# Inequality in nature and society

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**Most societies are economically dominated by a small elite, and similarly, natural communities are typically dominated by a small fraction of the species. Here we reveal a strong similarity between patterns of inequality in nature and society, hinting at fundamental unifying mechanisms. We show that chance alone will drive 1% or less of the community to dominate 50% of all resources in situations where gains and losses are multiplicative, as in returns on assets or growth rates of populations. Key mechanisms that counteract such hyperdominance include natural enemies in nature and wealth-equalizing institutions in society. However, historical research of European developments over the past millennium suggests that such institutions become ineffective in times of societal upscaling. A corollary is that in a globalizing world, wealth will inevitably be appropriated by a very small fraction of the population unless effective wealth-equalizing institutions emerge at the global level.**

ecology | economy | wealth | abundance | inequality

Several societies have seen as little as 1% of their population own approximately 50% of the total wealth. This was the case in many Western countries around 1900, including Britain, France, and Sweden, and some claim that at present, roughly 1% of the population owns 50% of total wealth at the global level (1, 2). Similarly, in natural communities, a small fraction of the total species often makes up most of the biomass; for instance, a recent study of the Amazon rainforest revealed that roughly 1% of the tree species account for 50% of the total stored carbon (3). Although the correspondence between the dominance in society and this famously diverse ecosystem may be a coincidence, it raises the questions of whether there might be generic intrinsic tendencies to such inequality, and what could be the unifying mechanisms behind it.

We first turn to the question of the extent to which patterns in nature and society are actually similar. The natural communities that we analyze range from mushrooms, trees, intestinal bacteria, and algae to flies, rodents, and fish (*SI Appendix*, section 1). Our societal data consist of estimates for different countries (1, 4–7) (*SI Appendix*, section 1). We focus on wealth and not income distribution, which is much less unequal and—perhaps surprisingly—poorly correlated with wealth inequalities across countries (*SI Appendix*, section 2). While income concerns a flow, wealth concerns a stock, just as biomass in species.

As a first illustration of the similarities of patterns in nature and society, consider the wealth distribution of the world's richest individuals compared with the abundance distribution of the Amazon's most common trees (Fig. 1 *A* and *B*). The patterns are almost indistinguishable from one another. For a more systematic comparison, we also analyzed the Gini indices of a wide range of natural communities and societies (Fig. 1 *C* and *D*). The Gini index is an indicator of inequality that ranges from 0 for entirely equal distributions to 1 for the most unequal situation. It is a more integrative indicator of inequality than the fraction that represents 50%, but the two are closely related in practice (*SI Appendix*, section 3). Surprisingly, Gini indices for our natural communities are quite similar to the Gini indices for wealth distributions of 181 countries (data sources listed in *SI Appendix*, section 1).

In societies, inequality is also found for other units besides the wealth of single actors or households. For instance, power law-like distributions characterized by high inequality are found in statistics on city sizes, number of copies sold of bestseller books, number of adherents of religious bodies, and number of links to web sites (9). In addition, firm size typically varies widely, with a few companies dominating the market (10, 11). At first glance, firm size may seem comparable on an abstract level to the wealth of households. Indeed, firms may grow and shrink depending on vagaries of markets and other factors. However, there are also important differences. For instance, firms are relatively ephemeral entities that are linked through a global web of shareholders (12) and may be fused or split depending on shareholders' decisions and antitrust legislation. In this paper, we limit our discussion to the wealth of households for our comparison of nature and society.

The patterns that we describe (Fig. 1) raise the question of whether the similarities between nature and society are a coincidence or might hint at universal underlying processes. Viewed in detail, the complex interplay of mechanisms that govern wealth distribution in society is obviously very different from the processes regulating the abundance of species in nature. However, as we argue, on an abstract level, there are in fact comparable generic processes at play (Fig. 2).

## Drivers of Inequality

The most obvious cause of inequality is an inherent difference in competitive power of the actors (Fig. 2, I). Particular sets of traits give some species a competitive edge, just as in society some individuals have traits that set them up for entrepreneurial success. Furthermore, dominance can be self-reinforcing. In most societies, wealth can come with power to set the rules in ways that favor further wealth concentration (4, 13, 14). In

### Significance

**Inequality is one of the main drivers of social tension. We show striking similarities between patterns of inequality between species abundances in nature and wealth in society. We demonstrate that in the absence of equalizing forces, such large inequality will arise from chance alone. While natural enemies have an equalizing effect in nature, inequality in societies can be suppressed by wealth-equalizing institutions. However, over the past millennium, such institutions have been weakened during periods of societal upscaling. Our analysis suggests that due to the very same mathematical principle that rules natural communities (indeed, a "law of nature") extreme wealth inequality is inevitable in a globalizing world unless effective wealth-equalizing institutions are installed on a global scale.**

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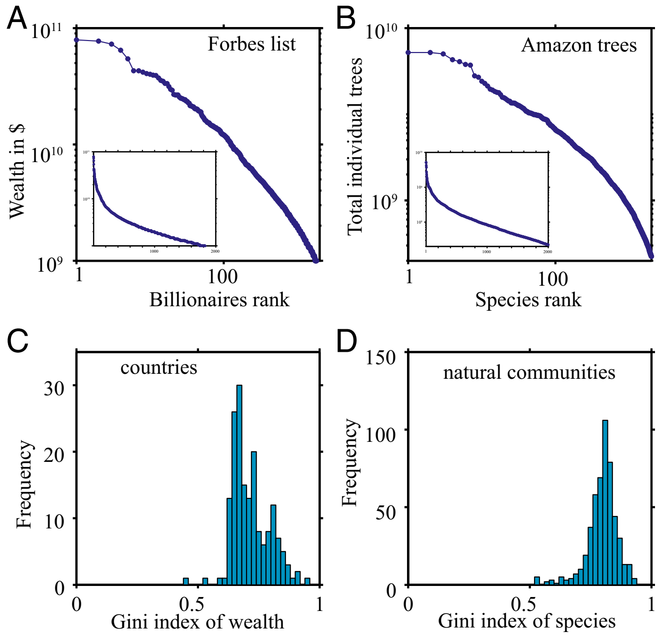


**Fig. 1.** Inequality in society (*Left*) and nature (*Right*). The *Upper* panels illustrate the similarity between the wealth distribution of the world's 1,800 billionaires (*A*) (8) and the abundance distribution among the most common trees in the Amazon forest (*B*) (3). The *Lower* panels illustrate inequality in nature and society more systematically, comparing the Gini index of wealth in countries (*C*) and the Gini index of abundance in a large set of natural communities (*D*). A complete list of data sources is provided in *SI Appendix*.

contrast, in nature, dominant species tend to have a disadvantage due to a disproportionally higher burden from natural enemies (15), as we discuss below. Some of the inequality in nature can be related to the fact that data represent abundance in terms of counts of individuals, which tend to be higher for smaller species; however, the sizes are not all that different within many of the analyzed communities (e.g., trees, rodents). In addition, our bacterial abundance is estimated from RNA, and the patterns are quite similar, suggesting that inequality is driven mostly by other factors.

Surprisingly, chance may be another particularly powerful driver of inequality. Even if no actor is intrinsically superior to others, inequality can emerge naturally if wealth (or abundance) is subject to random losses or gains (Fig. 2, II). This counterintuitive phenomenon is known from null models in ecology (16–18) as well as economics (2, 19). In society, gains and losses resulting from fluctuating financial stocks, business ownership, and other forms of wealth have a multiplicative character. In nature, the effects of fluctuating weather and natural enemies on birth and death rates have multiplicative effects on population sizes of all species. It is well known that multiplicative gains and losses tend to lead to lognormal distributions (18–20). The extent of the inequality in such a distribution (e.g., in terms of Gini index) depends on its SD. As we show below, for a finite world in which the gains of one actor imply losses of others, the effect of multiplicative random processes blows up to create extreme inequality.

Before getting to the fundamental explanation, we illustrate the phenomenon using two minimalistic null models. The first model describes the dynamics of the wealth of economic actors (e.g., households) depending a stochastic return on wealth (*SI Appendix*, section 4). The complement is an equally simple model of neutral ecological competition driven by stochastic growth rates (*SI Appendix*, section 5). We take the economic model as the central example. Starting with a perfectly equal distribution of wealth, inequality quickly rises until a few actors appropriate most of the wealth (Fig. 3 *A* and *B*) and the vast majority ends up with almost zero wealth. Very much the same pattern arises from the ecological model (*SI Appendix*, section 5). The extreme inequality may seem surprising, as no actor is intrinsically better than the others in these entirely chance-driven worlds. The explanation, mathematically, is that due to the multiplicity (gains and losses are multiplied by the actual wealth), absolute rates of the change tend to nil as wealth goes to zero (19). This causes very low wealth to be a "sticky" state, in the sense that getting out of it is extremely slow. The fundamental effect of this mechanism can be seen most easily from a two-actor version of the model, where despite the absence of intrinsic differences in competitive power, one of the actors entirely dominates at any given time (*SI Appendix*, section 6).

The stickiness of the close-to-zero state does not imply irreversibility. On rare occasions, there are shifts in dominance, illustrating that indeed, this kind of dominance results from chance rather that intrinsic superiority. For increasing numbers of actors, the result remains the same, but as the dominant position is always taken by a small minority or a single actor, the remaining small portion of wealth is shared by increasing numbers. The essential result is that intermediate wealth (the middle class) is intrinsically unstable. It repels any actors toward either the rich or (more likely) the low-wealth state. Those are "quasi-attractors" that occur only in the stochastically forced version of the otherwise entirely neutral model.

Although we are not aware of previous studies revealing the fundamental instability of intermediate wealth (or abundance) in stochastic neutral models, there is a long history of modeling chance-driven inequality (2, 16–19). Most of those studies build on multiplicative chance effects, but there is also a somewhat separate line of work inspired by the parallel between molecules in a gas-exchanging momentum and monetary exchange between actors in society (21, 22). Gases tend toward a state of maximum entropy in which the energy of molecules follows an exponential distribution. On closer look, inequality actually is not very great in such situations (*SI Appendix*, section 7). This makes intuitive sense, as the exchange of momentum among molecules can have an equalizing component. If one modifies the rules to capture the nature of economic transactions more realistically (e.g., assuming that transfer is never more than the capital of the poorest of the two in any direction), then the predictions of such physics-inspired models (22) do come very close to the multiplicative dynamics that we described and can indeed produce great inequality (23) (*SI Appendix*, section 7). In addition, relatively elaborate and realistic agent-based models of artificial societies predict the inevitable emergence of great inequality (24).

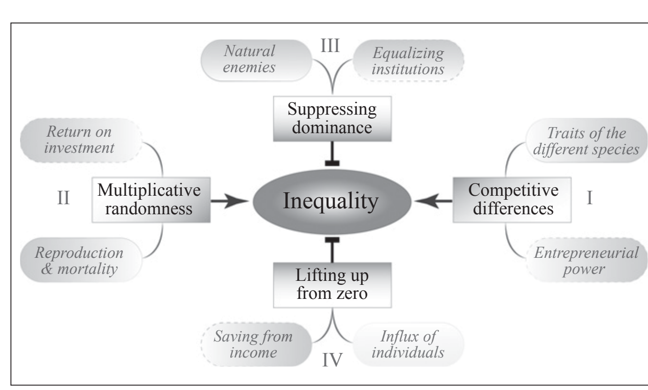


**Fig. 2.** Four unifying mechanisms that shape inequality and their specific drivers in nature (solid lines) and society (text boxes with dashed borders).

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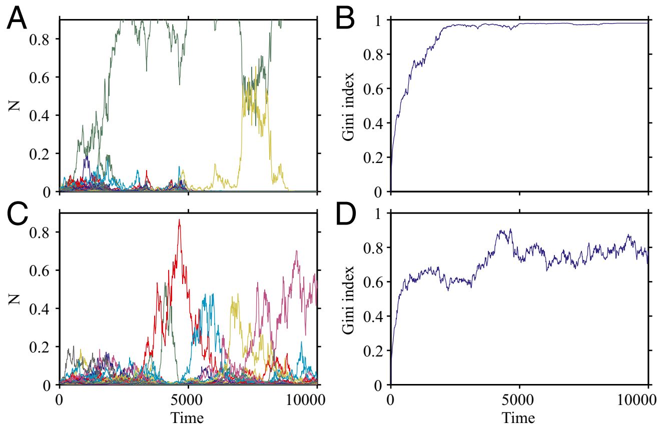


**Fig. 3.** Examples showing how simulations of wealth of actors (*Left*) starting from an entirely equal situation quickly lead to inequality (*Right*) emerging solely from multiplicative gains and losses of otherwise equivalent competitors. The simulations shown in *A* and *B* are without savings, while those in *C* and *D* represent simulations with savings, illustrating that such an additive process reduces the tendency for hyperdominance generated by the multiplicative gains and losses. The results are generated by a minimal model of wealth (*SI Appendix*, section 4). Similar results can be obtained from a model of neutrally competing species in a natural community (*SI Appendix*, section 5).

The bottom line when it comes to the drivers of inequality is that, all else being equal, great inequality tends to emerge from chance alone. This is quite counterintuitive. Imagine a simple classroom game (*SI Appendix*, section 7) in which each participant gets $100 to start. During each round, a dice roll determines random fractional gains or losses for each participant. The total classroom sum is kept constant in each step through a correction tax (a fixed percentage of each player's wealth). How unequal would the long-run outcome be expected to be? The surprising answer is that one of the players will typically hold almost all of the money—not because that player is superior, but just by chance. As we show, such inequality arises robustly from a wide range of models, including situations in which economies can grow or suffer occasional destructions (*SI Appendix*, section 9).

## Equalizing Mechanisms

There are essentially two classes of mechanisms that can reduce inequality: suppression of dominance (Fig. 2, III) or lifting the majority out of the sticky state close to zero (Fig. 2, IV). Starting with the latter, a small additive influx is a powerful antidote to the stickiness effect. In nature, local populations typically receive a trickle of immigration that contributes to population size in such an additive way (25). In society, savings from income represent an additive contribution to wealth. Adding such a flux to our minimal model of wealth allows more households to gain wealth, thus populating the middle class and regularly breaking episodes of dominance by the previously dominant households (Fig. 3 *D* and *E* and *SI Appendix*, section 8). Very much the same effect is seen in the ecological model if populations receive a small additive influx of individuals from neighboring populations (*SI Appendix*, section 5). The effect of an additive process is consistent with what we know from ecosystems and societies. In ecology, the "rescue effect" of immigration preventing population extinction is well documented (26, 27). In societies, saving is plausibly a way out of poverty (28); however, both historical and contemporary rates of savings are often close to zero for most households. This is either a result of consumption using up all income (because of low income or high consumptive wants) or the lack of need to save (because of the presence of alternative systems to cover future needs or buffer shocks, including kinship and welfare systems). Thus, while true poverty traps will contribute to wealth inequality, many households do not accumulate wealth in the developed world either (29). Therefore, the observed wealth concentration in most societies is consistent with predictions of inequality driven by return on assets in the absence of an additive saving process.

Perhaps a more intuitive antidote to inequality is repression of dominance (Fig. 2, III). In nature, this is an omnipresent phenomenon. The most abundant species tend to suffer proportionally more from natural enemies, including diseases, a mechanism that reduces dominance and allows a larger number of species to share resources (15). In the literature on microbial systems, this is known as the "kill the winner" principle (30). In societies, there is no comparable natural mechanism to constrain dominance. Occasional disasters, such as major wars, may have an equalizing effect by destroying capital or inducing redistribution, but in the long run inequality generally returns to the previous level (31). Economic growth also has been suggested to dampen inequality (2, 6, 29). However, analysis of our minimal model suggests that neither the occasional destruction of capital (in contrast to ref. 31) nor economic growth (in contrast to ref. 2) should be expected to markedly reduce inequality in the theoretical context of chance-driven dynamics (*SI Appendix*, section 9). On the other hand, societies do install institutions that may either sustain wealth inequality or reduce it and that have long-lasting (or quasi-permanent) effects on levels of wealth inequality. Power associated with wealth tends to facilitate further enrichment through the installation of wealth-protecting institutions, such as absolute property rights and the right to inherit (4, 13, 31). In contrast, societies may also install institutions that dampen inequality, such as taxation schemes (4, 29) (*SI Appendix*, section 8).

## Long-Run Instability of Equalizing Mechanisms

Although the four forces that we have highlighted (Fig. 2) may shape much of the observed patterns of inequality, determining their relative importance is not easy. Occasionally, however, perturbations of the balance provide valuable clues. In nature, the importance of repression of dominance (Fig. 2, III) is vividly illustrated by the occasional spectacular population explosion of newly invading species, explained by the release from the natural enemies they left behind: the so-called "parasites lost" phenomenon (32). The balance is typically restored over the subsequent decades as natural enemies catch up with the newcomers.

In societies, control of wealth inequality is also notoriously unstable over time. The drop and rebound in inequality over the last century has received much attention (2, 6, 29), but a careful analysis of historical sources reveals several waves of rising and falling inequality in history (4, 7, 33). Some of those cycles look surprisingly regular (33), suggesting that they might be governed by universal basic forces. Indeed, inequality and conflict are common elements across historical analyses, even though precise mechanisms of their interaction differ among cases (7, 31, 33).

It is becoming increasingly clear that institutions can play a dominant and long-lasting role in shaping societal prosperity and inequality (34). Indeed, on closer look, several historical cycles of inequality may be explained, at least in part, by the emergence of equalizing institutions followed by periods during which various mechanisms undermined the effectiveness of these institutions (4). An often-overlooked mechanism that may undermine the power of wealth-equalizing institutions is societal upscaling. Focusing on Western Europe, we can see how in the Middle Ages, and especially in the 12th to 14th centuries, local communities reduced inequality by limiting opportunities for transacting and accumulating land and capital, and developing mechanisms of redistribution, through guild or community systems, operating at the local level, where most of the exchange and allocation of land and capital took place (4). However, these town and village communities saw their institutional frameworks eroded by the growth of international trade, migration, and interregional labor and capital markets, as well as by the process of state formation with the rise of more centralized bureaucracies in the (early) modern period, triggering a long episode of rising inequality (5, 7, 35). In the late 19th century and early 20th century, institutions aimed at effectively constraining wealth accumulation were developed at the level of the nation state, with the emergence of tax-funded welfare states. Perhaps the most conspicuous of these institutions is the introduction of the inheritance tax, which limits wealth transfer to the next generation (2). Over the past decades, however, globalization has given way to a more unconstrained use and accumulation of wealth (29). The financial playing field for the wealthiest is now global, and mobility of wealth has greatly increased, providing immunity to national taxation and other institutional obstacles to wealth accumulation.

## Prospects

Our analysis suggests that even if all actors are equivalent, in the absence of counteracting forces, there is an intrinsic tendency for significant inequality to arise from multiplicative chance effects. Although the surprising similarity between inequality of species abundances and wealth may have the same roots on an abstract level, this does not imply that wealth inequality is "natural." Indeed, in nature, the amount of resources held by individuals (e.g., territory size) is typically quite equal within a species. While wealth inequality may have emerged as far back as the Neolithic era (31, 36), the relative amount of wealth appropriated by the richest has increased as societies have scaled up. One explanation for this effect is scale itself. Put simply, one can accumulate less wealth in a village than across the globe. However, as we have argued, another explanation is that installing effective institutions to dampen inequality becomes more challenging as scale increases. Excessive concentration of wealth is widely thought to hamper economic growth, concentrate power in the hands of a small elite, and increase the chance of social unrest and political instability (1, 2, 4, 37–39). This raises questions about the prospects for current societies. Phases of upscaling of governance successfully curbed unconstrained growth of inequality first in the communities of late medieval Europe and later in the nation states of the 20th century, but in both cases, this was a lengthy and painful process. Whether scaling up of effective governance can now be done at the global level and, if so, what this new form of governance might look like, remains unclear.

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