Equality’s fate: a natural history

Samuel Bowles
Santa Fe Institute, University of Siena, and University of Massachusetts (Emeritus)
17 November, 2004

I would like to thank the MacArthur Foundation, the Russell Sage Foundation and the Santa Fe Institute for support of this project. I draw upon joint work with Jung-Kyoo Choi and Astrid Hopfensitz (Bowles, Choi, and Hopfensitz (2003) and Bowles and Choi (2002)) and Suresh Naidu (Naidu and Bowles (2004)) as well as material presented in chapters 12 and 13 of Bowles (2004). I have also benefitted from contributions by Chris Boehm, Hillard Kaplan, Suresh Naidu, Ugo Pagano, Rajiv Sethi, Polly Wiessner, Elisabeth Wood, Peyton Young and participants in the Santa Fe Institute working group on inequality as an emergent property of social interactions, the September Seminar, and the working group on biology and the human behavioral sciences at the Central European University.

1. Introduction

Differences among people (and among peoples) in talents, strength, and other capacities are seemingly minor by comparison with the often-observed vast and historically persistent between-group and individual differences in economic fortunes, reproductive success, status, rights, and power. The same may be said of many non-human primates and other animals. *What processes translate seemingly small differences in individual capacities into social hierarchies characterized by large and persistent differences in access to valued resources and power over others*?

The structures of social interactions associated with these inequalities exhibit substantial differences across societies and through time. Included are unequal bargaining power in competitive markets, the use of state power to advance group interests, bonded labor and other forms of coercive resource transfers, racial and ethnic exclusion, hierarchically ordered or assortative mating systems and other forms of positive assortation, and many others. Do these processes share a common causal structure? Can the evolutionary success of hierarchically ordered societies in the past 10 millennia be traced to a common underlying dynamic?

Analogously, what accounts for the limited inequality and muted hierarchy observed in many societies? The proximate causal processes that reduce inequality in these societies are seemingly unrelated across time and among different societies. For example reproductive leveling, the formation of coalitions of subordinates to limit the power of dominants, the sharing of some foods and information and other forms of within-group variance reduction were probably common among our forager-ancestors as they are among foragers today. But these processes appear to have little in common with the extension of formal political rights to all citizens and the enlargement of these rights to claim resources, as in modern-day social democracies. Do these processes have common elements? Why have such egalitarian societies emerged and persisted over long periods?

Answering these questions requires an account of the dynamics of hierarchical structures. What accounts for major transitions between economically egalitarian and more unequal social orders such as occurred with the emergence of possession-based property rights and private storage of wealth associated with the domestication of plants and animals, or with the demise of Communist-ruled societies in the former Soviet Union and Eastern Europe, or the market reform of the Chinese economy?

Correspondingly, are there common processes underlying movement toward more equal outcomes such as the dramatic reduction in the income shares of the very rich over most of the 20th century in countries as diverse as the U.S., India, France, and the UK (Piketty and Saez (2003)). Are the causes underlying these trends also at work in the mid- to late-20th century land reforms in Taiwan, Korea, and West Bengal (Fei, Ranis, and Kuo (1979), Banerjee, Gertler, and Ghatak (2002)). Do these episodes have anything in common with the processes that have on occasion reigned in the political, juridical, social, and sexual privileges associated with wealth? Examples include the emergence of jury trial in some European judicial systems, rights to privacy and civil liberties, the accountability of political leaders to inclusive electorates, and what has been called by Herlihy and Klapische-Zuber (1985) "the great social achievement of the early Middle Ages" in Europe, namely "the imposition of the same rules of sexual and domestic conduct on both rich and poor."

I assume that the types of social relationships referred to generically as unequal and hierarchical have enough in common that it makes sense to attempt a common explanation of the entire suite of vertically ordered relationships. The most plausible justification of this assumption is that many of the distinct dimensions along which inequality is measured are causally related in ways that insure that wealth, reproductive success, political influence and so on are highly correlated. We know this to be untrue in numerous settings, from the substantial political authority exercised by Mae Enga big men who do not enjoy correspondingly disproportional material resources (Wiessner and Tumu (1998), see also Kelly (1993)) to the reverse situation characterizing the extraordinarily rich Swedish economic elite, to the many modern populations in which wealth and reproductive success are uncorrelated (Kaplan, Lancaster, Block, and Johnson (1995)). But even where the dimensions are not highly correlated, the causes contributing to dispersion along one dimension may be similar to the causes generating differences along another. Accounting for reproductive skew in an agrarian kingdom, for example, may draw upon the some of the same causal mechanisms that account for the concentration of political power in a big man social system, or wealth inequality in a capitalist economy.

I also assume that neither genetically transmitted individual differences in capacities nor genetically transmitted predispositions toward social dominance or hierarchical living provide an adequate explanation of the inequalities under study. That genetic differences among people cannot explain observed differences in command over material resources and other valued goods is suggested by three sets of facts.

.

First, substantial alterations of hierarchical and economically unequal structures often take place at a pace fare exceeding that of genetic evolution. The most dramatic of these changes is the emergence of hierarchically ordered states and the displacement of egalitarian foraging bands following the domestication of plants and animals about ten millennia ago (e.g. Allen (1997).) There are plentiful modern examples as well (some of them mentioned above) including the dramatic increase in income inequality following the liberal reforms of the Chinese economy (Ravallion and Chen (2004).)

Second, the genetic variance between the ancestral sub-populations of the people of the world is *an order of magnitude* less than the genetic variance among individuals within groups; but something like three quarters or more of global income inequality is between rather than within these groups.[1]

Third, while there may be a non-trivial role for genetically transmitted traits in explaining income differences within national economies, the evidence is not very robust (Bowles and Gintis (2002)), and the effects are not large. For example, the correlation among the logarithm of the wages of brothers in the U.S. exceeds one half, indicating that more than half of the variance in this measure of economic success is associated with influences that brothers have in common, such as family educational and economic status, and community of upbringing. Virtually none of this correlation is explained by one of the best measured and (genetically) heritable determinants of wages: height (Mazumder (2004).)

An important role of genetically transmitted predispositions towards dominance and subordination cannot be excluded, but the counter evidence is substantial. Humans share with our closest genetic relatives (chimpanzees and bonobos) a suite of counter-dominance behaviors suggesting a strong aversion to being bossed (Boehm (2004)); and some non-human primates appear to exhibit forms of inequality aversion in laboratory experiments (BBrosnan and De Waal (2003)). Moreover, among humans (including those in foraging groups and other small scale societies), experimental and other evidence suggests that many (perhaps most) humans are motivated by some form of inequality aversion and strong reciprocity (Falk, Fehr, and Fischbacher (2003), Henrich, Boyd, Bowles, Fehr, and Gintis (2004)).

The pages that follow identify a series of causal mechanisms consistent with the familiar idea that the degree of hierarchy and inequality in a population is an outcome of the technologies available for producing the livelihoods of its members and reproducing life and the social institutions governing these processes of production and reproduction. The approach is evolutionary in that it studies inequality and hierarchy in an explicitly dynamic framework, asking why plausible evolutionary processes might favor the long term persistence of more or less unequal outcomes.

In the next section I survey the formidable processes tending to generate persistent income polarization (or even runaway inequality), raising the question: why do we nonetheless observe substantially egalitarian and non hierarchical systems as common human forms of

---

[1] Rosenberg, Pritchard, Weber, Cann, Kidd, Zhivotovsky, and Feldman (2002). About three quarters of the global inequality in income is between countries (depending on which inequality measure one uses (Milanovic (2005)), from which it may safely be inferred that not less than this amount is between the (for the most part smaller) groups used in the Rosenberg et al study.

social organization?. Section 3 develops the idea that within-group leveling may contribute to a group's ability to survive environmental challenges and intergroup competition. Section 4 explains why highly unequal conventions may not be evolutionarily robust by comparison to less unequal conventions. The final section is a speculation about inequality in the very long run and how the evolutionary processes accounting for it might be modeled.

2. Cumulative Advantage: *technology, social interactions and runaway inequality*

The persistence of a particular configuration of inequality is commonly explained by its status as an asymptotically stable equilibrium in some plausible dynamical system. Dynamical systems typically support high and or increasing levels of inequality when they are characterized by cumulative advantage, that is, when small advantages at one time contribute to greater advantages at later periods. The positive feedbacks that contribute to cumulative advantage may result from winner- take-all reward systems (like tournament based pay, or mating systems with high male reproductive skew, as with gorillas), positive assortation and other advantageous sorting opportunities in marriage, coalition formation, residence, and co-production, and increasing returns to scale in production, coercion, and other processes. When these and other aspects of cumulative advantage are operative, small individual differences occurring by chance are magnified and may become persistent over long periods.

To explore this idea, suppose that an individual's income-generating assets (wealth, skills, and so on) are acquired directly from parents (considered as a single individual) and from randomly selected others in the population (in the form, say, of equal access to common resources, knowledge, public education and such). We summarize these two influences on one's income by expressing the expected income of individual i as $cy_{ip} + (1-\beta)\underline{y}$, where income is measured in natural logarithms, $\beta \in (0,1)$, and y_{ip} is the income level of individual i's parent and $\underline{y}$ is the average income level (assumed to be the same across generations). The value $(1-\beta)$ represents regression to the mean as introduced by Francis Galton (1889).

In each generation, the realized income of an individual, y_i, is his expected income plus a disturbance term, λ, that over time is independent of past values of income and independent and identically distributed with mean zero and variance σ_λ^2:

(1) $$y_i = \beta y_{ip} + (1-\beta)\underline{y} + \lambda_i$$

This stochastic process is a first-order auto regression with a steady state expected (logarithm of) income of $\underline{y}$. For values of β less than one the steady state variance of the logarithm of income (a standard unit-free measure of inequality) is:[2]

[2] To see this write μ_t, the variance in period t, as

(2) $\mu = \sigma_{\lambda}^{2}/(1-\beta^{2})$.

The steady state level of income inequality may be interpreted as the effect of stochastic shocks, blown up by the inter-generational transmission multiplier $(1-\beta^{2})^{-1}$ which is increasing in the extent of intergenerational transmission of income. The stationary distribution is thus the result of both chance (the numerator) and social structure (the denominator). For β exceeding one there is no steady state and the inequality will increase from year to year.

Why is it plausible to restrict the value of β to be less than one? Because it is the elasticity of one generation's income with respect to parental income, β measures the cumulative advantage of having a higher-income parent.[3] There is no reason why this derivative cannot exceed unity, and as we will see presently, some reason to think that it might.

To see this, we need to make the income-generating process explicit, and allow individuals to accumulate or consume income earning assets. Suppose that income is generated by combining human and physical capital (h and k respectively) according to the following income-generating function

(3) $y = f(k,h)$

Human capital is all culturally and genetically transmitted influences on one's capacity to earn income. Equation (3) need not be interpreted as a production function; it merely describes the ways that individuals may combine assets to generate income. What do we know about the shape of such income generating functions?

Studies of the U.S. and South African labor markets, suggest that the rate of return to schooling (the derivative of the logarithm of earnings with respect to years of schooling) is rising in years of schooling (Ashenfelter and Rouse (2000),Keswell (2004),Hertz (2003), see also Hauser, Warren, Huang, and Carter (2000).) A similar pattern appears to be at work concerning the returns to capital: Yitzhaki (1987) found that the appreciation of the value portfolios of corporate stocks (on the New York Stock Exchange) held by high-income

---

$$\mu_t = \beta^2\mu_{t-1} + \sigma_{\lambda}^2$$

Setting $\mu_t = \mu_{t-1}$ to get the steady state variance μ we get (2).

[3] The correlation between parental and offspring income, ρ is of course restricted to the unit interval, but $\beta = \rho\sigma/\sigma_p$ where σ and σ_p are the standard deviation of the logarithm of income in the current and parental generation, respectively. Thus if β exceeds 1, inequality must be rising.

individuals exceeded by a considerable margin the appreciation of portfolios held by less wealthy individuals.[4] Studies in low-income countries show that net worth strongly affects farm investment, and low wealth entails lower returns to independent agricultural production (Rosenzweig and Binswanger (1993).)[5] This evidence suggests that the wealthier farmers pursue riskier strategies with higher expected returns. The lack of insurance and restricted access of the poor to credit not only reduces incomes, it also increases the level of income inequality associated with a given level of wealth inequality.

These data do not establish any general properties of income generating functions, of course, but they do suggest the importance in some settings of both increasing marginal returns and complementarities among assets. Let us then consider a case in which the income generating function exhibits (over some relevant range) the following characteristics: the return to both human and material capital is rising in the amount of capital acquired ($f_{hh} > 0$, $f_{kk} > 0$), and the return to each form of capital is increasing in the amount of the other ($f_{hk} > 0$).

The last assumption expressing asset complementarity is consistent with the data just mentioned: the higher-income stock owners in Yitzhaki's study are surely also better educated, and those with more schooling in the U.S. labor market are also wealthier. The rate of return to schooling may increase in the wealth of the individual because wealth reduces the costs of job search and supports more nearly risk neutral occupational and geographical choices. Schooling may raise the rate of return to wealth for analogous reasons.

We return to the inheritance process, but instead of the intergenerational transmission described in equation (2), suppose that upon coming of age each individual inherits a level of both h and k, and then either accumulates or uses up both forms of capital (wealth can be consumed, and we assume that the knowledge, skills, physical capacities, health status and the

---

[4] Bardhan, Bowles, and Gintis (2000) and Bowles (2004) present models in which this result obtains for risk-neutral individuals due to the credit market disabilities faced by the less wealthy. It could occur for many other reasons, including decreasing absolute risk aversion.

[5] Rosenzweig and Wolpin (1993) showed that poor and middle-income Indian farmers could substantially raise their incomes if they did not confront credit constraints: not only did they under invest in productive assets generally, but the assets they did hold were biased towards those they could sell in times of need (bullocks) and against highly profitable equipment (irrigation pumps) which had little resale value. Similarly, Rosenzweig and Binswanger (1993) found that a standard deviation reduction in weather risk (the timing of the arrival of rains) would raise average profits by about a third among Indian farmers in the lowest wealth quartile, and virtually not at all for the top wealth holders, suggesting that risk reduction strategies adopted by the poor reduced their expected incomes.

like captured in h also depreciate unless renewed). Individuals will accumulate capital if the marginal return on the investment (the derivative of the income generating function, given the individual's current holdings) exceeds the individual's rate of time preference. To simplify matters we normalize the amount of both types of capital that an individual may have so that $\forall i$, $h_i \in [0,1]$ and $k_i \in [0,1]$.[6] For simplicity, assume that individuals differ only in their inheritance, and that those owning no assets have no incentive to accumulate, while those endowed with the maximal amounts of both have an incentive to dis-accumulate (or $f_{kk}(0,0)$, $f_{hh}(0,0)$, $f_{kk}(1,1)$ and $f_{hh}(1,1)$ are all less than the (common) individual rate of time preference.)

Consider the investment (or disinvestment) strategy of an individual with a small amount of human capital h^-, facing the rate of return to material capital schedule $f_k(k,h^-)$ and a rate of time preference δ as depicted in figure 1. If the individual's assets are less than k^- the individual will consume her wealth, while for values of between k^- and k^+ the individual will accumulate material wealth. Consider a second individual with more human capital, h^+, and, recalling that increased human capital raises the marginal effect of material capital ($f_{hk} > 0$), notice that the lower critical value (below which the individual will not accumulate) is reduced, while the upper critical value is increased as a result of the higher human capital endowment.

Figure 1 illustrates the capital accumulation dynamics of this population, the arrows on the horizontal axis indicating the movement of k in response to the accumulation or dis-accumulation incentives. The accumulation dynamics for human capital are similar. We model the joint dynamics of the two accumulation processes by

(4) $dh/dt \equiv \dot{h} = H\{f_h(k, h) - \delta\}$

(5) $dk/dt \equiv \dot{k} = K\{f_k(k, h) - \delta\}$

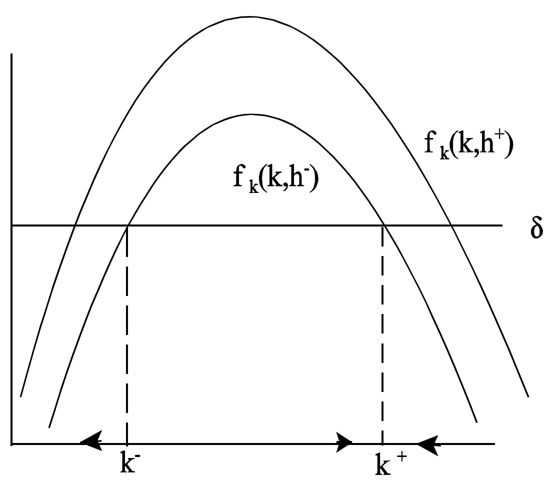

Figure 1. Optimal accumulation of wealth with differing levels of human wealth.

[6] Limiting the amount of material wealth an individual can have is arbitrary, but it does not affect the results, given the assumptions that immediately follow.

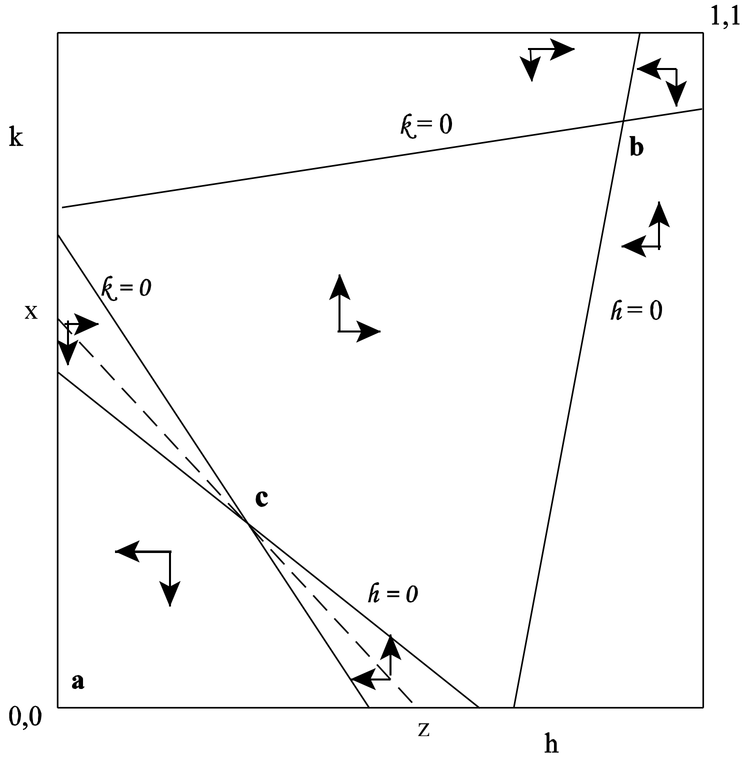

Figure 2. Joint accumulation of material and human capital. Points **a** and **b** are asymptotically stable equilibria, **c** is a saddle.

where H and K are positive constants indicating the speed of adjustment of the two accumulation processes.

These equations give the stationarity conditions $\dot{h} = 0$ and $\dot{k} = 0$, when respectively $\{f_h(k, h) - \delta\}$ and $\{f_k(k, h) - \delta\}$ equal zero. For other states, the direction of change implied by equations (4) and (5) is given in the vector field shown in figure 2. The functions $\dot{h} = 0$ and $\dot{k} = 0$ in the lower left portion of figure 2 are downward sloping due to the complementarity of the two determinants of income illustrated in figure 1: the critical value below which accumulation of one type of capital will not take place is lower, the better endowed is the individual with the other type of capital.

There are three equilibria in this system, **a**, **b** and **c** in the figure: individuals inheriting any combination of h and k will over time approach one of these states.. The point **c** is a saddle and will be reached (with vanishingly small probability) only by individuals inheriting assets along the dashed line xz. Those whose inheritance places them above xz will move to **b**, while those falling below xz will move to **a**. The line xz is therefore the boundary between the basin of attraction of the two stable equilibria.

It is clear from figure 2 that as long the population of individuals inherit assets placing some of them on each side of xz, the population will over time bifurcate into two classes, those with the minimum assets and those with the assets described by point **b**.[7] In the world described by this model, starting from a distribution of assets in the neighborhood of xz, inequality would grow over time until the population were sorted into the two classes just mentioned. Until it reached this stationary state, the system would exhibit the opposite of regression to the mean (the term analogous to β in the previous model exceeding unity).

Of course the deterministic assumptions of this model are unrealistic (the inheritance is modified only by a deterministic dynamic given by (4) and (5).) And the income generating assumptions abstract from relations of employment and borrowing between those with substantial and limited assets. But the model serves to illustrate a second way that cumulative advantage may work: small differences in individual endowments may be magnified by the individuals' optimal path of accumulation or dis-accumulation.

This dynamic suggests an extension of the intergenerational transmission model introduced above. Suppose the value of β depends on the level of assets inherited and hence on parental income, as illustrated in figure 3 so that we have:

(1') $y_i = \beta(y_{ip})y_{ip} + (1-\beta(y_{ip}))\underline{y} + \lambda_i$

This model exhibits runaway inequality for middling levels of inheritance (those in the neighborhood of the boundary between the two basins of attraction, xz) and convergence of expected income to two distinct levels at the extremes. For example, those with very wealthy parents would have endowments in near the maximum, and their wealth (in the absence of shocks) would converge downward to point **b**. For appropriate parameters this process produces a bimodal steady state distribution of income with substantial polarization ((Gardiner (2004):342-344).

---

[7] I am ignoring the vanishingly small probability that the population would converge to point **c.**

The bifurcation in the dynamical system just presented arises because the income generating function exhibits two characteristics: *complementarity* of the two types of capital in generating income, and *increasing marginal returns* to each type of capital over some ranges. A further, well studied contributor to income inequality is *positive assortation*, namely, the tendency of those with substantial income-earning assets to be paired with similarly well endowed individuals in marriage and other productive activities(Fernandez, Guner, and Knowles (2001), Kremer (1997)).

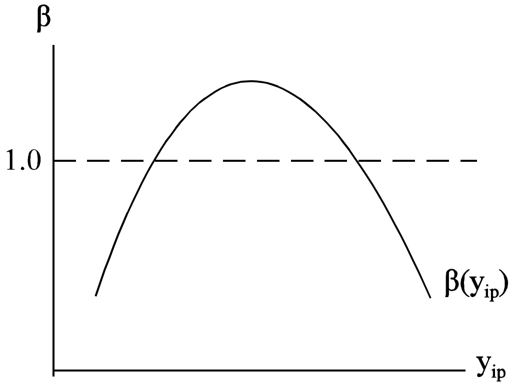

Figure 3. A state-dependent intergenerational transmission coefficient

On the basis of these intergenerational transmission and factor accumulation models, it seems likely that plausible values of the relevant parameters would generate high and in some circumstances increasing levels of income dispersion, even among individuals with substantially similar initial endowments.

While rapidly increasing inequality is sometimes observed (in the last quarter of the 20th century in the U.S., China, India, Canada and the UK for example) the long term stability of the income distribution in most nations and historical periods is remarkable. The models above thus serve to invert the "why inequality?" question and instead ask why we do not commonly see runaway inequality or persistent polarization, and why egalitarian and counter-dominance outcomes are as common as they are. A possible interpretation is that the institutions that regulate the distribution of income attenuate inequality in ways that do not appear in the above models.

3. Between-group Competition and Within-group Variance Reduction

Inter-group competition may favor egalitarian institutions if those institutions contribute to the survival of groups and thereby allow the proliferation of their institutions. Some have suggested, for example, that success in warfare is favored by both universal suffrage and monogamy (meaning potential wives are not monopolized by the elite), providing an explanation of the spread of these leveling institutions. Others have suggested that the information sharing and flexible job assignments that contribute to the competitive success of many large Japanese firms are made possible by the relatively egalitarian pay and employment policies adopted by these firms. Here I develop a variant of this idea.

That the suppression of within-group competition is a strong influence on evolutionary dynamics has been widely recognized in eusocial insects and other species (Smith and Szathmary (1995), Frank (1995), Michod (1996), Buss (1987), Ratnieks (1988)). Christopher Boehm (1982) and Irenaus Eibl-Eibesfeldt (1982) first applied this reasoning to human evolution, exploring the role of culturally transmitted practices which reduce phenotypic variation within groups. Examples of such variance-reducing practices are leveling institutions such as monogamy, food sharing among non-kin and other practices that reduce within-group differences in reproductive fitness or material well-being. Such structures may have attenuated within-group selection operating against individually-costly but group-beneficial practices, resulting in higher group average fitness or material success. If so, groups adopting these variance-reducing institutions would have had advantages in coping with climatic adversity, intergroup conflicts and other threats. According to this view, the evolutionary success of variance-reducing social institutions may be explained by the fact that they retard selection pressures working against in-group-beneficial individual traits, coupled with the fact that high frequencies of bearers of these traits reduces the likelihood of group extinctions and increases the likelihood that a group will expand and propagate new groups.

Beginning with Darwin (for example Darwin (1873):156 and other passages), a number of evolutionary theorists (J.B.S.Haldane (1932), William Hamilton (1975)) have suggested that human evolution might take place under the influence of multi-level selection along these lines. Among the distinctive human characteristics which may enhance group selection effects on genetic or cultural variation is our capacity for the suppression of within-group phenotypic differences in reproductive or material success and the frequency of intergroup conflict. The variance reducing institution modeled here is the commonly observed human practices of resource sharing among group members including non-kin, but the model could easily be extended to study other group level institutions that, like resource sharing, reduce the within group variance of material and hence reproductive success. Included are information sharing, consensus decision making, and monogamy.

The inheritance of group-level institutions (formally, conventions) results from a cultural transmission process based on learned behaviors: as new members of the population mature or immigrate, they adhere to the existing institutions, not due to any conformist predisposition, but because this is a best response as long as most others do the same. The resulting behavioral uniformity in adherence to a group's institutions permits us to treat the institution as a group-level characteristic. By contrast, the group-beneficial individual traits in our model are replicated by a standard payoff monotonic mechanism (types with above average payoffs tend to increase in frequency) in which the above pressures for uniformity are absent.

The Altruism Game: Row's Payoffs

	A	N
A	b-c	-c
N	b	0

The causal importance leveling in our simulations will be illuminated by a simple model of multi level selection in which between-group conflicts are absent. Consider a single trait, which may be absent or present in each individual in a large population the members of which each belong to one of a number of groups. For concreteness, consider an altruistic behavior which costs the individual *c* and confers a benefit of *b* (both measured in units of some material resource) on a randomly paired (single) other member of the group. This means that a member in a group composed entirely of A's (that is, altruists) has material payoffs exceeding those of a member another group with no altruists by the amount b-c.. As we assume b-c>0, altruism is group-beneficial. But in any mixed group, the expected payoffs of altruists will be lower than that of the N's (the non-altruists). So within-group selection will work against the altruists.

Let $p_{ij} = 1$ indicate that individual *i* in group *j* has the trait, with $p_{ij} = 0$ otherwise (those without the trait are N's). Using a discrete time framework, let *p* and *p'* represent the fraction of the population with the trait during a given time period and the subsequent period, respectively, and $\Delta p \equiv p'-p$. George Price (1972) showed that for any system of replication (cultural or genetic), Δp can be partitioned into group and individual effects. Define w_{ij} as the number of copies, next period, of an individual of type *i* in group *j*. Let w_{ij} depend additively on type *i*'s own trait and on the frequency of the trait in the group ($p_j \in [0,1]$) according to :

$$(6) \qquad w_{ij} = \beta_o + p_j\beta_g + p_{ij}\beta_i$$

where β_g and β_i are the partial effects on w_{ij} of the frequency of the trait in the group and the presence of the trait in the individual, respectively (the subscripts refer to *g*roup and *i*ndividual effects) and β_o, a constant, captures other influences on replication success.. Define $\beta_G \equiv \beta_g + \beta_i$ as the effect on the group average number of replicas of the frequency of the trait in the group (the difference in the number of replicas of an individual in a group composed entirely of those with the trait and a group entirely without is β_G). Thus using the definitions above, $\beta_i = -c$, $\beta_g = b$ and $\beta_G = b-c$. Then following Price (1972), and taking the expected value of Δp as an adequate approximation of Δp due to the large population size assumed, we have

$$(7) \qquad w\Delta p = var(p_j)\beta_G + \mathrm{E}\{var(p_{ij})\}\beta_i \text{ or}$$

$$w\Delta p = var(p_j)(b-c) - \mathrm{E}\{var(p_{ij})\}c$$

where *w* is the population-wide average of the number of replicas (which we normalize to unity) and the expectation operator E{} indicates a weighted average over groups (the weights being relative group size). The first term captures the group-selection effect (which is positive), while the second represents the effect of individual selection, which is negative (a simple derivation of this decomposition is in Bowles (2001)). Setting aside degenerate cases such as zero variances, it follows that an interior frequency of the trait will be stationary where these two terms are of equal absolute magnitude (assuming that the β's and variances making up these terms are themselves stationary). Because the second term is negative, the frequency of the A-trait within all surviving groups will fall over time. But as β_G is positive, this tendency will be offset by the continual extinction of groups with disproportionately low frequencies of the trait and their replacement by "new" groups with disproportionately high frequencies.

Then rearranging the stationarity condition for p (7) we see that $\Delta p=0$ when

(8) $$c/b = \text{var}(p_j)/[\text{E}\{var(p_{ij})\}+var(p_j)]$$

with $\Delta p > 0$ for $c/b < \text{var}(p_j)/[\text{E}\{var(p_{ij})\}+var(p_j)]$

$\Delta p < 0$ for $c/b > \text{var}(p_j)/[\text{E}\{var(p_{ij})\}+var(p_j)]$

The left hand term is the benefit-to-cost ratio of the altruistic trait. The right hand term is the ratio of between-group to the within-group plus the between-group variance of the trait. It is easily shown (Crow and Kimura (1970)) that this ratio measures the difference between the probabilities that an altruist will be paired with an altruist, P(A|A), and that a non-altruist be paired with an altruist, P(A|N). Thus

$$\text{r} \equiv \text{var}(p_j)/[\text{E}\{var(p_{ij})\}+var(p_j)] = \text{P(A|A) - P(A|N)}$$

The variance ratio, r, is thus a population-wide measure of the degree of non-randomness resulting not because of non-random pairing within groups, but because of the population is group-structured. Equation (3) shows that in order for an altruistic trait to proliferate in a population, the more costly (relative to the benefits) is the trait, the greater must be the between-group variance (relative to the within-group variance).

When the variance among group means is zero, A's no longer have the advantage of being in groups with disproportionally many A's. In this case group selection is inoperative, so only a costless form of group benefit could proliferate. By contrast when $var(p_{ij}) = 0 \ \forall j$, groups are either all A or all N, and one meets only one's own type, independently of the composition of the total population. In this case, within-group selection is absent and between-group selection is the only selective force at work.

Thus the force of group selection will depend on the magnitude of the group benefit relative to the individual cost (b and c in the example) and the degree to which groups differ in their frequency of the trait, relative to the degree of within-group variance of the trait. Rewriting (8) as $rb\text{-}c= 0$ we see that the stationarity condition for p in a group-structured population is just another version of Hamilton's rule for the degree of positive assortation permitting an altruistic trait to proliferate when rare. In this respect, multi-level selection works by the same processes as other evolutionary processes based on non random pairing

Figure 4 shows how the group structure of the population overcomes the disadvantage of bearing the costs of altruistic behaviors. While the expected payoff to the non-altruist (π_N) exceeds that to an altruist (π_A) when they both have the same probability of being paired with an altruist, the difference in the probability of meeting an altruist conditional on one's type may overcomes this disadvantage. The figure illustrates a value of the variance ratio r (that is, the difference P(A|A) - P(A|N)) that is just sufficient to equate the expected payoffs of the two types and thus to maintain a stationary value of *p*. How large this difference must be depends, as we have seen and as the figure makes clear, on the payoff differences between the bearers of the two traits.

Group-level social institutions may reduce these within group payoff (and hence fitness) differences between the A's and the N's. Suppose that in the absence of leveling institutions the selection process within a group is modeled (for group *j*) by the standard replicator dynamic equation

(9) $\Delta p_j = p_j(1- p_j)(\pi^A - \pi^N) = p_j(1- p_j)(-c)$

Now imagine that the group has adopted the practice that was common among virtually all foragers and many other human groups of within-group resource sharing. Some fraction of the resources an individual acquires -- perhaps specific kinds of food as among the Ache (Kaplan and Gurven (2004))-- is deposited in a common pot to be shared equally among all group members. This sharing institution may be modeled as a linear tax, $t \in [0,1)$, collected from the members payoffs, with the proceeds distributed equally to all members of the population. The effect is to reduce payoff differences between A's and N's, that is: $\pi^A - \pi^N = -(1-t)c$.

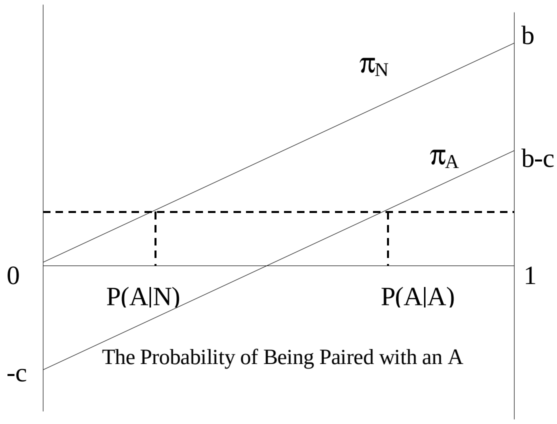

Figure 4 **The evolution of an altruistic trait in a group-structured population**. If the population structure's variance ratio, *r**, is such that the difference in the conditional probabilities of being paired with an A (P(A|A) - P(A|N)) is as shown, *p* is stationary, because the expected payoffs of the two types π_A and π_N are equal.

Figure 5 shows the effect of resource sharing on the payoff differences of the two types. The difference in the probability of meeting an A (conditional on ones own type) that equalizes expected payoffs is no longer P(A|A) - P(A|N) = r* as shown in Figure 1, but is now $P^T(A|A) - P^T(A|N) = r^T$ with $r^T < r^*$. Comparing the two figures one sees that r*=c/b while $r^T = c(1-t)/b$. As a result, were the population structure as in Figure 1 (namely, r*) and the sharing institution in place (t>0), then $\pi_A > \pi_N$. so p will increase.

Taking account of resource sharing

(10) $\Delta p_j = p_j(1-p_j)(1-t_j)(-c)$

from which it is clear that sharing retards the within-group selection against the A's. This can be seen by noting that

(11) $\partial \Delta p_j / \partial t_j = -p_j(1-p_j)(-c)$

which for $p_j \in (0,1)$ is positive, meaning that resource sharing attenuates the negative selection against the A's. Note that the effect is greater when p_j is close to one half.

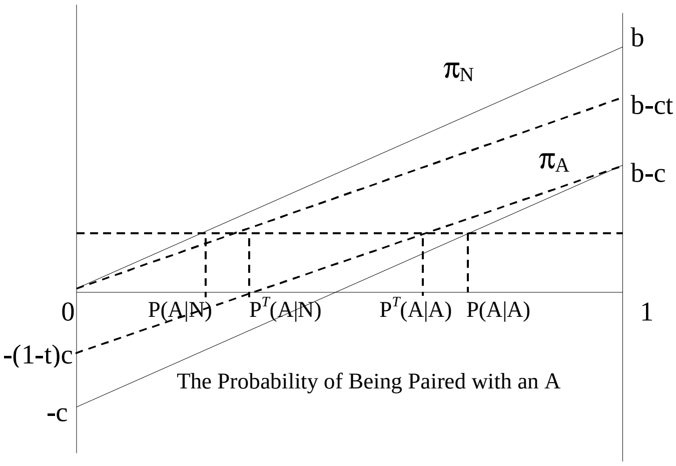

Figure 5. Resource sharing increases the relative importance of population structure in the evolution of an altruistic trait. The dashed payoff functions indicate the effect of within group resource sharing; the altruistic trait will proliferate if r = r*.

Thus an egalitarian sharing rule attenuates the exploitation of A’s by N’s, retarding the selection pressures against the A’s and thereby reducing the size the negative individual selection term in the Price equation (7). As a result, groups with higher tax rates tend to have more A’s and hence are favored in between-group competition. This latter effect means that a higher tax rate will proliferate in the population.

Simulations of the coevolution of altruistic individual behaviors and sharing at the group level, using parameters that may describe some ancestral human populations and their environments confirm the expectations of the model (.Bowles, Choi, and Hopfensitz (2003).) We represented group competition as infrequent lethal conflict in which the groups with more A’s have a higher probability of winning, and in which winners extend their institutions to the losers’ territory. We introduced a rising marginal and average cost of resource sharing to capture the incentive effects and administrative costs of sharing systems. We found that for sufficiently small group size, frequent intergroup conflicts and limited inter group migration, the simulated population sustains high frequencies of altruists and significant levels of resource sharing within groups.

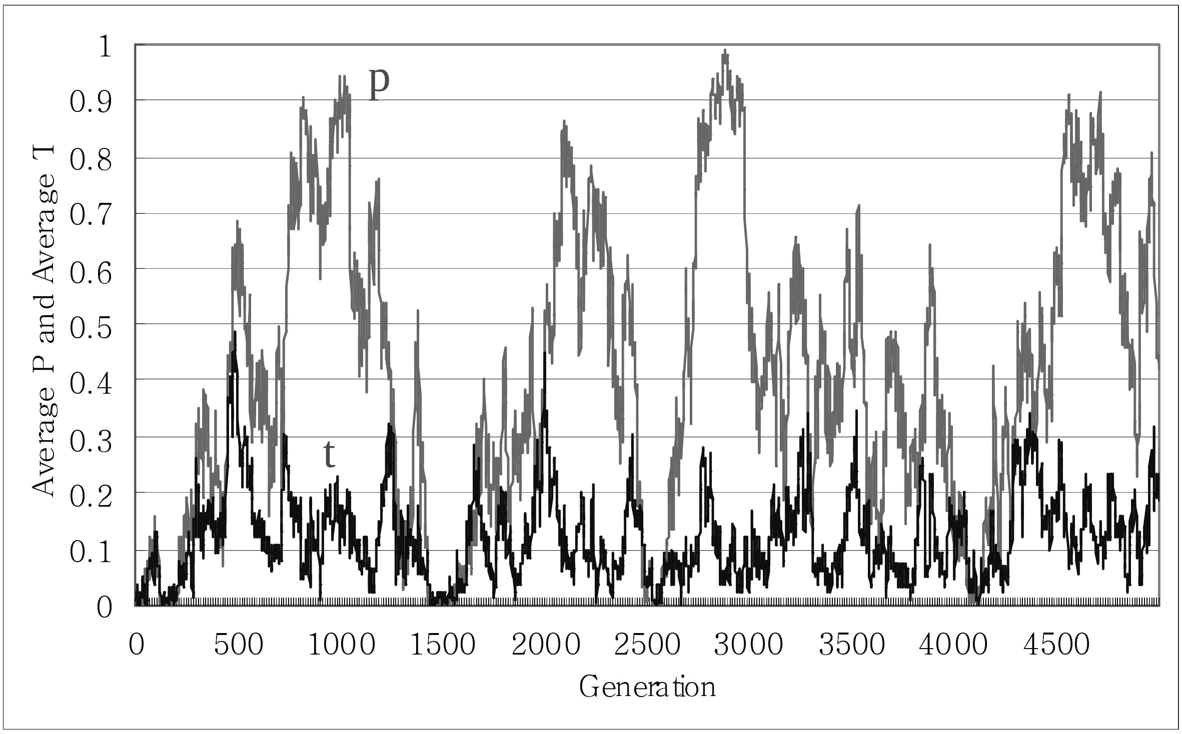

Figure 6: The coevolution of egalitarian taxation and altruistic individuals.

The co- evolution of the fraction of the total population who are A's and the average rate of taxation across all 20 groups (starting from a situation in which no groups shared, and there were no altruists) is depicted in Figure 6.[8] Very high levels of p generally lead to a reduction in average tax rates (when p is high the incentive costs of the tax system outweigh the benefits as there are few N's present). This in turn induces a sharp decline in p.

We turn now from between-group competition as a possible contributor to egalitarian outcomes to within-group class conflict.

4. The Fragility of Highly Unequal Conventions

Are institutions that implement substantial inequalities between highly polarized

---

[8] The between-group migration rate for this simulation was 0.2, group size was 20, and the frequency of conflict was 0.28 (approximately once every 4 generations). Extensive experimentation with the parameter set, econometric analysis of the resulting time series, and evidence concerning the plausibility of the parameter set are presented in Bowles, Choi, and Hopfensitz (2003)

classes more vulnerable to being overturned than more egalitarian institutions? A Marx-inspired answer to this question would explore the way that polarized economies contribute to the conditions under which successful collective action might overturn the status quo in favor of a more egalitarian alternative. Here I develop this reasoning using an adaptation of stochastic evolutionary game theory in which the stochastic influences on the evolutionary process take the form of intentional collective action rather than mutation-like errors. In this model two characteristics of institutions affect the likelihood of successful oppositional collective action: the payoffs to the two classes under each of the institutions and the size of the sub-populations in each class. Payoffs and class size affect the fragility or robustness of institutions because they jointly determine both the minimum numbers of collective action participants required to induce a transition and the likelihood that stochastic events combined with the intentional pursuit of class interests will produce the required numbers. We will see that egalitarian institutions are indeed favored in this setup, but that very unequal institutions may persist for long periods even when they are less efficient (produce a smaller joint surplus) than an alternative more egalitarian institution.

I study the evolutionary dynamics governing transitions between two contractual conventions in a two-person two-strategy game in a large population of individuals subdivided into two classes, the members of which are randomly paired to interact in a non-cooperative game with members of the other classes. Individuals' best- response play is based on a single-period memory, and they maximize their expected payoffs based on the distribution of the population in the previous period.

The classes, initially assumed to be of equal size, are termed A's and B's, and each when paired with a member of the other group may chose action 1 or 0, with the A's payoffs, a_{ij} representing the payoff to an A-person playing action *i* against a B-person playing action *j*, and analogously for the B's. If the members of the pair choose the same action they get positive benefits, while if they chose different actions they get nothing. For concreteness, suppose the sub-groups are economic classes selecting a contract to regulate their joint production, which will only take place if they agree on a contract. Payoffs are shares of the joint surplus of the project, with the no-production outcome normalized to zero for both. The payoffs, with the A's as the row player, and the B's as column player, are thus:

Figure 7
Payoffs in the contract game

	B offer contract 1	B offer contract 0
A offer contract 1	a_{11} b_{11}	0 0
A offer contract 0	0 0	a_{00} b_{00}

To capture the conflict of interest between the two groups, let us assume that $b_{00} > b_{11}$

= $a_{11} > a_{00} > 0$ so the B's strictly prefer the outcome in which both play 0, the A's prefer the equal division outcome which results when both play 1.[9] Both of these outcomes are strict Nash equilibria, and thus both represent conventions, which I will denote E_0 and E_1 (or {0,0} and {1,1}). Both populations are normalized to unit size, so I refer equivalently to the numbers of players and the fraction of the population, abstracting from integer problems.

The state of this population in any time period t is $\{\alpha_t, \beta_t\}$, where α is the fraction of the A's who played 1 in the previous period and β is the fraction of the B's who played 1. For any state of the population, expected payoffs a_i and b_i for the A's and B's respectively playing strategy *i*, depend on the distribution of play among the opposing group in the previous period, or dropping the time subscript:

$$a_1 = \beta a_{11};\ \ a_0 = (1-\beta)a_{00};\ \ b_1 = \alpha b_{11};\ \text{and}\ b_0 = (1-\alpha)b_{00}.$$

The relationship between the population state and the expected payoffs to each action is illustrated in Figure 8.

Individuals take a given action -- they are 1-players or 0-players -- and they continue doing so from period to period until they update their action, at which point they may switch.[10] The updating is based on the expected payoffs to the two actions; these expectations are simply the payoffs which would obtain if the previous period's state remained unchanged (the population composition in the previous period being common knowledge in the current period.) While this updating process is not very sophisticated, it may realistically reflect individuals' cognitive capacities and it assures that in equilibrium -- when the population state is stationary -- the beliefs of the actors formed in this naive process are confirmed in practice.

---

[9] I refer to {1,1} as the "equal" convention as a shorthand. The levels of well-being attained by the A's and B's cannot be determined without additional information (if the A's are share croppers who interact with only one B (a landlord), while B's interact with many A's, the "equal" convention would exhibit unequal incomes of the two groups, for example).

[10] Giving individuals a longer (than one period) memory, or a less naive updating rule, or a more limited knowledge of the distribution of types in the other sub-population, would not yield substantially different insights about the questions explored here. The overlapping-generations assumption concerning updating is, however, important as it means that the stochastic shocks due to idiosyncratic play (to be introduced presently) are persistent as the realized distribution of play in the previous period reflects the shocks experienced over many past periods.

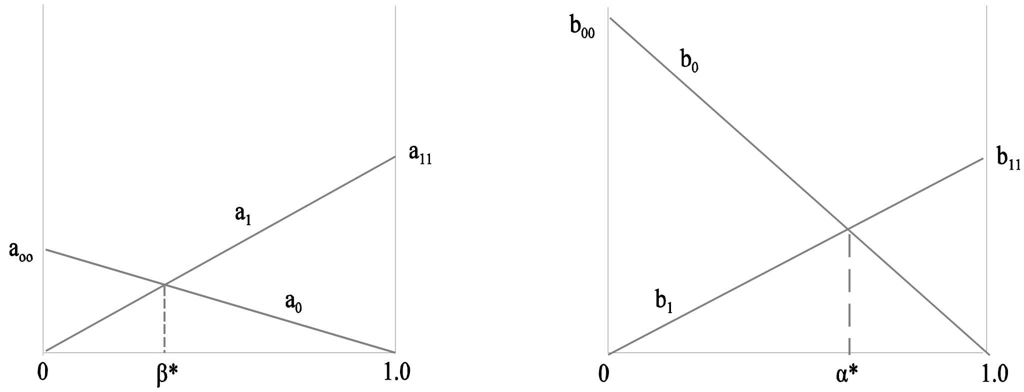

Figure 8. Expected payoffs. Note: A’s payoffs depend on β the fraction of B’s offering contract 1, while the B’s payoffs depend on α the fraction of A’s offering contract 1. Because $b_{00} > b_{11} = a_{11} > a_{00}$, the convention E_1 (that is, α=1=β) is preferred by the A’s while E_0 is preferred by the B’s.

Individuals are represented simply as bearers of the strategies they have adopted, while the distribution of strategies among them varies. I will analyze the single-period change in the population state (Δα,Δβ) under the assumption that individual updating of strategies is monotonic in average payoffs so that Δα and Δβ have the signs respectively, of $(a_1 - a_0)$ and $(b_1 - b_0)$. The resulting population dynamics are illustrated in Figure 9 where the relevant regions are defined by:

(12) $\alpha^* = b_{00}/(b_{11}+b_{00})$

$\beta^* = a_{00}/(a_{11}+a_{00})$

these two population distributions equating the expected payoffs to the two strategies for the two sub-populations, respectively. These values of α and β define best response functions: for $\alpha<\alpha^*$ B's best response is to play 0, and for $\alpha\geq\alpha^*$ B's best response is to play 1, with β* interpreted analogously.

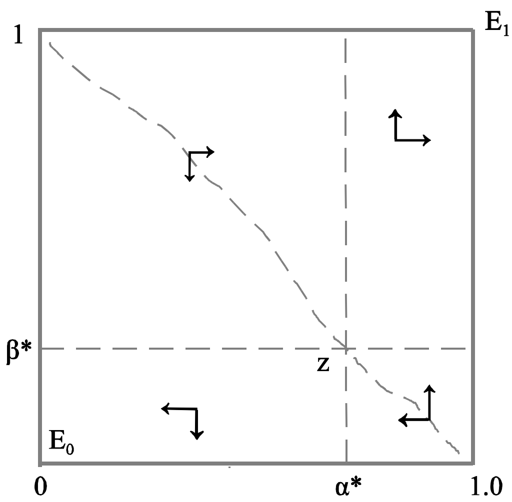

Figure 9 The state space. Note: E_1 and E_0 are absorbing states in the non-stochastic dynamic; z is a saddle.

For states $\alpha<\alpha^*$ and $\beta<\beta^*$ (in the southwest region of Figure 9) it is obvious that Δα and Δβ are both negative and the state will move to {0,0}. Analogous reasoning holds for the northeast region. In the northwest and southeast regions of the state space we may define a locus of states from which the system will transit to the interior equilibrium α^*,β^*, with states below that locus transiting to {0,0}, and above the locus to {1,1}. The basin of attraction of {0,0}, is the area below the dashed downward-sloping line in Figure 9; its size will vary with $\alpha^*\beta^*$. While the interior equilibrium $\{\alpha^*,\beta^*\}$ is an unstable Nash equilibrium (a saddle), the outcomes {0,0} and {1,1} are absorbing states of the dynamic process, meaning that if the population is ever at either of these states, it will never leave.

How, then, might institutional change occur? Suppose there is a probability ε that when individuals are in the process of updating, each may switch type for idiosyncratic reason. Thus ($1-\varepsilon$) represents the probability that the individual pursues the best response updating process described above. Idiosyncratic play can lead to transitions from one convention to another in the following way. If the status quo convention is {0,0} but a sufficiently large number of A's play 1 for some reason not captured by the model, then in the next period, the best response of the B's, having encountering these 1-playing A's will be to play 1 as well. In the next period, the best response of the A's who encountered these 1-playing B's will be to play 1, and so on, possibly leading to the "tipping" of the population from the {0,0} to the {1,1} convention. Conventions which require a large amount of idiosyncratic play to dislodge, while requiring little idiosyncratic play to access will persist over long periods, and if eclipsed by some other convention they will readily reemerge.

Suppose the idiosyncratic play just introduced takes the form of intentional participation in a collective action seeking to dislodge the status quo convention in favor of the other. Thus with probability ε the individual is "called" to a meeting at which, should there be sufficient numbers attending to induce a transition should they all engage in the collective action against the status quo, all decide to play idiosyncratically. (This is a degenerate model of the collective action problem to illustrate the dynamic, a more complete model is provided in Bowles (2004)).

Thus if the status quo is the {0,0) convention preferred by the B's, it will take α^* or more idiosyncratically playing A's (playing contract 1) to induce the best-responding B's to do the same, inducing a transition from {0,0} to {1,1}. Thus α^* may be termed a "collective action barrier" giving the minimum number of A's required to sacrifice the income from one period's contract in order to increase the likelihood of an institutional transition benefitting their group. A transition in the reverse direction would be induced by $1-\beta^*$ or more idiosyncratically playing B's (the A's prefer {1,1} so they will not seek to dislodge it). Which of these transitions is more likely in a single period depends on the payoffs as these determine α^* and β^*. The population will spend most of its time governed by the contract to which the transition is most probable.

It is easy to show that if the groups are of equal size, the population will spend most of its time at the more equal convention (Bowles (2004) Naidu and Bowles (2004)). The reason is as follows (see figure 10). By comparison with some relatively equal "benchmark" convention, increasing the degree of inequality of an alternative convention makes the unequal convention more persistent (requiring more idiosyncratic play to dislodge it). But this effect is more than offset by a counter effect: increasing the inequality of the alternative makes the benchmark even more persistent. So the effect of greater inequality in the alternative convention is to slow down the process of transition in an asymmetrical way, disproportionately retarding the transitions from the equal to the unequal convention. For this reason, the more unequal is the alternative contract, the greater the amount of time the population spends at the equal (benchmark) contract.

This is illustrated in figure 11 which shows (the height of the bars) the fraction of a very long period of time that the population will be in the neighborhood of the alternative contract if the benchmark is the egalitarian {1,1} contract above, and the alternative contract gives σρ to the As and (1-σ)ρ to the Bs. The efficiency (joint surplus) of the contract is given by ρ (for the benchmark ρ is 2) and the level of inequality by σ ∈ [0, ½] It is clear that both inefficient and unequal contracts are penalized in this dynamic. For example, the figure shows that a convention that gives the A's 0.2 of the total surplus must be 25 percent more efficient (that is ρ = 2.5) than the benchmark egalitarian (σ = ½, ρ = 2) contract.

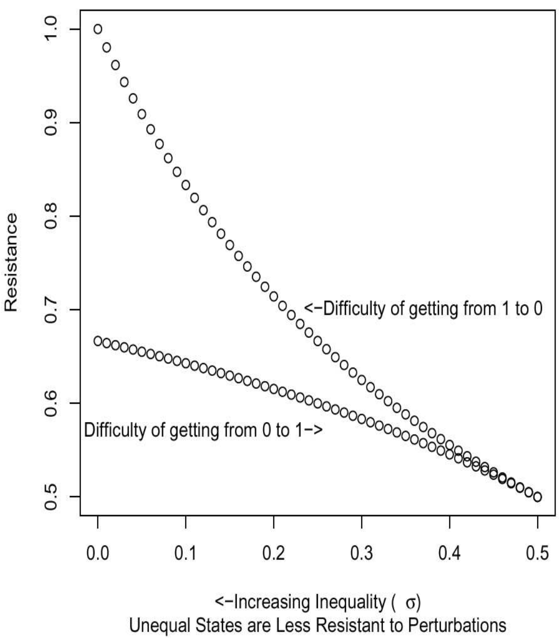

Figure 10 Unequal conventions are not robust. It takes more idiosyncratic play to move from the equal to the more unequal convention than the reverse

If the number of A's exceeds the number of B's however, as would typically be the caseif the A's are wage workers or share croppers, for example, highly unequal conventions may be very persistent, even if they are much less efficient than the benchmark. Figure 12 shows the effect of assuming sub-populations of different size (retaining the degenerate model of collective action) for an alternative contract with σ = 0.3 and with the ρ values as shown.

By contrast to the equal sub-population size case depicted in Figure11, when population sizes differ the intentional nature of non-best-response behavior makes a difference: unequal and quite inefficient conventions may be highly persistent. For example, in the equal population size case a convention with σ = 0.3 needed a ρ of 2.25 to be equally persistent to E_1; but if the A's number 18 and the B's 6, the two conventions are equally persistent when the unequal convention is much *less* efficient than the benchmark, that is ρ = 1.25 Where there are 21 A’s (and 3 B’s) the population will spend most of the time in the unequal convention even if its level of efficiency is half that of the equal convention. Note that the level of inequality measured by the average income of B's relative to A's is n(1-σ)/σ(24-n), each B interacting with more A's as their relative share of the population increases. Thus at the convention E_0 if σ = 0.3 and the A's and B's are equally numerous, the B's have an income 2.33 times the A's but when there are 21 A's and 3 B's, the ratio is 16.33. Thus highly unequal distribution of income may result from unequal sub-population sizes, and may be persistent because of the unequal sub-population sizes.

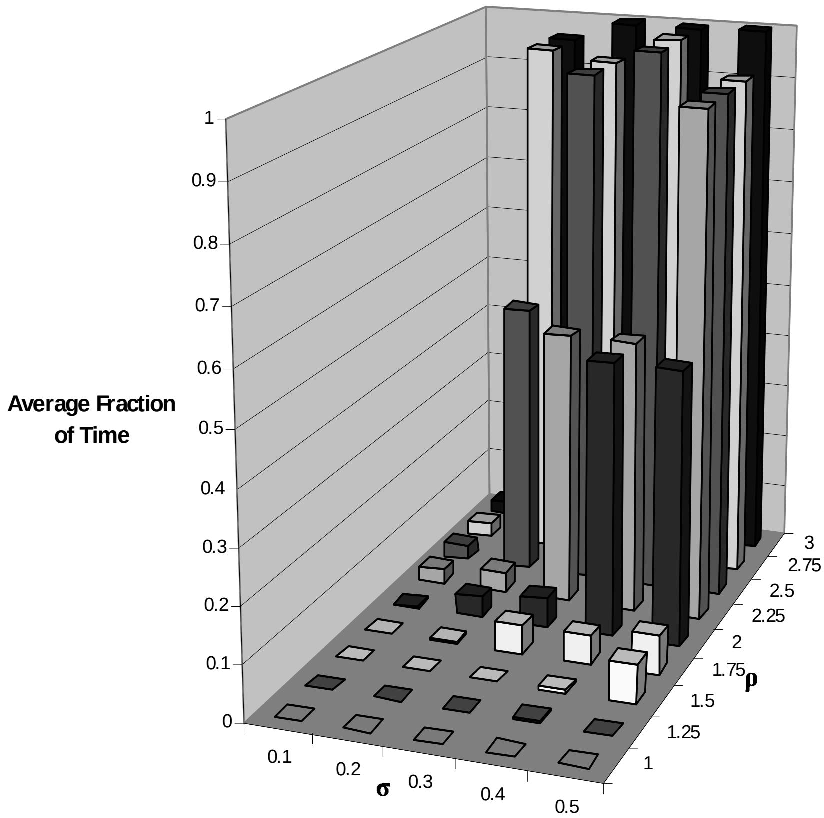

Figure 11. Efficient and equal conventions are stochastically stable with equal sub-population sizes. Note: the Benchmark convention is E_1 for which ρ = 2 and σ = ½.

The evolutionary success of unequal and inefficient conventions benefitting the smaller of the two classes is readily explained. As long as rate of idiosyncratic play is less than the critical fraction of the population required to induce a transition (which I assume), smaller groups will more frequently experience "tipping opportunities" when the realized fraction of the population who are "called" by chance exceeds the expected fraction (ε itself). The theory of sampling error tells us that the class whose numbers are smaller will generate more "tipping" possibilities. Small size does not facilitate collective action if more than the critical number are "called": recall that in this case, all of those called will choose the risk dominant strategy, and this is independent of their numbers.

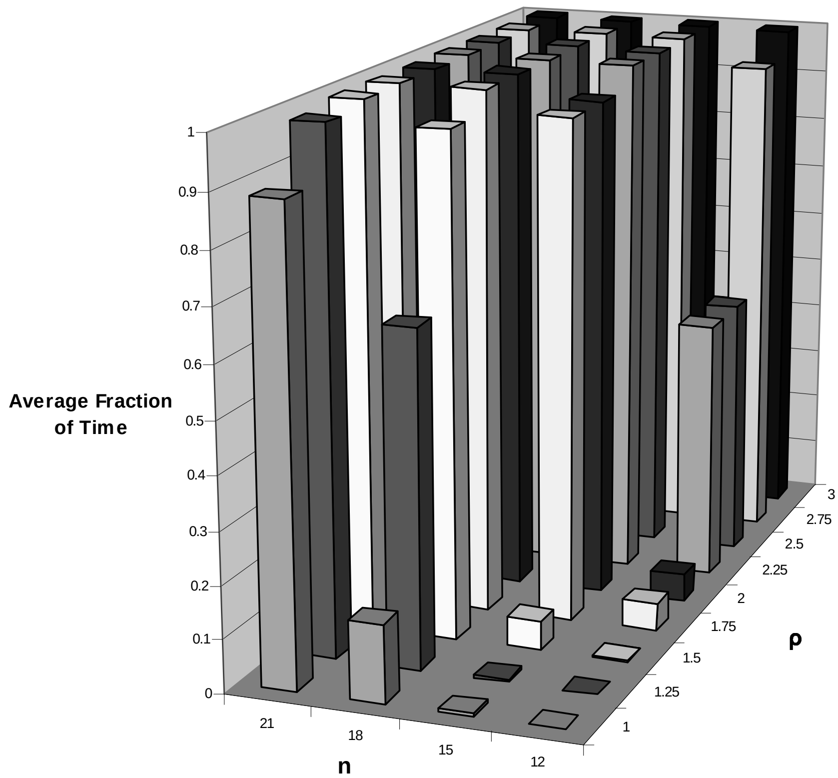

Figure 12. Unequal conventions persist when the poor outnumber the rich. Note: total population is 24; the Benchmark convention is E_1 ($\sigma = ½$, $\rho = 2$). E_0 is characterized by the values of ρ indicated and $\sigma = 0.3$.

The evolutionary advantages of equal conventions are enhanced if the rate of idiosyncratic play (ε) is made state-dependent. Our interpretation of idiosyncratic play as participation in class-based collective action motivates letting ε be increasing the degree of class polarization at each state. Esteban and Ray (1994) provide a polarization measure, κ, designed to capture the collective identity of the members of a class as well as the income economic differences between the classes. As its calculation requires only the class income difference and the size of each class, it is readily calculated for each of our states for a variety of class sizes. We let

$$\varepsilon = \underline{\varepsilon}^{1/(1+\alpha\kappa)}$$

where α is a positive constant, so where polarization is absent (where the two classes have the same income) $\varepsilon = \underline{\varepsilon}$. To give some idea of the effects of this formulation if $\underline{\varepsilon} = 0.1$ and $\alpha = 5$, then for classes of equal size, the rate of idiosyncratic play is 0.18 if $\sigma = 0.4$ and 0.39 if σ is 0.1.

The effect is to destabilize unequal conventions especially where class size is approximately equal. For example from figure (12) we see that with state-independent ε and an alternative contract of $\sigma = 0.3$ and $\rho = 2$, the population will spend virtually all of the time (96%) at the alternative contract and thus virtually none at the benchmark (egalitarian) convention. Our calculations show, by contrast, that with state dependent ε (using the above formulation) the population spends only 0.05 percent of its time at the unequal alternative contract and virtually all at the egalitarian contract. Thus the formulation of the nature of the state dependence of idiosyncratic play is essential to the predictions of this model.

5. Equality's Fate: *Some speculations*

From a very long run perspective, two big facts about inequality stand out. First, humans descended (and are not very different genetically) from an animal (the common ancestor of us, chimps, bonobos and gorillas) that almost certainly lived in a society of marked dominance hierarchies. Second, for perhaps the first 90 percent of the entire time that modern humans have existed (since about 100 thousand years ago) most humans lived in foraging bands that were strikingly egalitarian in access to valued resources and power, at least when compared to the substantial inequalities of the agrarian autocracies and capitalist economies that were to follow and the societies of non-human primates (with the possible exception of bonobos) that had preceded our foraging ancestors. What explains this great U-turn? And what does an answer to this question suggest about the future of equality?

The causal mechanisms operative in the models above (commutative advantage, between group competition, within-group class conflict) have been presented ahistorically, as if they were time-invariant. But to explain the U-turn we need to take account of the changing nature of human livelihoods. The forces at work over this very long run concern (at least) four aspects of production, reproduction, and distribution.

The first is the nature of stochastic shocks to which humans have been exposed, and the opportunities for insuring against these shocks given the mode of livelihood and the organization of reproduction of the groups in question. The thrust of this argument is that the ecology and livelihood of the typical foraging band entailed substantial individual uncertainty primarily because hunting success is very sporadic (Hawkes (2000)). Because the main sources of nutrition were difficult to store, self-insurance over time (through saving and accumulating reserves) was ineffective. As a result, within-group contemporaneous consumption smoothing was widely adopted. The domestication of plants and animals made storage effective, allowing self-insurance (by the more productive) to displace co-insurance.

The second is that our foraging ancestors (unlike non-human primates) were substantial meat eaters who often acquired their nutrition in huge packages, the marginal benefits to which (in fitness or other benefits) were sharply diminishing beyond a small fraction of the package size. As a result that the opportunity cost of sharing was quite limited, and the cost of not sharing with needy competitors was substantial (Blurton-Jones (1987)). By contrast, post-domestication livelihoods are often acquired in highly divisible pieces, the returns to which (over the relevant scale) are not so sharply diminishing.

The third aspect is that the life cycle of learning, productivity and consumption among foragers differs greatly from our primate ancestors in that the costs of child rearing are substantially greater, creating a large net deficit for most families when their children are past infancy but not yet productive hunters and gathers. Resource sharing among families within groups facilitates the long learning times associated with human (but not other primate) development (Kaplan and Gurven (2004)). This is but an early example of the socialization of the costs of reproduction a more recent example of which is the Nordic welfare state.

The fourth dimension, and the one I would like to explore here, concerns the nature of the technology by which livelihoods are produced, and especially the degree to which the forms of wealth involved generate cumulative advantage and are privately appropriable and hence may be transmitted within families across generations.[11] Suppose that livelihoods are produced and the next generation are reproduced using three kinds of wealth: material capital, somatic wealth, and knowledge. By somatic wealth I mean (following Kaplan) the individual's bodily capacities and condition, including health, mental acuity, strength and learning abilities. Knowledge wealth, by contrast is a stock of information to which one may have access (through the traditions, lore, technical manuals, libraries, and other information sources available to members of a group.)

[11] An aspect of this process – the extent a technology permits the clear definition of property rights – is the explanation for the emergence of possession-based individual property at the time of the domestication of plants and animals advanced in Bowles and Choi (2002)

Production and reproduction typically require some of all three kinds of wealth. Scientific and technical knowledge must often be embodied in material wealth in order to be effective. Access to knowledge wealth requires at least minimal levels the learning and information processing capacities that are elements of somatic capital. As these examples suggest, the three inputs are often (but not always) complementary, the effectiveness of one increasing in the level of the other. One could take account of these and other complementarities among the types of wealth by adopting a generalized Cobb-Douglas or CES income generating function. In the former case we would have

$$y = Ak_m^{\alpha m}k_s^{\alpha s}k_k^{\alpha k}$$

where y is a measure of output, A is a positive constant and α_m , α_s , α_k measure the relative importance of material, somatic and knowledge wealth in the production proces. For positive levels of all three inputs, each exponent measures the elasticity of output with respect to the type of wealth concerned. For example a one percent increase in material wealth will increase output by α_m per cent. A convenient way to represent the relative importance of each type of wealth is illustrated in figure xxx. Each point in the simplex gives the exponent as indicated. The sum of the exponents is a measure of the extent of economies of scale: increasing all inputs by one percent will increase output by $\alpha_m + \alpha_s + \alpha_k$ per cent. The function exhibits complementarity among all three inputs: the derivative of y with respect to each type of wealth is increasing in the levels of the other types.

The three types of wealth exhibit the properties in the table below.

	Material	Somatic	Knowledge
Cumulative advantage	Yes	No	Yes
Privately appropriable and transmissible	Yes	Somewhat	Effectively no

Characteristics of Three Types of Wealth

These properties ore not entirely determined by the technical nature of the wealth, of course: with confiscatory inheritance laws, for example, material wealth may not be transmissible across generations, and with well defined and aggressively enforced intellectual property rights knowledge may be privately appropriable and the its benefits intergenerationally transmissible.

But the technical features of the category of wealth greatly influence the extent to which it exhibits the properties listed.

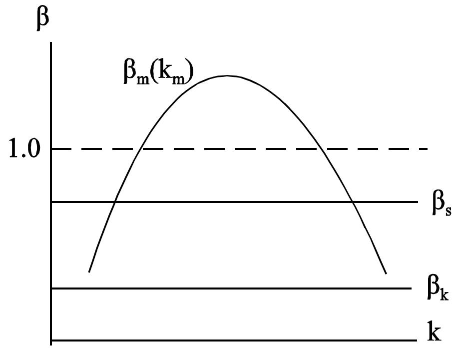

Figure 13. Intergenerational persistence for three types of wealth: material, somatic, and knowledge

Now consider the intergenerational transmission of wealth as before, and let us as in equation (1) collapse the transmission-across-generations process with the accumulation process so that we write $k_{j\,t}$ as the wealth of type j {material, somatic, knowledge} of the t th generation at the time that they pass on their wealth to the next generation (namely having inherited wealth from the previous generation as in the first model in section 2 and having then accumulated or dis-accumulated, as in the second model). Assume (contrary to the accumulation model for h and k) that the accumulation and transmission processes for these three types of capital are independent (the level of one type of wealth not affecting the transmission or accumulation of the other). This assumption may be particularly inappropriate for the case of knowledge wealth, for the productivity of free information may depend critically on access to material and somatic capital.[12] Then we can write

$$k_{j\,t} = \beta_j\, k_{j\,t-1} + (1-\beta_j)\underline{k}_j \quad + \lambda_j \quad j \in [m, s, k]$$

where $\underline{k}_j$ is the societal mean of wealth of type j, and λ_j is a mean-zero disturbance term with standard deviation σ_j (and like λ in equation (1), it is independent and identically distributed and is uncorrelated with $k_{j\ t-1}$). Call this an intergenerational persistence (rather than transmission) process as it includes both the literal transmission (‘handing down’ from parent to offspring) and the process of accumulation or dis-accumulation taking place over the life course. The β’s are persistence coefficients.

[12] If the production function has the Cobb Douglas form (above) the variance of the logarithm of income can then be expressed as the sum of the variances and covariances of the (logarithm) of the three types of capital, weighted by coefficients reflecting the relative contributions of the three to income generation, the degree of economies of scale, and the degree of complementarity among the three types of capital:

$$var(y) = \alpha_m^2\ var(m) + \alpha_s^2 var(s) + \alpha_k^2 var(k) + \alpha_m\alpha_k covar\ (mk) + \alpha_m\alpha_s covar(ms) + \alpha_k\alpha_s\ covar(ks)$$

Given the entries in the above table, and the reasoning in section 2, it is plausible to suppose that the values of β are as they appear in figure 13.. The intergenerational persistence process for material wealth gives an inverted-U persistence coefficient for the cumulative advantage reasons presented in section 2.

The persistence process for somatic wealth exhibits significant regression to the mean ($\beta_s < 1$) over its entire range. The reason is that cumulative advantage in accumulating somatic capital is quite limited (due to the limited nature of the necessary site of the investment, the body) and the inheritance process for the traits that are essential to generating income is characterized by limited heritability and limited assortative mating on the relevant traits.

Finally β_k is characterized by strong regression to the mean because, despite positive feedbacks in the process of knowledge generation, the zero-cost copying aspect of knowledge its substantially public good nature makes its inheritance within families very weak (most of the knowledge to which one has access is based on the stock of knowledge enjoyed by the average member of one's group.)

Recall that a persistence process characterized by regression to the mean at the extremes and movement away from the mean over intermediate ranges (like β_m) will (for appropriate parameters) generate a stationary (ergodic) distribution of wealth that is bimodal, that is, polarized By contrast, if regression toward the mean characterizes the persistence process, as we have seen, the stationary distribution is uni-modal and its variance is given by

$$\mu = \sigma_\lambda^2 / (1- \beta^2).$$

Thus the three persistence processes given in figure 13 could sustain the stationary distributions given in figure 14.

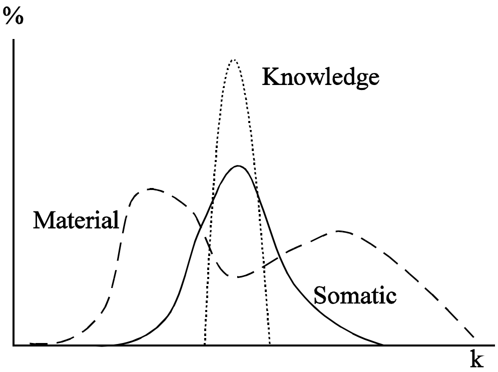

Figure 14. Stationary distributions (steady state frequency distribution) for three types of wealth.

A possible interpretation of the U-turn is the following. Our foraging ancestors produced their livelihoods (and reproduced themselves) relying primarily on somatic capital and knowledge. This, along with the group-survival advantages of within-group variance-reduction and the other contributors to hunter-gatherer egalitarianism mentioned above, provided the economic underpinnings for a culture and political process that discouraged the emergence of social dominance hierarchies and persistent differences in wealth.

Agriculture (and later machine-assisted industry) greatly enhanced the importance of material wealth, and reduced the relative importance of somatic capital, and probably also reduced the importance of knowledge capital. The result was a class division characterized by substantial polarization. The essential role of material capital in income generation and its polarized distribution along with increasing returns in the effective use of coercion further contributed to social dominance hierarchies and economic inequality. Inequality may have been somewhat attenuated by the vulnerability of highly unequal conventions to insurgent collective action demonstrated in the previous section.

Material wealth remains important today, but the importance of knowledge and other so-called 'fugitive resources' (Arrow (1999)) is rapidly increasing. Whether current attempts to enclose the 'knowledge commons' can 'domesticate' these fugitive resources, so that their persistence coefficients come to resemble that of material wealth, is one of the major political and economic battles of the coming decades. If these efforts fail, the increasing economic importance of knowledge may contribute to the realization of a more egalitarian future

Works cited

Allen, Robert C. 1997. "Agriculture and the Origins of the State in Ancient Egypt." *Explorations in Economic History*, 34, pp. 135-54.

Arrow, Kenneth. 1999. "Technical information and industrial structure," in *Firms, Markets and Hierarchies*. Glenn Carroll and David Teece eds. Oxford: Oxford University Press, pp. 156-63.

Ashenfelter, Orley and Cecilia Rouse. 2000. "Schooling, Intelligence, and Income in America," in *Meritocracy and Economic Inequality*. Kenneth Arrow and Samuel Bowles and Steven Durlauf ed: Princeton University Press, pp. 89-117.

Banerjee, Abhijt , Paul J. Gertler, and Maitreesh Ghatak. 2002. "Empowerment and Efficiency:Tenancy Reform in West Bengal." *Journal of Political Economy*, 110:2, pp. 239-80.

Bardhan, Pranab, S. Bowles, and H. Gintis. 2000. "Wealth Inequality, Credit Constraints, and Economic Performance," in *Handbook of Income Distribution*. Anthony Atkinson and Francois Bourguignon eds. Dortrecht: North-Holland, pp. 541-603.

Blurton-Jones, Nicholas, G. 1987. "Tolerated Theft, Suggestions about the Ecology and Evolution of Sharing, Hoarding, and Scrounging." *Social Science Information*, 26:1, pp. 31-54.

Boehm, Christopher. 1982. "The Evolutionary Development of Morality as an Effect of Dominance Behavior and Conflict Interference." *Journal of Social and Biological Structures*, 5, pp. 413-21.

Boehm, Christopher. 2004. "What makes humans economically distinctive? A three-species evolutionary comparison." *Journal of Bioeconomics*.

Bowles, Samuel. 2001. "Individual Interactions, Group Conflicts, and the Evolution of Preferences," in *Social Dynamics*. Steven Durlauf and Peyton Young eds. Cambridge, MA: MIT Press, pp. 155-90.

Bowles, Samuel. 2004. *Microeconomics: Behavior, Institutions, and Evolution*. Princeton: Princeton University Press.

Bowles, Samuel and Jung-Kyoo Choi. 2002. "The First Property Rights Revolution." *Santa Fe Institute Working Paper 02-11-061*.

Bowles, Samuel, Jung-Kyoo Choi, and Astrid Hopfensitz. 2003. "The coevolution of individual behaviors and group level institutions." *Journal of Theoretical Biology*, 223:2, pp. 135-47.

Bowles, Samuel and Herbert Gintis. 2002. "The Inheritance of Inequality." *Journal of Economic Perspectives*, 16:3, pp. 3-30.

Brosnan, Sarah and Frans B. De Waal. 2003. "Monkeys reject unequal pay." *Nature*, 425:18, pp. 297-99.

Buss, L.W. 1987. *The evolution of individuality*. Princeton: Princeton University Press.

Crow, James F. and Motoo Kimura. 1970. *An Introduction to Population Genetic Theory*. New York: Harper & Row.

Darwin, Charles. 1873. *The Descent of Man*. New York: D. Appleton and Company.

Eibl-Eibesfeldt, Irenaus. 1982. "Warfare, Man's Indoctrinability and Group Selection." *Journal of Comparative Ethology*, 60:3, pp. 177- 98.

Esteban, Joan and Debraj Ray. 1994. "On the measurement of polarization." *Econometrica*, 62, pp. 819-52.

Falk, Armin, Ernst Fehr, and Urs Fischbacher. 2003. "On the Nature of Fair Behavior." *Economic Inquiry*, 41:1, pp. 20-26.

Fei, J., G. Ranis, and S. Kuo. 1979. *Growth with Equity: The Taiwan Case*. New York: Oxford University Press.

Fernandez, Raquel, Nezih Guner, and John Knowles. 2001. "Love and Money: A Theoretical and Empirical Analysis of Household Sorting and Inequality." *NBER Working Paper Series no. 8580*. National Bureau of Economic Research: Cambridge.

Frank, Steven A. 1995. "Mutual Policing and Repression of Competition in the Evolution of Cooperative Groups." *Nature*, 377, pp. 520-22.

Galton, Francis. 1889. *Natural Inheritance*. London: Macmillan.

Gardiner, C.W. 2004. *Handbook of Stochastic Methods: for Physics, Chemistry, and the Natural Sciences*. Berlin: Springer.

Haldane, J.B.S. 1932. *The Causes of Evolution*. New York: Harper and Brothers.

Hamilton, W. D. 1975. "Innate Social Aptitudes of Man: an Approach from Evolutionary Genetics," in *Biosocial Anthropology*. Robin Fox ed. New York: John Wiley and Sons, pp. 133-55.

Hauser, Robert M., John Robert Warren, Min-Hsiung Huang, and Wendy Y. Carter. 2000. "Occupational Status, Education, and Social Mobility in the Meritocracy," in *Meritocracy and Economic Inequality*. Kenneth Arrow and Samuel Bowles and Steven Durlauf ed: Princeton University Press, pp. 179-229.

Hawkes, Kristen. 2000. "Hunting and the Evolution of Egalitarian Societies: Lessons from the Hazda," in *Hierarchies in Action: Cui Bono?* M. W. Diehl ed: Southern Illinois University Center for Archaeological Investigations, Occasional Paper 27.

Henrich, Joe, Robert Boyd, Samuel Bowles, Ernst Fehr, and Gintis Gintis. 2004. *Foundations of Human Reciprocity: Economic Experiments and Ethnographic Evidence in 15 Small-scale Societies*. Oxford: Oxford University Press.

Herlihy, D. and C. Klapische-Zuber. 1985. *Tuscans and their Families*. New Haven: Yale University Press.

Hertz, Thomas. 2003. "Upward Bias in Estimated Returns to Education: Evidence from South Africa." *American Economic Review,* 93:4, pp. 1354-68.

Kaplan, Hillard and Michael Gurven. 2004. "The Natural History of Human Food Sharing and Cooperation: A Review and a New Multi-Individual Approach to the Negotiation of Norms," in *The Moral Sentiments: Origins, Evidence, and Consequences*. Herbert Gintis, Samuel Bowles, Robert Boyd and Ernst Fehr eds. forthcoming.

Kaplan, Hillard, Jane Lancaster, J. A. Block, and S. E. Johnson. 1995. "Fertility and fitness among Albuquerque men: A competitive labor market theory," in *Human Reproductive Decisions*. R. I. M. Dunbar ed. New York: St. Martin's press.

Kelly, Raymond C. 1993. *Constructing Inequality: The Fabrication of a Hierarchy of Virtue Among the Etoro*. Ann Arbor: University of Michigan Press.

Keswell, Malcolm. 2004. "Education and Racial Inequality in post-Apartheid South Africa." *Santa Fe Institute Working Paper*.

Kremer, Michael. 1997. "How Much Does Sorting Increase Inequality?" *The Quarterly Journal of Economics*, 112:1, pp. 115-39.

Mazumder, Bhashkar. 2004. "Sibling Similarities, Differences, and Economic Inequality." Federal Reserve Bank of Chicago.

Michod, Richard. 1996. "Cooperation and conflict in the evolution of individuality, 2. Conflict mediation." *Proceedings of the Royal Society of London, B*, 263, pp. 813-22.

Milanovic, Branko. 2005. *Worlds Apart: Global and International Inequality 1950-2000*. Princeton: Princeton University Press.

Naidu, Suresh and Samuel Bowles. 2004. "Institutional Innovation: Equilibrium selection with intentional idiosyncratic play." Santa Fe Institute.

Piketty, Thomas and Emmanuel Saez. 2003. "Income Inequality in the United States: 1913-1998." *Quarterly Journal of Economics*, 118:1-39.

Price, George R. 1972. "Extension of Covariance Selection Mathematics." *Annals of Human Genetics*, 35, pp. 485-90.

Ratnieks, Francis. 1988. "Reproductive Harmony via Mutual Policing by Workers in Eusocial Hymenoptera." *American Naturalist*, 132:2, pp. 217-36.

Ravallion, Martin and Shaohua Chen. 2004. "China's (Uneven) Progress Against Poverty." *Development Research Group, World Bank*.

Rosenberg, Noah A., Jonathan K. Pritchard, James L. Weber, Howard M. Cann, Kenneth K. Kidd, Lev A. Zhivotovsky, and Marcus W. Feldman. 2002. "Genetic structure of human populations." *Science*, 298, pp. 2381-85.

Rosenzweig, Mark and Hans P. Binswanger. 1993. "Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments." *Economic Journal*, 103:416, pp. 56-78.

Rosenzweig, Mark and Kenneth I. Wolpin. 1993. "Credit Market Constraints, Consumption Smoothing, and the Accumulation of Durable Production Assets in Low-Income

Countries: Investment in Bullocks in India." *Journal of Political Economy*, 101:2, pp. 223-44.

Smith, J. Maynard and Eors Szathmary. 1995. *The Major Transitions in Evolution*. Oxford: Oxford University Press.

Wiessner, Polly and Akii Tumu. 1998. *Historical Vines: Enga Networks of Exchange, Ritual, and Warfare in Papua New Guinea*. Washington: Smithsonian Institution Press.

Yitzhaki, Shlomo. 1987. "On The Relation Between Return and Income." *Quarterly Journal of Economics*, 102:1, pp. 77-95.