefit function. For a network of sufficient size (assuming it remains a star) if the concavity of the benefit function (the negative of ratio of its second to first derivative) is constant, the second effect (stemming from the decreased slope of the benefit function) must dominate the

first. Thus while inequality in measures of centrality must increase with the size of the network as long as it remains a star, the degree inequality in the distribution of benefits on the network is non-monotonic in network size. As a result centrality and inequality in the network need not be positively correlated, a result similar to that found in (5)

A more complete treatment would consider the formation of the economic networks that are here taken as given (15) as well as the process of intergroup competition for resources and how this may have been affected by the aggregate efficiency of the surviving networks, thus providing an equilibrium selection mechanism when different forms of network with differing distributions of value co-existed (as they surely did during the Holocene).

Discussion

The emergence of political and economic inequality during the Holocene may be explained at least in part by a progression downwards through the rows of Table 2. The domestication of plants and animals induced changes in the benefits and costs of link formation, leading to the emergence of more sparse and asymmetrical networks. In some cases (but not all) the bargaining power thus afforded to more central elements allowed some network members to capture substantial fractions of the surplus. Additional influences not modeled here include a probable reduction in risk exposure associated with the dramatic decline in climatic variance during the Holocene (16) which would have reduced the optimal number of links to maintain for the purpose of risk pooling. Increases in the size of interacting groups (both settlement size and the geographical spread of exchange and other interactions) probably also led to less dense networks thus inhibiting coalition formation and enhancing the shares of central individuals.

Finally, the equilibrium distributions in table 2 assume the absence of relevant differences in the individuals making up the population, so the attainment of an advantageous central position is by chance. But in contrast to the Pleistocene, under Holocene conditions one would expect initial accidentally gained advantage in network location would persist and as a result the long run stationary distribution of wealth on the network would be increased. This is because the value of a link to a particular node varies with the node's wealth, and the forms of wealth introduced by domestication (land, livestock, stored grain) were more readily transmitted across generations than the wealth of the forager economy (17). As a result, the advantage of the

central individual in one generation would be reproduced in the next, making inequality heritable.

Other explanations, for the most part complementary to the one offered here, have stressed the value of domesticates for luxury consumption and ceremonial display (6), the contribution of agriculture to the intensity of intergroup conflict (18-20), population pressure (21), the role of domestication in allowing for unambiguous definition of possession based property(22) facilitating storage(23, 24) and increasing the intergenerational transmission of wealth with a concomitant increase inequality in the stationary distribution of wealth(17), and the increased value of specialists (including those in coordination) associated with larger settlements and a more complex division of labor(25, 26).

<i>Network</i>	<i>Deviation u</i>	<i>Max transfer</i>	<i>Max payoff</i>	<i>Difference</i>	<i>Gini</i>
Pleistocene (symmetric) g^P	na	0	$f(3) - 3c$	0	0.0
Pleistocene (bargaining) g^{PB}	$f(2) - 2c$	$f(3) - f(2) - c$	$4f(3) - 3f(2) - 6c$	$4\{f(3) - f(2) - c\}$	0.08
Holocene (star \rightarrow line) g^{2L}	$f(2) - 4/3 c$	$f(3) - f(2) + c/3$	$4f(3) - 3f(2) - 2c$	$4(f(3) - f(2) - c/6)$	0.18
Holocene(star \rightarrow clique) g^{2C}	$f(2) - 2c$	$f(3) - f(2) + c$	$4f(3) - 3f(2)$	$4\{f(3) - f(2) + c/2\}$	0.27
Holocene (star \rightarrow autarchy) g^1	0	$f(3) - c$	$4f(3) - 6c$	$4f(3) - 6c$	0.75

Table 2. Political and economic inequality on Pleistocene and Holocene networks. Source: text. Where a node has bargaining power (all except the first row) the others receive the amount in the second column, which is the most they could make in a feasible deviating coalition.. In the H network, the payoffs prior to transfers are $f(3) - c$ for the peripheral nodes and $f(3) - 3c$ for the hub. The final column is the Lorenz based Gini coefficient ranging from complete equality (0) to complete inequality (0.75 for $n=4$) based on $f(q) = \ln(q+1)$ and $c= 0.2$. The total value(joint surplus) of the P networks is $4(f(3) - 3c)$ and of the H networks $4(f(3) - 3c/2)$ or 3.145 and 4.345 respectively in the numerical example.

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