WORKING PAPERS ON
CAPITAL AS POWER

No. 2020/01

Economic Development and the Death of the Free Market

Blair Fix

May 2020

http://www.capitalaspower.com/?p=3905

Economic Development and the Death of the Free Market

Blair Fix

May 23, 2020

Abstract

Free markets are, according to neoclassical economic theory, the most efficient way of organizing human activity. The claim is that individuals can benefit society by acting only in their self interest. In contrast, the evolutionary theory of multilevel selection proposes that groups must *suppress* the self interest of individuals. They often do so, the evidence suggests, by using hierarchical organization. To test these conflicting theories, I investigate how the 'degree of hierarchy' in societies changes with industrial development. I find that as energy use increases, governments tend to get larger and the relative number of managers tends to grow. Using a numerical model, I infer from this evidence that societies tend to become more hierarchical as energy use grows. This result is inconsistent with the neoclassical theory that individual self-interest is what benefits society. But it is consistent with the theory of multilevel selection, in which groups suppress the self-interest of their members.

Keywords: hierarchy; free market; economic development; sociality; cultural evolution; multilevel selection; energy

1 Free-market theory in an evolutionary context

There is perhaps nothing more central to mainstream economics than the belief in free markets. The idea is seductively simple. Guided only by self-interest, individuals can act through the market to benefit the whole of society. This notion of the 'invisible hand' [1] has become foundational to neoclassical economics. The theory proposes that in a perfectly competitive market, the autonomous actions of selfish individuals will lead to an outcome that is 'Pareto optimum' [2]. In this situation, no person can be made better off without making at least one person worse off.

This theory of free markets is not without critics. Heterodox political economists have pointed out many flaws in neoclassical theory, mostly related to its unrealistic assumptions [3–13]. My goal here, however, is not to revisit this debate, but instead to broaden it. The theory of free markets is, at its core, a theory of how human groups can organize. It postulates that groups can organize effectively using decentralized competition, and that the selfish actions of individuals can benefit the group. The problem with this theory is that it contradicts, in almost every detail, the modern evolutionary understanding of how social organisms function.

According to the theory of multilevel selection, social organisms face a fundamental dilemma. Actions that are best for the group rarely maximize relative fitness within the group [14–18]. This creates a tension between the self-interest of individuals and the interest of the group. To resolve this tension, social organisms find ways to suppress the self-interest of individuals. How they do so is an open-ended question. But the history of social evolution reveals a common trend. As groups become larger and more complex, they tend to become more hierarchical (Sec. 2).

In this evolutionary context, the theory of free markets is an outlier. It posits that, contrary to what is observed across other social organisms, humans need not suppress self-interest to organize in large groups. And we need not use hierarchical organization. We can build complex societies, the theory claims, using decentralized competition.

My goal here is to test this claim. I look for evidence that human societies remain decentralized (or perhaps become more decentralized) as they industrialize. I find little evidence that this is true. Instead, the evidence suggests that to industrialize, human societies turn to hierarchical organization. I find that as energy use increases, governments tend to get larger and the relative number of managers grows (Sec. 3). Using a model, I infer from this data that the 'degree of hierarchy' in human societies tends to increase with energy use (Sec 4 and 5).

This evidence suggests that human societies do not use atomistic competition to develop. In this regard, free-market theory appears to be incorrect. Paradoxically, however, I find that at the same time that hierarchy seems to have grown, free-market theory became increasingly popular. Looking at the United States, I find that as my measures of hierarchy increased, so did the word frequency of free-market jargon (Sec. 6). To make sense of this paradox, I speculate that free-market theory may actually aid the growth of hierarchy. It does so, I propose, by serving as a belief system that legitimizes superior-subordinate relations.

To summarize, the available evidence suggests that as human societies industrialize, they turn increasingly to hierarchical organization. This is consistent with the theory of multilevel selection, but inconsistent with the neoclassical theory of free markets.

2 Hierarchy

My entry point to studying free markets is to look at their opposite — namely *hierarchy*. Whereas free markets are about autonomy, hierarchy is about the loss of autonomy and the centralization of control. While I am ultimately interested in hierarchy in human societies, I will begin by discussing hierarchy in the broader context of life on earth.

Hierarchical structure is ubiquitous in the natural world — so much so that the social scientist Herbert Simon proposed that hierarchy is the 'architecture' of complexity' [19]. The idea is that complex systems are built by merging simpler components, creating a hierarchy of subsystems. Along with this hierarchy of structure, Simon argued, comes a hierarchy of control. Complex biological systems are generally not composed of autonomous subcomponents. Instead, as complexity grows, subcomponents surrender autonomy to a centralized system of command and control.

The evolution of life on Earth supports this idea that hierarchy is the 'architecture' of complexity. Through a series of 'major evolutionary transitions', life has grown more complex [20]. Although different in form, each transition appears to obey the same principle: more complex structure grows from the merger of simpler sub-units.

Life began, we presume, when organic molecules assembled into larger entities. The basic structure that emerged — and remains to this day — is that of the cell. In the next major transition, eukaryotic cells evolved (we believe) from the merger of two prokaryotic cells — a bacterium and an archaeon [21–24]. The bacterium became the mitochondria of modern eukaryotes, while the archaeon became the cytoplasm and nucleus. In the next transition, eukaryotic cells evolved into multicellular organisms — a symbiosis that seems to have happened multiple times [25]. In the last major transition, solitary organisms evolved into 'eusocial' species that cooperate in large groups [26–28]. With their large colonies and intricate caste structure, the social instincts (ants, bees, termites) are the most conspicuous example of this eusociality. Modern humans, some scientists believe, may be the latest addition to the eusocial club [29–32].

Looking at these major transitions, we see that they obey the two principles of hierarchy. First, more complex structure is built from simpler components. Second, the growth of complexity seems to involve the centralization of control. Let us begin with the nesting aspect of hierarchy, which we see everywhere in life. Eukaryotic cells, for instance, are built from simpler organelles (i.e. the nucleus and mitochondraia). Multicellular organisms, in turn, are built from simpler cells. And eusocial colonies are built from individual organisms. Each new layer of complexity, it seems, is assembled by merging simpler components.

This nested hierarchy, Herbert Simon proposes, occurs through a process of evolutionary problem solving [19]. Structures evolve that solve specific problems. The cell, for instance, solves the problem of separating 'living' matter from 'non-living' matter. Once this problem is solved, the newly created structure serves as the building block to solve new problems. Eukaryotic cells, for instance, built on the structure of prokaryotes to solve a new problem — one of energetics. When bacterium evolved into eukaryotic mitochondria, they shed most of their DNA, freeing up more energy for protein synthesis [33, 34]. This free energy, in turn, may be what allowed eukaryotes to grow more complex than their prokaryotic counterparts [35, 36].

In addition to hierarchy in the 'nesting' sense, the evolution of life also follows the principle of hierarchy in the sense of centralized control. Large, complex organisms are not composed of autonomous units. Instead, the growth of complexity seems to involve the gradual loss of autonomy among sub-units, and the growth of centralized control. The eukaryotic cell, for instance, is not composed of autonomous organelles. Instead, sub-units are governed by a 'command and control center' — the nucleus [37]. Similarly, multicellular animals have evolved centralized control in the form of the nervous system [38]. Eusocial insects have elaborate caste systems in which most individuals surrender their reproductive capacity to a single queen [39, 40]. Humans (who are possibly the latest eusocial species) also organize using hierarchy. Evidence suggests that as societies become more populous, they add new layers of administrative hierarchy [41, 42].

The use of centralized control may arise for two (related) reasons. First, assembling a larger system from many smaller components requires coordination. Although decentralized coordination may be possible, it seems that coordination within and among living things usually involves at least some degree of centralization. Related to this problem of coordination is the suppression of self-interest. Major transitions in evolution have all involved the merger of previously autonomous units. According to the theory of multilevel selection, this merger is not possible unless the self-interest of sub-units is suppressed [43–45].

Multilevel selection theory proposes that there is almost always a conflict between the interests of the group versus the interests of individuals *within* the group [14–18]. For the group's sake, it is best if individuals act altruistically. (Note that altruism is defined in terms of action — sacrificing fitness for the benefit of the group — not in terms of intent [14, 46].) But for individuals within the group, acting selfishly is advantageous. David Sloan Wilson and E.O. Wilson summarize this tension in the following dictum: "Selfishness beats altruism within groups. Altruistic groups beat selfish groups. Everything else is commentary." [17]. For groups to succeed, multilevel selection theory proposes that they must suppress the selfishness of their sub-components — whether these are molecules, organelles, cells or individuals.

Hierarchy may be a general solution to this problem of suppressing selfishness. By surrendering autonomy to a system of centralized control, the components of a hierarchical system are no longer free to pursue their own self-interest. Instead, they must do what they are 'told'. In some groups, this control is nearly absolute. In multicellular animals, for instance, muscle cells are almost completely under the control of the central nervous system. In other groups, such as the social insects, control is not nearly so centralized. In general, the degree of centralized control seems to relate to the cohesiveness of the group. Groups that are highly cohesive (like multicellular organisms) have a high degree of centralization. Groups that are less cohesive (like social animals) have less centralization. So if we were to posit a general rule, it would be this: the more cohesive the group, the more hierarchical it is.

2.1 A clash of theories

The major transitions in evolution suggest that hierarchy is an important tool for organizing complex groups. Interpreted using multilevel selection theory, hierarchy is a tool for suppressing the self-interest of group members. If the principles of multilevel selection are correct, then a similar trend should hold among humans. As societies become more complex, they should become more hierarchical.

This prediction stands in marked contrast to the one made by neoclassical economic theory. According to neoclassical theory, humans can organize effectively without any form of centralized control. All that is needed is a decentralized market. To arrive at this conclusion, neoclassical theory turns the postulates of multilevel selection theory on their head. Multilevel selection theory proposes that successful groups must *suppress* the self-interest of individuals. Mainstream economic theory, in contrast, argues that groups can organize by *stoking* self-interest. If each person acts in their own self-interest, the thinking goes, they will be led 'as if by an invisible hand' to benefit the whole society.

First proposed by Adam Smith [1], this appeal to decentralized organization is now a central tenet of mainstream economics. It is called the 'first fundamental theorem of welfare economics'. This theorem states that under conditions of perfect competition (meaning all firms are 'price takers'), markets will allocate resources in a way that is 'Pareto efficient' [2]. This means it is impossible to make any individual better off without making at least one individual worse off.

There is a fundamental clash, then, between the theory of multilevel selection and the economic theory of free markets. Multilevel selection theory proposes that successful groups must suppress the self-interest of individuals, and often use hierarchy to do it. In contrast, neoclassical theory proposes that successful groups must stoke individual self-interest using decentralized organization. If neoclassical economic theory is correct, then hierarchy should play no role in economic development. But if multilevel selection theory is correct — and humans follow the same pattern seen across other species — then human societies will become more hierarchical as they grow more complex.

3 Evidence for the growth of hierarchy

To shed light on the debate between economic and evolutionary theory, I attempt to measure the growth (or lack thereof) of hierarchy with economic development.

To measure economic development, I use energy use per person. I choose not to use the more common measure of development — real GDP — for two reasons. First, there are many 'aggregation problems' inherent in the calculation of real GDP [47, 48]. These problems occur largely (but not exclusively) because real GDP is based on the unit of prices, which are unstable. This instability introduces ambiguity in the value of real GDP. Second, I use energy rather than real GDP because the latter has no corollary in natural systems. Energy, in contrast, is a 'universal currency' in the natural sciences [49]. The flow of energy is what makes physical systems depart from equilibrium [50]. It is what makes life possible [51, 52]. The flow of energy (per unit of mass) may even be an indicator of complexity [53]. For these reasons, I use the flow of energy as a measure of economic scale, and possibly of economic complexity.

To measure social hierarchy, I use an indirect approach. I choose measures that are conceivably (but not directly) related to hierarchy. I then use a model to infer from these measures the growth of hierarchy. I use this indirect approach because the direct data on organizational hierarchy is too sparse to draw conclusions about historical and geographic trends. To date, only a handful of studies exist that quantify hierarchy within business firms. (For case studies, see [54–60]. For aggregate studies, see [61–69].) While useful for studying hierarchy at a point in time [70, 71], these studies are too sparse to infer general trends. For this reason, I study trends in hierarchy indirectly. To infer the extent of social hierarchy, I use two proxies: (1) the relative size of government; and (2) the relative number of managers. I will first discuss the trends in these proxies, and then show (in Sec. 4 and 5) how these trends relate to hierarchy.

Figures 1–4 show how the size of government and the management share of employment vary with energy use per person. Each figure plots international data ranging over roughly the last 3 decades. Lines indicate the path through time of individual countries. Select countries are labeled with three-digit codes. (See iban.com/country-codes for code definitions.) For data sources and methods, see Section 8.

I will begin by looking at how government size changes with energy use. I measure government size in terms of its share of total employment. I define 'government' as the entire public sector, including state-owned firms. Figure 1 shows the international trend between government size and energy use. As energy use per capita increases, governments tend to get larger.

Energy use is not, however, the only factor that affects government size. Politics are also important. To investigate the role of politics, Figure 2 replots the data shown in Figure 1. This time, however, I differentiate

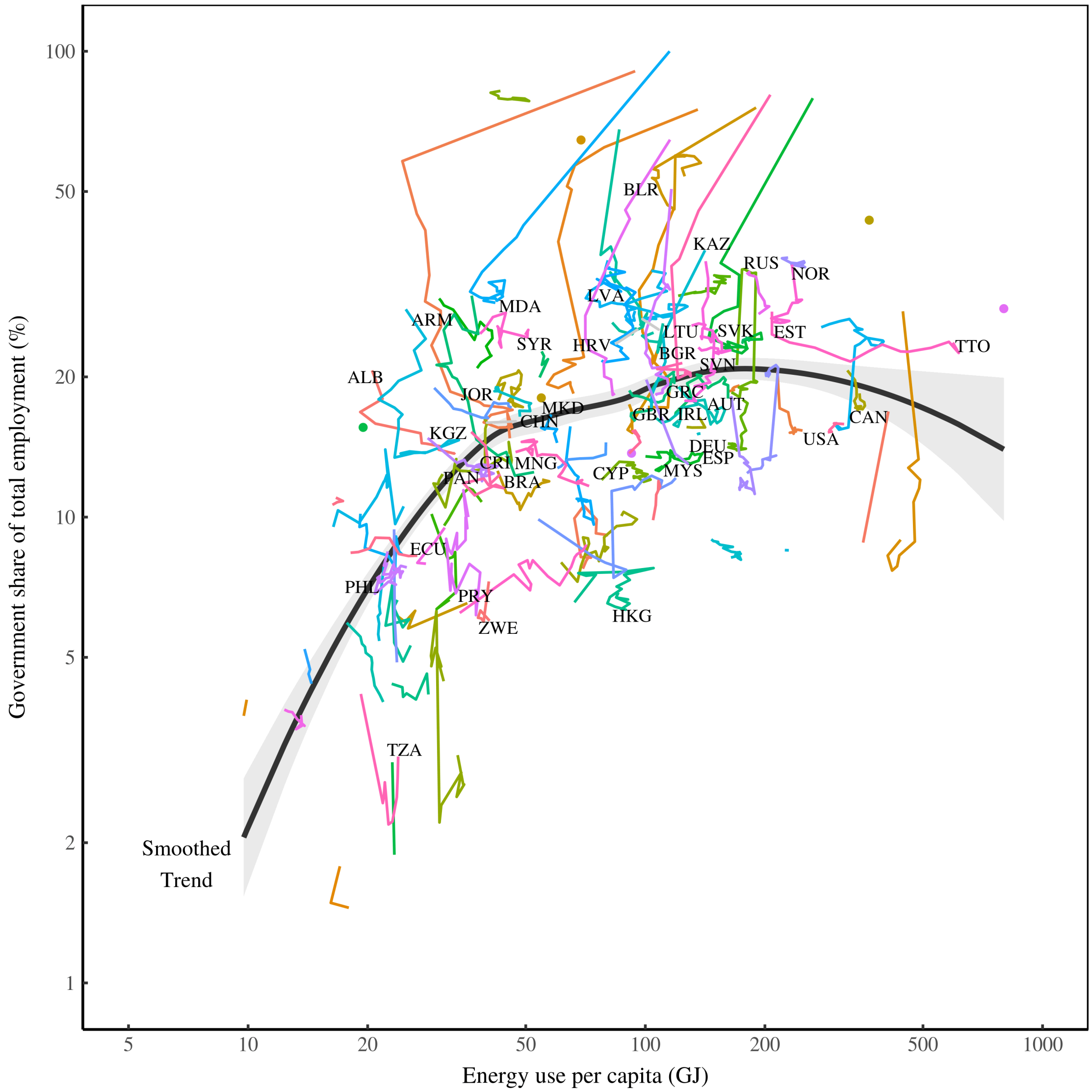

Figure 1: Government's share of employment vs. energy use per capita

This figure plots international data relating the government share of employment to energy use per capita. Lines represent the path through time of individual countries. Points represent countries with a single observation. Select countries are labeled with alpha-3 codes. For data sources, see Section 8.

between two types of countries: (1) those that have (or once had) communist governments; and (2) countries that have never had a communist government. It is easy to see the difference between the two types of countries. Those that have had communist regimes tend to have larger governments than those that have not.

On a historical note, the data in Figure 2 captures the collapse of the Soviet Union in action. The data begins in 1990, just when the Soviet Union disbanded. Former Soviet states like the Ukraine, Estonia, Moldova and Armenia begin (in 1990) with almost 100% government employment — a relic of their communist history. But over the next decade, governments in these countries shrank drastically, collapsing to levels similar to their non-communist counterparts. With this government collapse came a decline in energy use.

Given the intense battle, in the 20th century, between capitalism and communism, it is unsurprising that politics affect the size of government. What is surprising, however, is that regardless of politics, governments tend to get larger as energy use increases. The inset panel in Figure 2 shows this trend. Here I smooth the raw data (within each type of country) using a local polynomial regression. The results are interesting. In both communist and non-communist countries, governments tend to grow larger with energy use. Note that the trend is non-linear. Government grows rapidly with initial development before eventually plateauing. I discuss the significance of this non-linear trend in Sections 4 and 5.

Larger government is not the only organizational change that comes with greater energy use. The relative number of managers seems to increase as well. Figure 3 shows the international trend. Here I measure the number of managers as a share of total employment, plotting this share against energy use per capita. As with the size of government, the relative number of managers grows with energy use. And it does so non-linearly. The size of the management class grows rapidly during initial stages of

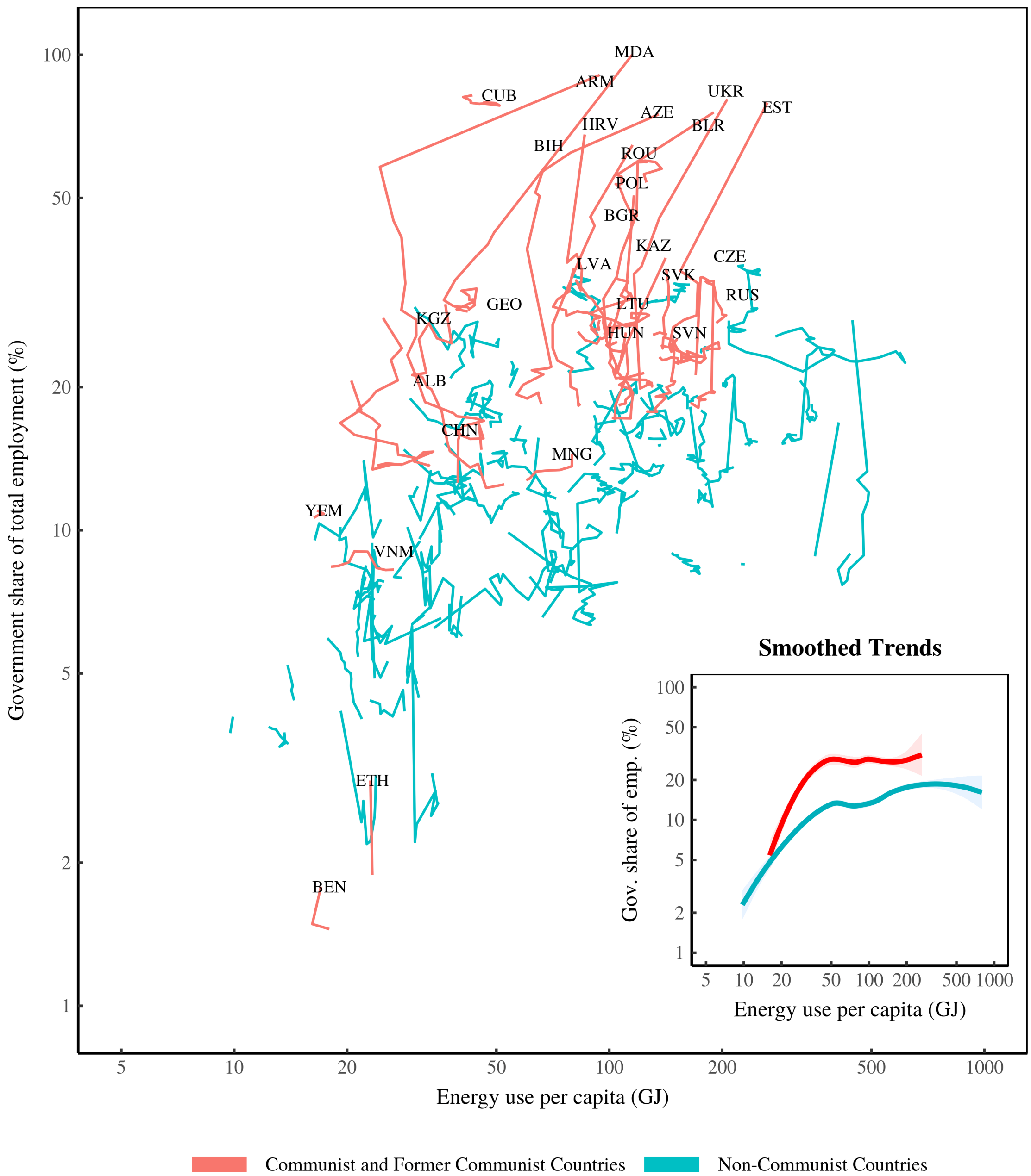

Figure 2: Government's share of employment vs. energy use per capita by political spectrum

This figure reproduces the data in Fig. 1, but distinguishes between communist and non-communist countries. 'Communist countries' are those that have (or have once had) a communist regime. Lines represent the path through time of individual countries. Communist countries are labeled with alpha-3 codes. The inset panel shows the smoothed trends, calculated with a local polynomial regression. For data sources, see Section 8.

development, before eventually plateauing.

Unlike government size, however, the management share of employment appears to be unrelated to politics. To show this non-relation, Figure 4 replots the data from Figure 3, but this time differentiates between political regimes. Unlike with government size, communist/non-communist politics appear not to affect the number of managers. The inset panel in Figure 4 emphasizes this non-distinction. Here I show the smoothed trend within each type of country, calculated using a local polynomial regression. The trend within communist (and formerly communist) countries is virtually identical to the trend within non-communist countries.

What is clear from this evidence is that governments, as well as the management class, tend to grow as energy use increases. What does this tell us about the growth (or lack thereof) of hierarchy. It hints, I argue, that hierarchy increases with economic development. Governments are hierarchical institutions whose purpose is, in large part, to command and control. And the job of managers is to coordinate the activities of other people. This is an act not of autonomy, but of centralized control. So in an intuitive sense, the evidence suggests that hierarchy grows with energy use. To make this intuition more rigorous, I will show that a simple model of hierarchy predicts the trends in government and management-class size.

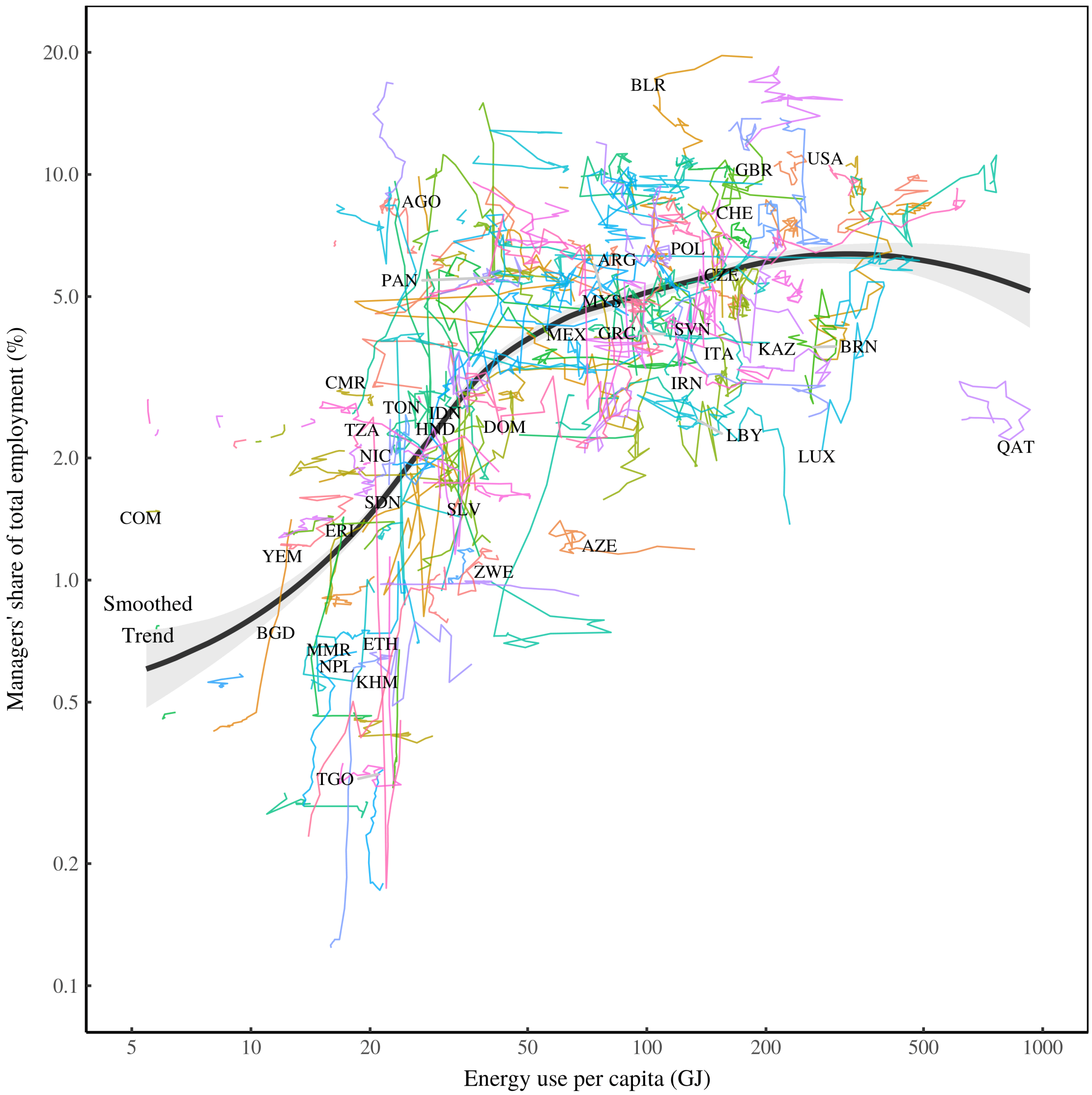

Figure 3: Managers' share of employment vs. energy use per capita

This figure plots international data relating the managers' share of total employment to energy use per capita. Lines represent the path through time of individual countries. Select countries are labeled with alpha-3 codes. For data sources, see Section 8.

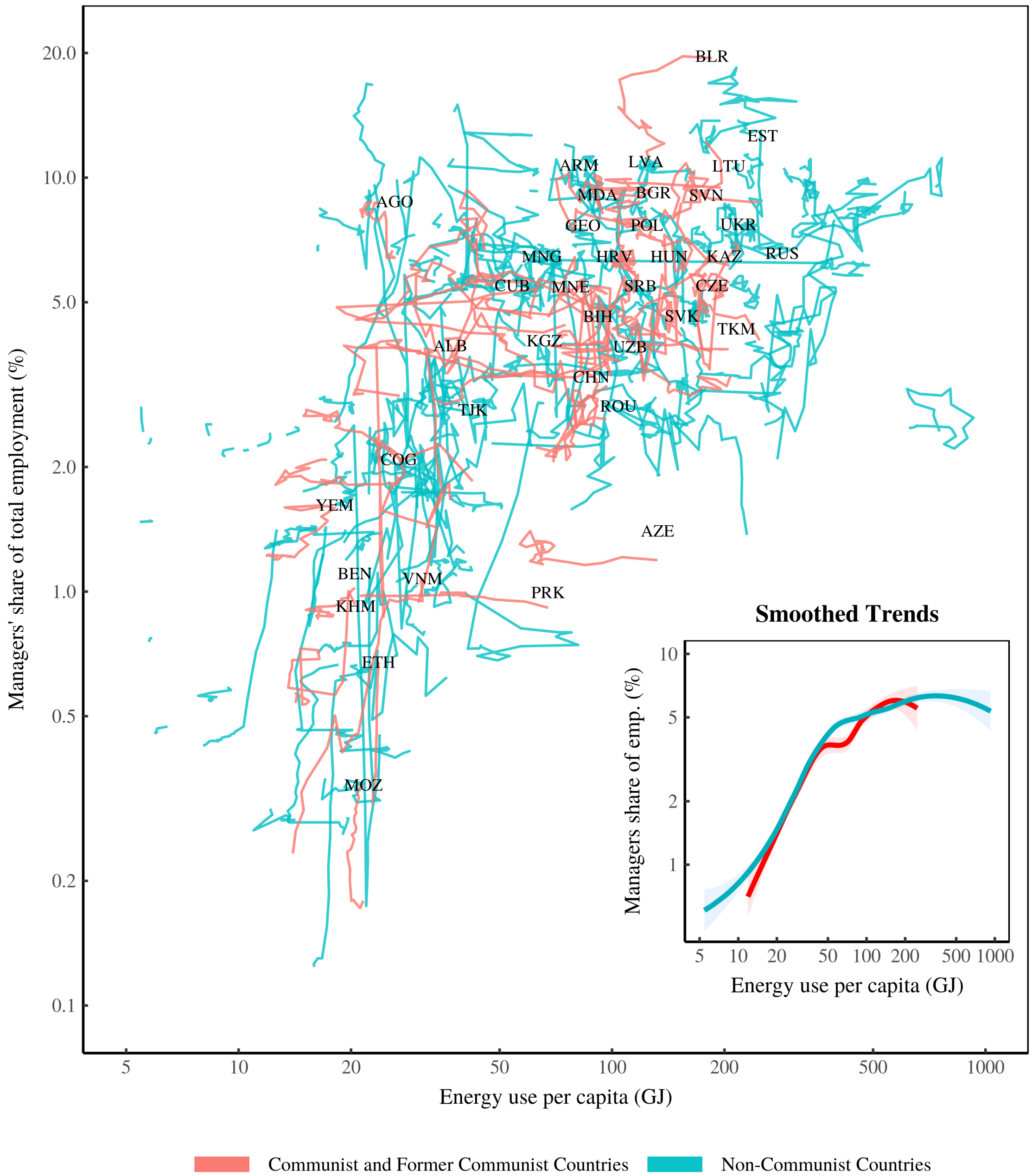

Figure 4: Managers' share of employment vs. energy use per capita by political spectrum

This figure reproduces the data in Fig. 3, but distinguishes between communist and non-communist countries. 'Communist countries' are those that have (or have once had) a communist regime. Lines represent the path through time of individual countries. Communist countries are labeled with alpha-3 codes. The inset panel shows the smoothed trends, calculated with a local polynomial regression. For data sources, see Section 8.

4 A model of energy and hierarchy

To interpret the trends in government size and management employment, I develop a model of how hierarchical organization changes with energy use. The model is based on the observation that as energy use increases, institutions tend to become larger [72]. Figure 5 shows this trend for business firms, plotting average firm size by country against energy use per person.

As energy use increases, the average firm size tends to grow. But rather than being caused by all firms growing slightly larger, the growth of average firm size is caused by large firms grow larger still. As energy use increases, the tail of the size distribution of firms gets *fatter*. The inset panel in Figure 5 shows this trend. Here I group countries of the world by energy-use quartile, and then plot (on a log-log scale) the aggregate size distribution of firms within each quartile. As energy use increases, the slope of the distribution grows shallower, indicating a fatter tail.

This change is relatively simple to model. As an approximation, the size distribution of firms follows a power law [73, 74]. This means that the probability of finding a firm with N members is roughly:

$$p(N) \propto \frac{1}{N^{\alpha}} \tag{1}$$

This power-law behavior is evident in the inset panel in Figure 5. When plotted on a log-log scale, the size distribution of firms appears roughly as a straight line — a characteristic feature of power laws [75,76]. As energy use increases, the power-law exponent (α) decreases. Table 1 summarizes this trend.

As a first approximation, it seems we can use a single parameter — the power-law exponent α — to model how institution size changes with energy use. Here I model the size distribution of institutions with a dis-

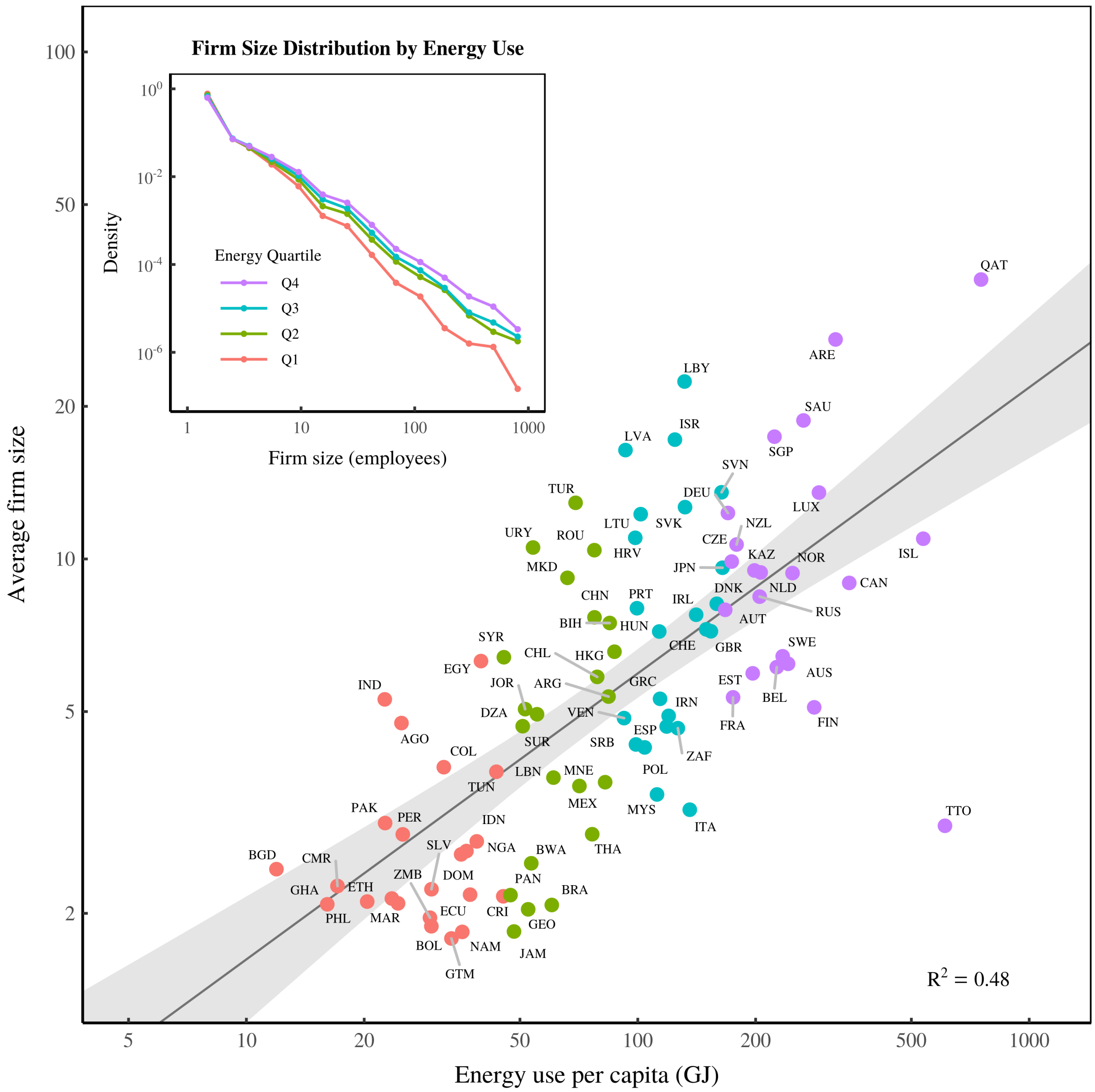

Figure 5: How firm size changes with energy use

This figure compares the average size of firms (within countries) to energy use per capita. Countries are labeled with alpha-3 codes. Color indicates the energy quartile of each country (its rank, by energy use, in a four-class quantile). The black line shows a log-log regression, with the associated 95% confidence interval. The inset panel shows the associated firm-size distributions. Within each energy quartile, I plot (on a log-log scale) the aggregate size distribution of firms (i.e. the size distribution across all countries in the quartile). For sources and methods, see Section 8.

Table 1: Firm-size statistics by energy-use quartile

Energy quartile	Average energy use per capita (GJ)	Average firm size	Power-law exponent of firm size distribution
Q1	27.9	2.6	2.09
Q2	63.8	4.7	1.94
Q3	121.8	7.5	1.85
Q4	257.4	9.5	1.74

Notes: Statistics are for groups of countries ranked by energy-use quartile (see Fig. 5). Average energy use is calculated as the unweighted mean of per capita energy use within each energy quartile. Firm-size statistics are calculated on the aggregate firm size distribution within each energy quartile. For sources and methods, see Section 8.

crete power law. To simulate changing energy use, I allow the exponent α to vary between model iterations. In each iteration, I model energy use per capita (E_{pc}) as a function of average firm size $\overline{N}$:

$$E_{pc} = a \cdot \left(\overline{N}\right)^b \tag{2}$$

I determine the parameters a and b by regressing Eq. 2 onto the international data shown in Figure 5.

4.1 Modeling hierarchy

To simulate the hierarchical structure of institutions, I use a model developed independently by Herbert Simon [77] and Harold Lydall [78]. In this model, hierarchies have a nested structure defined by the 'span of control' — the number of subordinates controlled by each superior. We assume that this span is fixed (within and across hierarchies), meaning each superior controls the same number of subordinates. The size of the span of control determines the shape of the corresponding hierarchy (Fig.

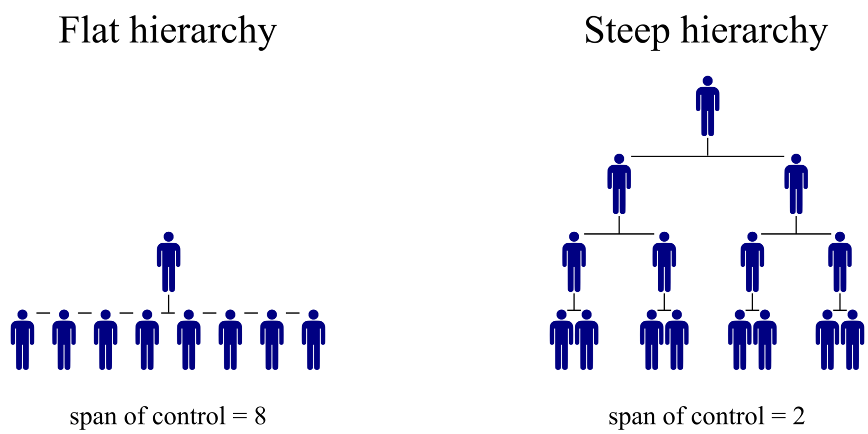

Figure 6: How the span of control determines hierarchy 'shape'

6). A large span of control creates a hierarchy that is 'flat'. A small span of control creates a hierarchy that is 'steep'.

I model the hierarchical structure of institutions using three equations. (For a derivation of these equations, see Section 8.) Given the span of control (s) and the total membership in the institution (N_T), the number of ranks (n) in the hierarchy is:

$$n = \left\lfloor \frac{\log\left[1 + N_T(s-1)\right]}{\log(s)} \right\rfloor \tag{3}$$

Here $\lfloor\rfloor$ denotes rounding down to the nearest integer. The number of people in the bottom hierarchical rank is:

$$N_1 = N_T \left(\frac{1 - 1/s}{1 - 1/s^n} \right) \tag{4}$$

The size of each hierarchical rank h (where increasing h denotes moving up the hierarchy) is then a function of the span of control:

$$N_h = \left\lfloor \frac{N_1}{s^{h-1}} \right\rfloor \tag{5}$$

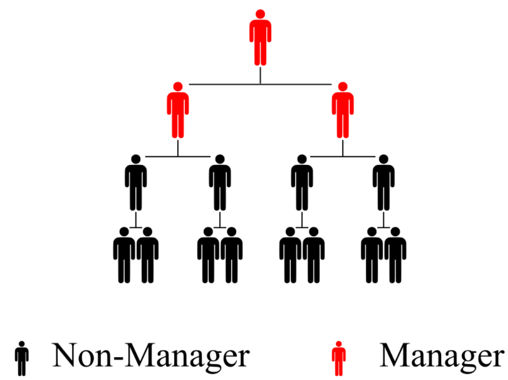

Figure 7: Modeling managers in a hierarchy

I model 'managers' as everyone in hierarchical rank 3 and up.

The size N_T of each institution is taken from the randomly generated power-law distribution. The span of control s is a free parameter that varies between model iterations.

4.2 Modeling managers

Within hierarchies, people who occupy top ranks tend to be managers. Conversely, people who occupy bottom ranks tend to be non-managers. For modeling purposes, I assume that there is a rank threshold that divides managers from non-managers. I assume that everyone in and above hierarchical rank 3 is a 'manager'. Everyone below this rank is a 'non-manager'. The idea is that people in the bottom rank are 'shop floor' workers. People in the second rank are 'working supervisors' [79]. Everyone else is a professional manager. Figure 7 illustrates this model.

Given this assumption, the relative number of managers in an institution depends on two factors: (1) the size of the institution; and (2) the span of control. Larger institutions will tend to have more managers (as a portion of total employment) than smaller institutions. This is because these larger institutions have more hierarchical ranks than their smaller counterparts. Institutions with a smaller span of control will also tend to have more managers, as the corresponding hierarchy is 'steeper'.

The management share of employment (M/N) within a hierarchy is given by Eq. 20, where n is the number of hierarchical ranks and s is the span of control:

$$\frac{M}{N} = \frac{1 - s^{n-2}}{1 - s^n} \tag{6}$$

Because this equation is non-linear, the management share of employment grows rapidly as the first few hierarchical ranks are added. But as more ranks are added, the relative number of managers plateaus at $1/s^2$.

Note that Eq. 6 gives the management share of employment within a single hierarchy. We are interested, however, in the management share of employment across *all* hierarchies. The equation for this global average depends on the size-distribution of hierarchies. In the model used here, I do not derive a general formula for this global average, but instead calculate it numerically.

4.3 Modeling government

To model the size of government, I take inspiration from a biological phenomenon: the biomass spectrum [80]. Across the entire range of life (from bacteria to large mammals) the abundance of organisms declines predictably with mass [81]. Small organisms are ubiquitous. Large organisms are rare.

To model government size, I take inspiration from this regularity amidst difference. Elephants are different than bacteria, yet their abundance is still predictable from their size. Might the same be true of government? Governments are obviously different than other institutions. Governments can tax their citizens, enforce laws and wage war — all things that firms cannot do. But what if, despite these differences, governments fit into the overall size distribution of institutions? What if governments behave as if they were the largest 'firms'. If so, then the employment share of government could be predicted from the size distribution of institutions.

As a first approximation, I model governments as the *n* largest institutions. Here *n* is a free parameter that varies between model iterations. To simulate the size distribution of institutions, I draw one million observations from a power-law distribution. Of these observations, the largest *n* are defined as 'governments'. The rest are defined as 'firms'.

4.4 Model predictions

The hierarchy model predicts how both government size and the relative number of managers should change with energy use. In Figures 8 and 9, I compare these predictions to real-world trends.

Let us begin with the growth of government (Fig. 8). The model predicts that governments should tend to grow larger as energy use increases. There is, however, significant leeway for this trend to be pushed 'up' (to larger government) or 'down' (to smaller government). In the model, this leeway stems from the number of 'firms' in government. Here governments are modeled as the *n* largest institutions (firms), where *n* is a free parameter. Increasing the number of firms in government increases the size of government at the given level of energy use.

I interpret the number of 'firms' in government as a political preference. Societies with leftist politics tend to let government do what would, in right-wing societies, be done by private firms. In the model, this leftward shift in politics corresponds to adding 'firms' to government. For instance, a healthcare 'firm' in a right-wing society becomes a healthcare branch of government in a left-wing society. So moving left on the political spectrum involves adding 'firms' to government. Moving right

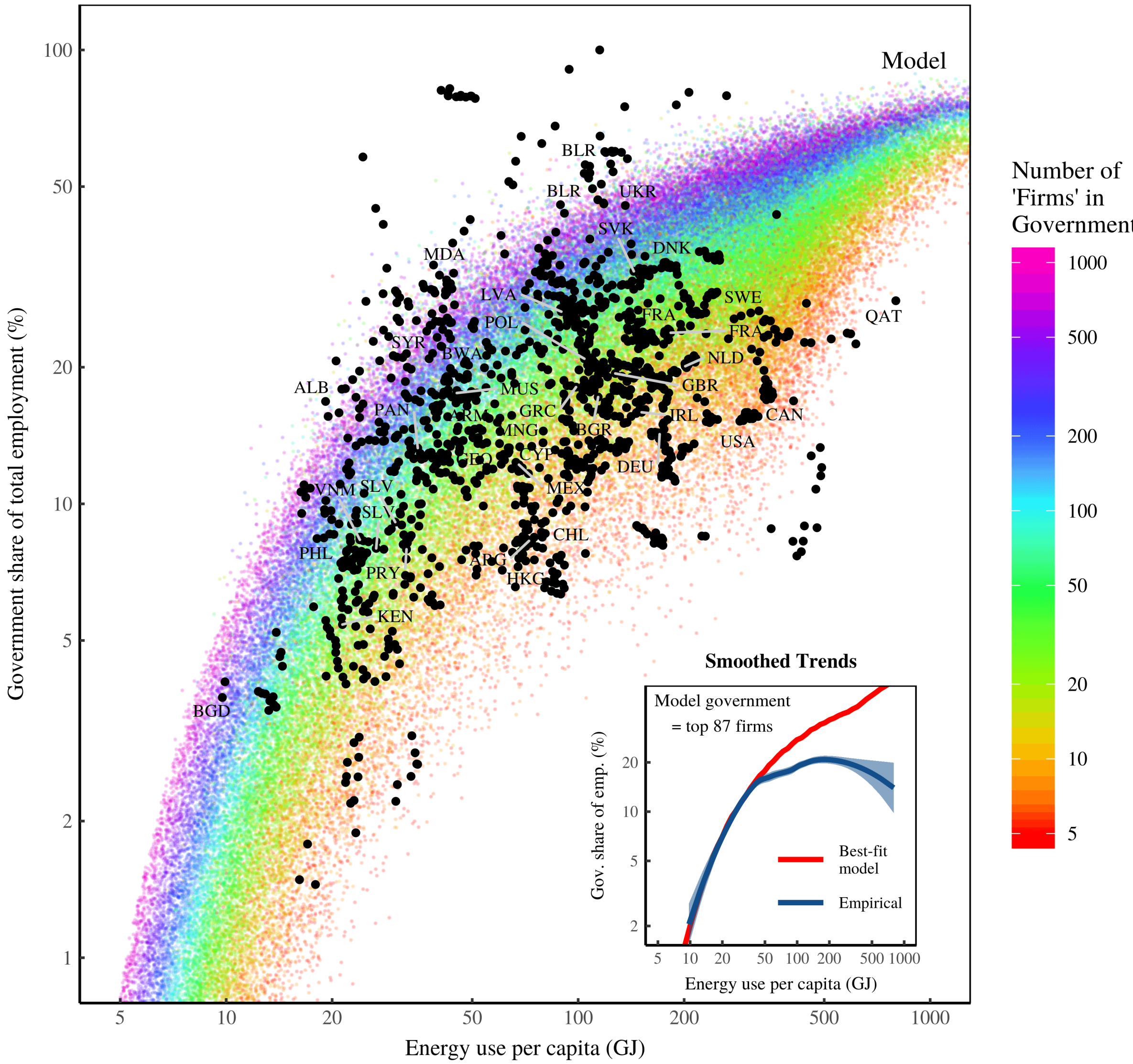

Figure 8: The modeled growth of government with energy use

This figure compares empirical trends to the modeled relation between government share of employment and energy use per person. Each colored dot represents a model iteration. Color indicates the number of 'firms' in modeled government (the model's sole parameter). Real-world data is plotted over top of the model as black points. Select countries are labeled with alpha-3 codes. The inset panel shows the smoothed trends for the empirical data and the best-fit model.

involves taking 'firms' away from government.

Given this interpretation, the model suggests that politics strongly affect the size of government. But the model also suggests that there is a larger trend that has little to do with politics. Governments tend to get larger as energy use increases. In our model, this stems from a change in the entire size distribution of institutions, of which governments are a part. Governments, the model suggests, are riding a larger wave of institutional change.

The inset panel in Figure 8 shows how the best-fit model compares to the smoothed trend in real-world data. (For fitting methods, see Sec. 8.) In this model, government consists of the 87 largest institutions. The model closely predicts the growth of government during initial stages of development. For large energy use, however, the model diverges from the real-world trend. This may be because the model is wrong. Alternatively, political preferences (for government) may change with energy use. I leave it for future research to better understand this discrepancy.

Switching now to the growth managers, Figure 9 compares model predictions to real-world trends in energy use and the management share of employment. Here color shows the span of control of the modeled hierarchies. A smaller span of control produces a 'steeper' hierarchy, which leads to more managers at a given level of energy use. A larger span of control produces 'flatter' hierarchies, which leads to fewer managers at a given level of energy use. Virtually all of the empirical data can be fit with a span of control between 2 and 7 — a range that is consistent with the span of control observed in real-world hierarchies (see Fig. 13 in Sec. 8).

The model predicts that the management share of employment should grow rapidly during initial stages of development. As energy use continues to increase, however, the management share of employment plateaus. This, our model suggests, is a characteristic effect of hierarchy. In the

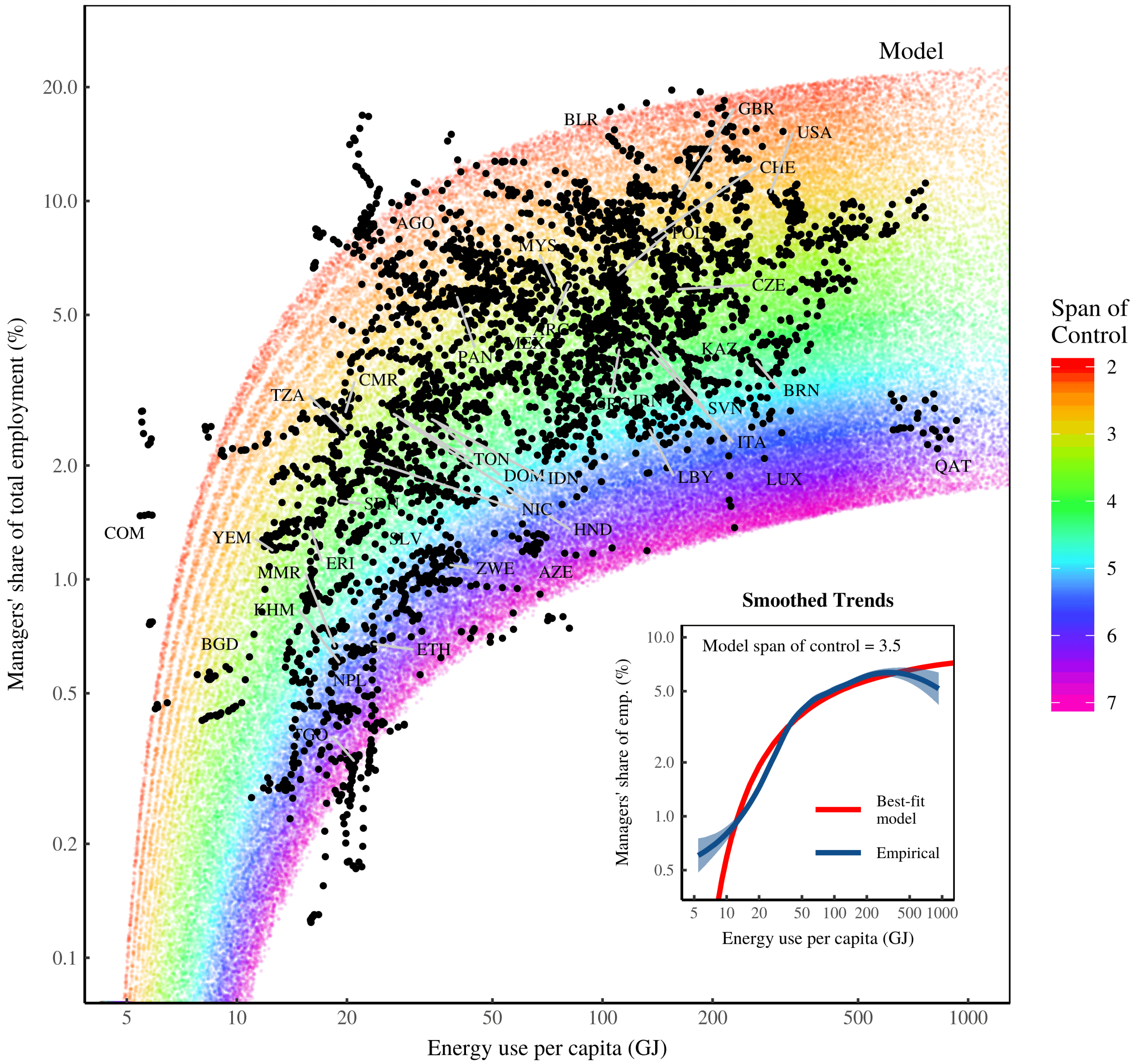

Figure 9: The modeled growth of management with energy use

This figure compares empirical trends to the modeled relation between the management share of employment and energy use per person. Color indicates 'span of control' — the number of subordinates controlled by each superior (the model's sole parameter). Real-world data is plotted over top of the model as black points. Select countries are labeled with alpha-3 codes. The inset panel shows the smoothed trends for the empirical data and the best-fit model.

limit that the entire population is organized in a single hierarchy, the management share of employment will be $1/s^2$, where s is the span of control.

The inset panel in Figure 9 compares the best-fit model (which has a span of control of 3.5) to the smoothed trend in real-world data. (For fitting methods, see Sec. 8.) The fit is quite close, departing only at extremes of energy use, where the empirical sample size is small.

5 Inferring the growth of hierarchy

The model suggests that the growth with energy use of both government and managers is consistent with the general growth of hierarchy. Assuming that the model is correct, we can use it to infer how hierarchy changes with energy use. To do this, I find the model iteration that best fits a given empirical observation. I then measure the 'degree of hierarchy' in the model and infer that this is what exists in the real-world society. (Since this inference is model dependent, we should treat it with appropriate uncertainty.) Once all real-world observations have been fitted, I infer the trend in hierarchy.

5.1 Measuring the degree of hierarchy

A hierarchy is a type of network in which connections have a tree-like structure. Most real-world networks have a complicated structure that is neither purely hierarchical nor purely non-hierarchical. To measure this structure, network scientists have proposed several ways of quantifying the 'degree of hierarchy' in a network. By treating society as a network of relations, we can apply these measures to humans.

I use two different measures to quantify the degree of hierarchy in the model: (1) 'global reaching centrality'; and (2) the concentration of

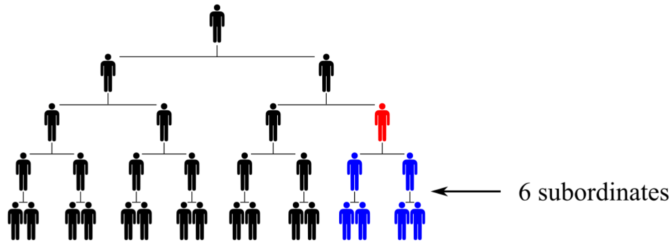

Figure 10: Subordinates in a hierarchy

'hierarchical power'.

Global reaching centrality has been proposed as universal measure of the degree of hierarchy in a network [82,83]. It is based on the concept of a 'directed network' — a network in which connections between nodes have a direction. In terms of hierarchy, we can think of this connection as a form of control. If person A controls person B, the network connection is directed from A to B. (This direction can also have a weighting that signifies the strength of control. Here I assume that all relations are 100% directed.) The 'local reaching centrality' of person A is the portion of people that can be reached by following the directed network. In a hierarchy this corresponds to counting subordinates. The local reaching centrality C_R of person i:

$$C_R(i) = \frac{N_s(i)}{N-1} \tag{7}$$

Here $N_s(i)$ is the number of subordinates below person i, and N is the total number of people in the network. Figure 10 shows an example. The red individual has 6 subordinates within a hierarchy of 31 people, giving a local reaching centrality of $6/31 = 0.19$.

The 'global reaching centrality' of the network is defined as the sum of the differences between the local reaching centrality of each person and the maximum reaching centrality, C_R^{max}:

$$GRC = \frac{\sum_{i=1}^{n} \left[\, C_R^{max} - C_R(i) \, \right]}{N-1} \tag{8}$$

Global reaching centrality can range between 0 to 1. A value of 0 indicates no hierarchy. A value of 1 indicates a ‘perfect hierarchy’, in which a single individual controls the rest of the population. The global reaching centrality of the hierarchy in Figure 10 is 0.92.

A distinguishing feature of global reaching centrality is that ‘flat’ hierarchies (with a large span of control) are considered the most hierarchical. Whether this is so is a question of definition. Within human hierarchies at least, we usually consider ‘steep’ hierarchies to be more hierarchical than ‘flat’ hierarchies. Because of this belief, I propose a second measure of the degree of hierarchy — one that equates steeper hierarchies with ‘more’ hierarchy.

Like global reaching centrality (when it is applied to human hierarchies), this measure focuses on control over subordinates. For ease of reference, I give this control a name — I call it ‘hierarchical power’. The idea is that control over subordinates is a form of power — it increases “the possibility of imposing one’s will upon the behavior of other persons” [84]. In a hierarchy, the hierarchical power P of person i is:

$$P(i) = n_s(i) + 1 \tag{9}$$

Here $n_s(i)$ is the number of subordinates controlled by person i. The reasoning here is that all individuals start with a baseline power of 1, indicating they have control over themselves. Hierarchical power then increases proportionally with the number of subordinates. As an example, the red individual in Figure 10 has a hierarchical power of 7 (6 subordinates + 1). To quantify the ‘degree of hierarchy’ in a society, I measure the concentration of hierarchical power using the Gini index. This value can range from 0 (no hierarchy) to 1 (maximum hierarchy).

5.2 Assumptions

To calculate the degree of hierarchy in the model, I assume that there are no directed relations between institutions. This means that hierarchical relations are confined within institutions. In the real world, power relations between institutions do exist via the interlocking network of ownership [85, 86]. But I exclude this complexity here. I also exclude any variation in the strength of power relations, meaning all relations are fully directed.

Lastly, the model does not directly simulate the chain of command within hierarchies. Instead, it simulates aggregate hierarchical structure — the number of people in each rank. To calculate the degree of hierarchy, I assign each individual the average number of subordinates below their rank, defined as:

$$\overline{N}_s(h) = \frac{\sum_1^{h-1} N_i}{N_h} \tag{10}$$

Here h is the hierarchical rank, N is the membership in each rank, and $\overline{N}_s$ is the average number of subordinates.

5.3 Fitting the model

I fit the model to the real-world data for management employment and energy use (Fig. 9). For each country-year observation, I chose the model that minimizes the following error function:

$$\varepsilon = [\log E_r - \log E_m]^2 + [\log M_r - \log M_m]^2 \tag{11}$$

Here E_r and E_m are energy use per capita in the real-world observation and model, respectively. M_r and M_m are the management share of employment in the real-world observation and model, respectively. Because the model is stochastic, I choose the 10 best-fit iterations, and average the measured degree of hierarchy across these models.

5.4 Inferred trends in hierarchy

Figure 11 shows the inferred trend in the 'degree of hierarchy'. The main panel shows the concentration of hierarchical power, measured with the Gini index, plotted against energy use per capita. The inset panel shows the same trend, but measures the 'degree of hierarchy' using global reaching centrality.

The two measures of hierarchy show essentially the same trend. Human societies, the model suggests, become more hierarchical as energy use increases. But this growth of hierarchy is not linear. Instead, the degree of hierarchy appears to grow rapidly during initial stages of development, after which it plateaus.

The reasons for this non-linear behavior stem from the assumptions of the model, coupled with basic features of hierarchy. The model assumes that institutions grow larger with energy use. As institutions grow, they add new hierarchical ranks, increasing the 'degree of hierarchy' in the society. The non-linear behavior in the 'degree of hierarchy' occurs because new ranks are added in proportion to the logarithm of institution size (a behavior that has been observed in real-world groups [41,87,88]). This means that new ranks are added rapidly at first, but the rate slows

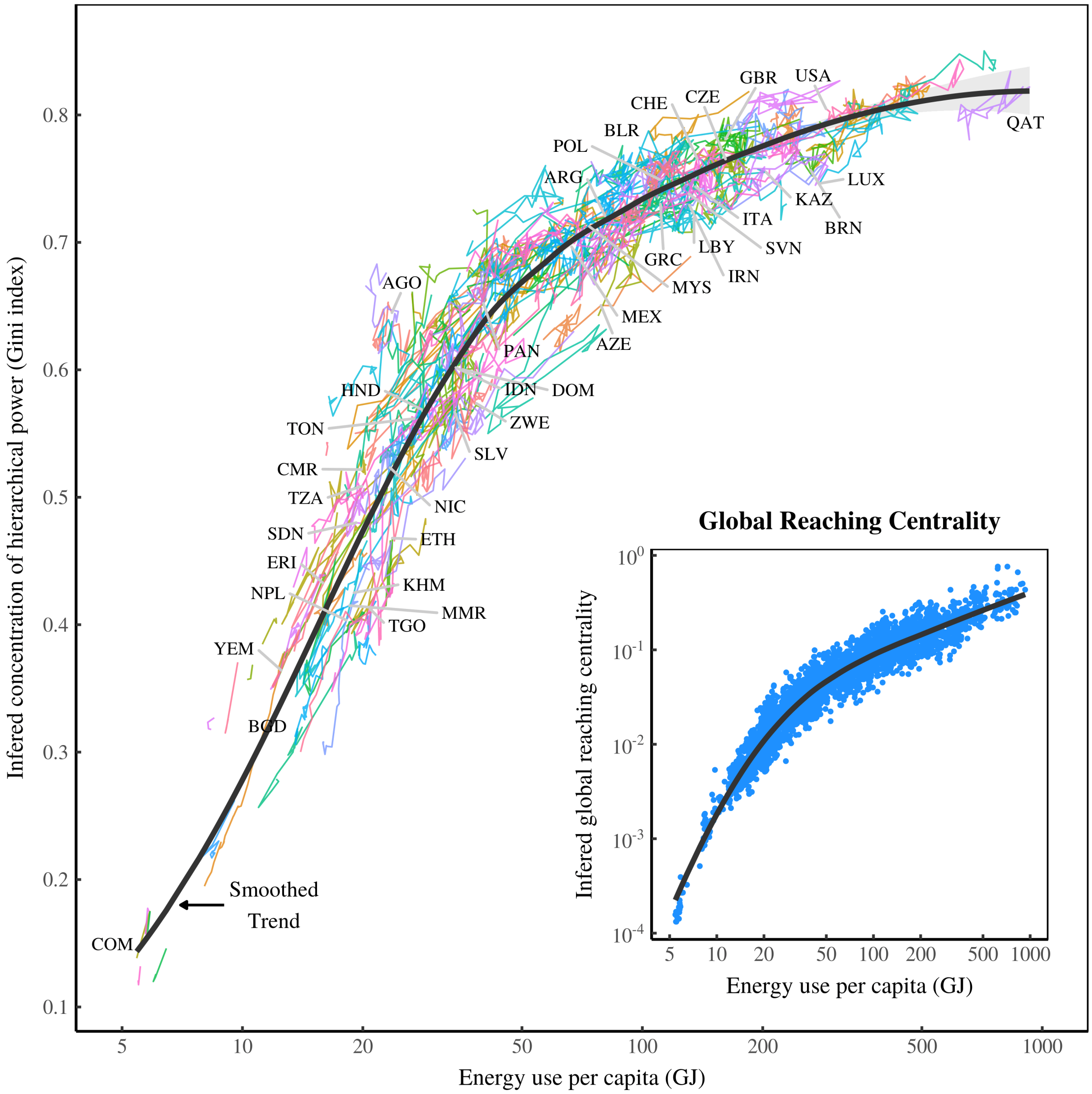

Figure 11: The inferred degree of hierarchy vs. energy use

This figure shows how the inferred degree of hierarchy in human societies changes with energy use. The main panel shows the inferred concentration of hierarchical power, measured using the Gini index. Colored lines indicate the inferred path of countries through time. Select countries are labeled with alpha-3 codes. The black line shows the smoothed trend, calculated with a local polynomial regression. The inset panel shows the same model inferences, but measures the degree of hierarchy using global reaching centrality.

as institutions grow larger. Consequently the degree of hierarchy grows non-linearly with energy use.

6 Rethinking free-market theory

From the model, I infer that societies tend to become more hierarchical as they develop. What does this mean for our two competing theories — multilevel selection theory and free-market theory?

Interpreted using multilevel selection theory, the evidence suggests that humans may use hierarchy as a way to suppress competition within groups. As the need for coordination grows (with the increasing complexity of economic activity) societies therefore become more hierarchical. The process is a complex evolutionary one — with larger (hierarchical) groups beating out smaller (less-hierarchical) groups. How and why this actually happens is an open question. But the (inferred) fact that it happens is consistent with multi-level selection theory.

The same evidence, in contrast, is difficult to interpret using the economic theory of free markets. According to this theory, small-scale (market) competition is the optimal form of social organization. Yet to industrialize, human societies seem to do the opposite of what the theory advocates. They turn not to atomistic competition, but instead to large-scale hierarchical organization. One could argue, of course, that societies would be better off if they abandoned hierarchy in favor of atomistic competition. But there is little evidence that industrial development could be achieved this way. So a reasonable interpretation of the evidence is that free-market theory is incorrect. The complex activities needed for industrial development cannot be achieved (as the theory claims) using small-scale competition.

Were we studying (non-human) animals, we could leave it at that. The evidence favors one theory (multilevel selection) but not the other (the economic theory of free markets). The problem, though, is that we are not studying animals. We are studying humans. And humans have beliefs that shape our behavior. This means that social-scientific theories must be evaluated in two separate ways. First, they must be evaluated on their factual merit. I will call this the 'scientific' component of the theory. Second, social-scientific theories must be evaluated in terms of their effect on human behavior. I will call this the 'ideological' component of the theory.

What is important is that the ideological component of a theory does not depend on the scientific component. Put simply, a social-scientific theory can be simultaneously incorrect and ideologically potent. Karl Marx's theory of capitalism is a good example [89]. Critics have argued that Marx's theory is fundamentally flawed [4,9,11,90]. Yet few scholars dispute Marx's impact on history. Without Marx's ideas, the communist revolutions of the 20th century may never have occurred.

In the case of Marxist theory, it is straightforward to understand the ideological component. Marx claimed that the injustices of capitalism could be solved only by communist revolution [91]. Inspired by Marx's ideas, revolutionaries like Lenin and Mao did precisely what Marx proposed — they led communist revolutions to overthrow capitalism.

When it comes to free-market theory, however, the ideological component is less easily understood. On the face of it, free-market theory advocates atomistic competition. Yet the theory became popular at precisely the time when small-scale competition was being replaced by large-scale hierarchy. Figure 12 shows this trend in the United States.

Here I plot the relative word frequency (in American written English) of four free-market terms: 'small business', 'free market', 'competitive market' and 'perfect competition'. I take this word frequency as a measure of the prevalence of free-market ideas. Against this word frequency, I plot our two proxies for hierarchy: the government share of employment and the management share of employment. Over the last century, it seems that free-market jargon became more come common at the very time that hierarchy grew.

How should we interpret this trend? One possibility is that the spread of free-market language was a reaction to the growth of hierarchy. Seeing the growth of government and large firms, free-market proponents reacted by writing more frequently about the merits of small-scale competition. But despite the increasing prevalence of their ideas, free-market proponents were unable to stop the growth of government and large firms. If this interpretation is correct, then free-market ideas do have an atomistic effect. It is just that these ideas failed to catch hold.

There is, however, another interpretation that deserves to be explored. When we separate a theory into a scientific and ideological component, there is no reason to insist that the two sides be connected. In other words, the ideological effect of a theory (its effect on human behavior) can be different from the theory's factual claims. Free-market theory argues that small-scale competition is the most effective form of social organization. But when put into action, perhaps free-market ideas lead to the opposite of what they claim. Might free-market thinking *foster* (not hinder) the growth of hierarchy? The evidence in Figure 12 suggests that this possibility is worth exploring.

6.1 Belief systems as 'massive fictions'

According to multilevel selection theory, social animals face a fundamental dilemma. To be successful, social groups must suppress the selfish behavior of individuals. The problem is that within the group, selfish behavior is advantageous. David Sloan Wilson and E.O. Wilson call this dilemma the 'fundamental problem of social life' [17]. The existence of sociality is predicated on solving this problem.

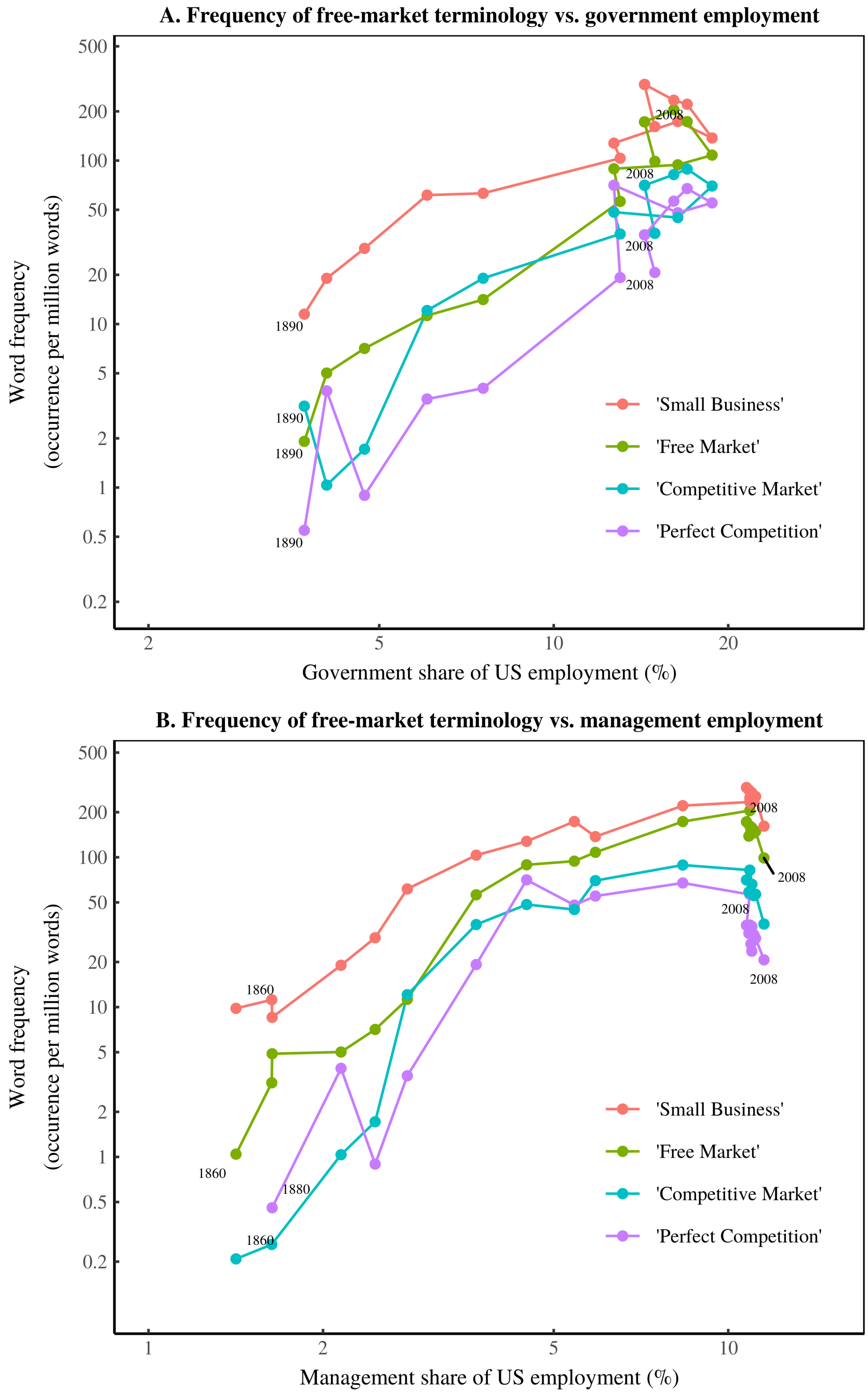

Figure 12: Frequency of free-market terminology in American English vs. the US government and management share of employment

This figure shows the relative frequency in American English of four free-market terms. Panel A compares this word frequency to the government share of US employment. Panel B compares it to the management share of employment. For sources and methods, see Section 8.

Humans, it seems, have developed a way to motivate altruism that is unique. We rely, at least in part, on the power of beliefs. Successful groups adopt belief systems that motivate group cohesion [92]. Importantly, these beliefs need not be scientifically true. So long as they motivate altruism, the factual component of the beliefs is irrelevant. For this reason, David Sloan Wilson argues that belief systems are often 'massively fictional':

> Groups governed by belief systems that internalize social control can be much more successful than groups that must rely on external forms of social control. For all of these (and probably other) reasons, we can expect many belief systems to be *massively fictional* in their portrayal of the world. [93] (emphasis added)

To solve the fundamental problem of social life, Wilson argues that belief systems contain a (possibly universal) untruth. They portray altruistic behavior as beneficial to the individual. In so doing, these belief-systems promote altruism by denying the sacrifice that it necessarily (according to multilevel selection theory) involves.

As an example of such a 'massively fictional' belief system, Wilson studies the worldview of the Hutterites (a communal sect of protestants living in northwestern North America). The Hutterite worldview, Wilson finds, contains no grey areas [46]. Actions are portrayed either as good for both individuals and groups, or bad for both individuals and groups. By masking the costs of altruism, this belief system may be how Hutterites motivate communal behavior.

Interestingly, Wilson finds a striking parallel between the communal beliefs of the Hutterites and the libertarian (i.e. free-market) beliefs of Ayn Rand [46]. Like the Hutterites, Rand's worldview seems to have no grey areas. Actions are portrayed either as good for both individuals and the group, or bad for both individuals and the group. There is, however, an important distinction between the Hutterites' beliefs and Rand's libertarianism. The Hutterites portray *prosocial* behavior (traits like 'brotherliness' and 'mutual help') as good for both the individual and the group. Rand, in contrast, portrays *antisocial* behavior (traits like 'egoism' and 'selfishness') as good for both the individual and the group.

Noting this fact, Wilson argues that Rand's worldview — and free-market thinking in general — may be detrimental to group cohesion. This conclusion is reasonable. But it presumes that free-market ideas (which are avowedly antisocial) lead to antisocial behavior. It is possible, however, that the reverse might be true. Free-market ideas might actually promote prosocial behavior by motivating the formation of hierarchy.

6.2 Motivating hierarchy

Although we do not commonly think of them this way, hierarchical relations involve altruism. In a hierarchical relation, one person submits to the will of another. By doing so, the subordinate suppresses their own self-interest, and instead does what their superior commands. This is a form of altruism. The question that concerns us here is — how do societies motivate this submissive behavior?

An obvious way is to openly promote it. Societies that take this route will promote submission as being beneficial to individuals. The Hutterites, for instance, seem to do just that. Their belief system promotes 'obedience' and 'surrender' as good for both individuals and the group [46]. Other religions similarly promote submission. *Obsequium religiosum* — religious submission — is a central tenet of Catholic dogma [94]. Confucianism advocates *tsun-wang* — submission to authority [95]. In Islam, 'submission' is implied in the name of the faith itself [96].

To promote hierarchy, however, this appeal to submission must have an asymmetry. To function, hierarchies require both submission and dominance. So behind the appeal to submission, there must be an assumption that not everyone submits. Some people must have the right to wield authority. In religious hierarchies, the asymmetry is often maintained by appealing to the authority of God. Everyone submits to the will of God, but not equally so. Some people — those with power — claim to speak for (or derive their authority from) God. This leads to doctrines like the 'divine right of kings' [97]. The pharaohs of ancient Egypt went so far as to proclaim themselves gods [98].

Using the language of Michele Gelfand [99], we might call the appeal to submission the 'tight' approach to motivating hierarchy. It openly asks individuals to submit to authority. Is there a corresponding 'loose' approach to motivating hierarchy? I propose that free-market thinking — with its emphasis on choice and freedom [100, 101] — may be one such 'loose' approach.

This claim appears, at first, to be contradictory. So-called 'loose' cultures value freedom and autonomy, which are the opposite of hierarchy. It is possible, however, for the idea of freedom to lead to its mirror opposite. The reason has to do with the concept of 'freedom' itself. In an important sense, 'freedom' is impossible among social animals. The problem is that there are two types of freedom that, when applied to all individuals, are contradictory. First, there is 'freedom to', which is about one's ability to enact one's will. Second, there is 'freedom from', which is about one's ability to avoid the undesirable actions of others. The two types of freedom contradict one another. Everyone cannot, for instance, be free to be racist while also being free from racism. One person's 'freedom to' comes at the cost of another person's 'freedom from'.

Much like proclaiming that everyone should be submissive, advocating for 'market freedom' for all individuals is a contradiction. This, I believe, may be how free-market thinking motivates hierarchy. When applied to the real world, the 'freedom' of the free market is marked by an asymmetry. In abstract form, free-market theory stands for the autonomy of *individuals*. But in more concrete form, the theory stands for the autonomy of *firms*. This switch is apparent in neoclassical economic theory. The theory proposes that 'perfect competition' (implying atomistic competition between individuals) is the ideal form of social organization. But the same theory accepts that firms — which do not use the free market within their bounds — are the basic unit of production [102].

This switch from autonomy of the individual to the autonomy of the group, I propose, is how free-market ideas promote hierarchy. It is easiest to see how this might work by applying the idea to ourselves. We use the word 'free will' to describe our own freedom to put conscious thoughts into action. Yet when we look inside ourselves, the concept of 'free will' is contradictory. Individual humans are a community of cooperating cells, organized in a hierarchy. This means that our 'free will' is predicated on a large number of cells being 'unfree'. If you are free to lift your arm at will, this requires that brain cells have control over muscle cells. So the 'free will' of the individual is predicated on the 'unfreedom' of most of the individual's constituents.

I propose that the same principle applies when free-market ideas are put in action. While, in principle, they stand for the autonomy of the individual, in practice they stand for the autonomy of business firms. By promoting this autonomy, these ideas may implicitly legitimize the hierarchy within firms. The 'freedom' of the free market therefore translates into the power of firm owners to command. It is 'power in the name of freedom'[1]. This doublespeak may be why free-market thinking has spread at the very time that hierarchy appears to have increased. Contrary to the theory's scientific claim, the ideological effect of free-market thinking may be to facilitate the growth of hierarchy.

This idea is speculative, but could be tested. One way would be to see how various measures of cultural 'tightness' and 'looseness' relate to the measures of hierarchy adopted here (specifically, the management share of employment, which appears uncorrelated with political regimes). If the reasoning above is correct, then 'loose' cultures may (paradoxically) be more hierarchical than 'tight' cultures.

7 Conclusions

Peter Brown and Peter Timmerman argue that mainstream economics is an 'orphaned discipline'. It is founded, they claim, on a "dated and unrevised metaphysical and prescientific vision" that is "incompatible with what we know about the universe and our place in it" [103]. Looking at free-market theory in the context of the modern understanding of evolution, this assessment rings true.

Adam Smith's concept of the invisible hand was a plausible hypothesis when it was proposed more than two centuries ago [1]. Given the state of knowledge at the time, it seemed possible that self-interest, if properly channeled, could benefit groups. But as our knowledge of evolution has progressed, this hypothesis has grown steadily less plausible. The problem is that the major transitions in evolution show a pattern that is the opposite of the invisible hand. Rather than organize decentrally, each wave of group formation seems to use at least some form of centralization. And rather than stoke the self-interest of subcomponents, successful groups seem to suppress it. And they often do so by using hierarchy.

Whether it is the symbiosis of the eukaryotic cell, the coordination in multicellular organisms, or the cooperation among eusocial animals, this pattern seems to hold. Competition among subcomponents is suppressed using some form of centralized organization. And yet, if the economic theory of free markets is correct, humans are the exception to the rule. We can organize, the theory claims, not by suppressing competition within groups, but by stoking it.

This claim becomes even more important if we consider that modern humans may be the most recent major evolutionary transition. In the last 10,000 years we have transitioned from being a social species that lived in groups of several hundred [104–106], to an 'ultrasocial' species living in groups a million strong [29–32]. If we have accomplished this feat through decentralized competition (as free-market theory claims is possible), then the evidence should surround us. And since this transition has accelerated in the last half century [107,108], we need not look to the deep past to study it. We can look at modern trends between nations.

Looking at these trends, the evidence suggests that human societies have developed in a way that is consistent with the major evolutionary transitions of the past. As societies industrialize (evident by growing energy use), it seems they turn not to decentralized competition, but to increasingly large-scale hierarchy.

Where, then, does this leave the economic theory of free markets? A conservative conclusion is that free-market theory is inconsistent with the evidence. A more radical conclusion is that free-market theory is best treated not as a scientific theory, but as a belief system — a claim that heterodox political economists have made many times [9,109–117]. If this more radical interpretation is true, then we must grapple with a paradox. Free-market theory advocates for the autonomy of individuals. Yet the spread of free-market thinking has happened at the very time that hierarchy seems to have increased. One possible explanation is that free-market ideas, when implemented, actually promote centralization. This idea is speculative, but is worth investigating.

Regardless of the behavioral effects of free-market ideas, the evidence reviewed here suggests that societies do not use atomistic competition to develop. Given this finding, it may be time for evolutionary-minded scientists to stop treating neoclassical economics as a competing framework, and instead view it as a cultural artifact to be explained.

8 Sources and methods

All data and code for this paper are available at the Open Science Framework: https://osf.io/gbvnh/. Code for the hierarchy model is available at github: https://github.com/blairfix/energy_hierarchy_mod. R versions of the hierarchy-model functions are available at https://github.com/blairfix/hmod.

8.1 Data sources

Communist/non-communist status. I classify a country as 'communist' if it has, or once had, a regime that claimed to be Marxist–Leninist. See the supplementary materials for a detailed list of sources.

Energy use per capita. Data for energy use per capita comes from the World Bank, series EG.USE.PCAP.KG.OE. To these values I add an estimate for energy consumed through food (2000 kcal per day).

Government employment. Data for government employment comes from ILOSTAT series GOV_LVL_PSE (all public sector employees). I divide this series by the size of the labor force reported in World Bank series SL.TLF.TOTL.IN. Data for US government employment share (Fig. 12A) comes from:

- 1890 to 1928: Historical Statistics of the United States, Table Ba 470-477
- 1929 to present: Bureau of Economic Analysis series 6.8A-D (total persons engaged in production)

Managers' employment. International management share of employment data is from ILOSTAT Table TEM_OCU, series EMPoc1P. Management employment share for the US (Fig. 12B) comes from:

- 1860 to 1990: Historical Statistics of the United States, Table Ba 1033-1046
- 1990 to present: Bureau of Labor Statistics Current Population Survey series LNU02032453 (management employment) divided by Bureau of Economic Analysis series 6.8D (total persons engaged in production)

Firm size. Data for firm size comes from the Global Entrepreneurship Monitor (GEM), series 'omnowjob'. To calculate firm size, I merge all data over the years 2001-2014. Because the GEM data over-represents large firms, I use only firms with 1000 or fewer employees. For method details, see the Appendix in [72]. Power-law exponents for firm-size distributions are estimated using the R PoweRlaw package [119].

Free-market word frequency. Word frequency of free-market jargon is from the Google Ngram corpus for American English.

8.2 Hierarchy-model equations

The hierarchy model used in this paper is based on equations derived independently by Herbert Simon [77] and Harold Lydall [78]. In this model, hierarchies have a constant span of control. We assume that there is one person in the top rank. The total membership in the hierarchy is then given by the following geometric series:

$$N_T = 1 + s + s^2 + ... + s^{n-1} \tag{12}$$

Here n is the number of ranks, s is the span of control, and N_T is the total membership. Summing this geometric series gives:

$$N_T = \frac{1 - s^n}{1 - s} \tag{13}$$

In my model of hierarchy, the input is the hierarchy size N_T and the span of control s. To model the hierarchy, we must first estimate the number of hierarchical ranks n. To do this, we solve Eq. 13 for n:

$$n = \left\lfloor \frac{\log\left[1 + N_T(s-1)\right]}{\log(s)} \right\rfloor \tag{14}$$

Here $\lfloor\rfloor$ denotes rounding down to the nearest integer. Next we need to calculate N_1 — the employment in the bottom hierarchical rank. To do this, we first note that the firm's total membership N_T is given by the following geometric series:

$$N_T = N_1 \left(1 + \frac{1}{s} + \frac{1}{s^2} + ... + \frac{1}{s^{n-1}} \right) \tag{15}$$

Summing this series gives:

$$N_T = N_1 \left(\frac{1 - 1/s^n}{1 - 1/s} \right) \tag{16}$$

Solving for N_1 gives:

$$N_1 = N_T \left(\frac{1 - 1/s}{1 - 1/s^n} \right) \tag{17}$$

Given N_1, membership in each hierarchical rank h is:

$$N_h = \left\lfloor \frac{N_1}{s^{h-1}} \right\rfloor \tag{18}$$

Sometimes rounding errors cause total employment of the modeled hierarchy to depart slightly from the size of the original inputted institutions. When this happens I add/subtract members from the bottom rank to correct the error. The model is implemented numerically in C++, using the Armadillo linear algebra library [120].

8.3 Modeling Managers

I model managers as all individuals in and above rank 3. In a firm with n hierarchical levels, the number of managers is equivalent to the membership in a hierarchy with $n-2$ levels. Using Eq. 13, we find that the number of managers M is:

$$M = \frac{1 - s^{n-2}}{1 - s} \tag{19}$$

By dividing Eq. 19 by Eq. 13, we can find the management share of employment (M/N) in the firm:

$$\frac{M}{N} = \frac{1 - s^{n-2}}{1 - s^{n}} \tag{20}$$

8.4 Finding the best-fit model

To find the model parameters that best fit the trends in empirical data (inset Fig. 8 and Fig. 9), I first bin model results in log-spaced bins by energy use. (This smooths the stochastic noise that is built into the model.) In each bin, I calculate the average energy use and the average of the statistic of interest (either the management share of employment or the government share of employment). I then interpolate linearly between this averaged points, creating a function that relates energy use to the government/management share of employment. I use this numeric function to compute the error between the model and the raw empirical data. The error function is:

$$\varepsilon = [\log S_r - \log S_m]^2 \tag{21}$$

Here S_r is the real-world statistic (either government or management share of employment) and S_m is the model statistic. The best-fit model minimizes this error.

8.5 Verifying the span of control

In the management model, the span of control is a free parameter that varies between model iterations. One way to test the model is see if fitted values for the span of control are consistent with observations from real-world firms. To do this I fit the model to the energy-management empirical data using the error function in Eq. 11. The resulting distribution (for all country-year observations) of the fitted span of control is shown in Figure 13. I compare this distribution to the span of control distribution reported in case studies of firm hierarchy. The model's estimated span of control is in a range that is consistent with the real-world observations. A t-test ($p = 0.77$) and ks-test ($p = 0.08$) both indicate that the two distributions are statistically indistinguishable at the 5% level.

Acknowledgments

This research was made possible in part by Hilliard MacBeth, Grace and Garry Fix, Steve Keen, and Ed Zimmer. Thank-you for your support.

Notes

[1]I thank Jonathan Nitzan for suggesting to me the phrase 'power in the name of freedom'.

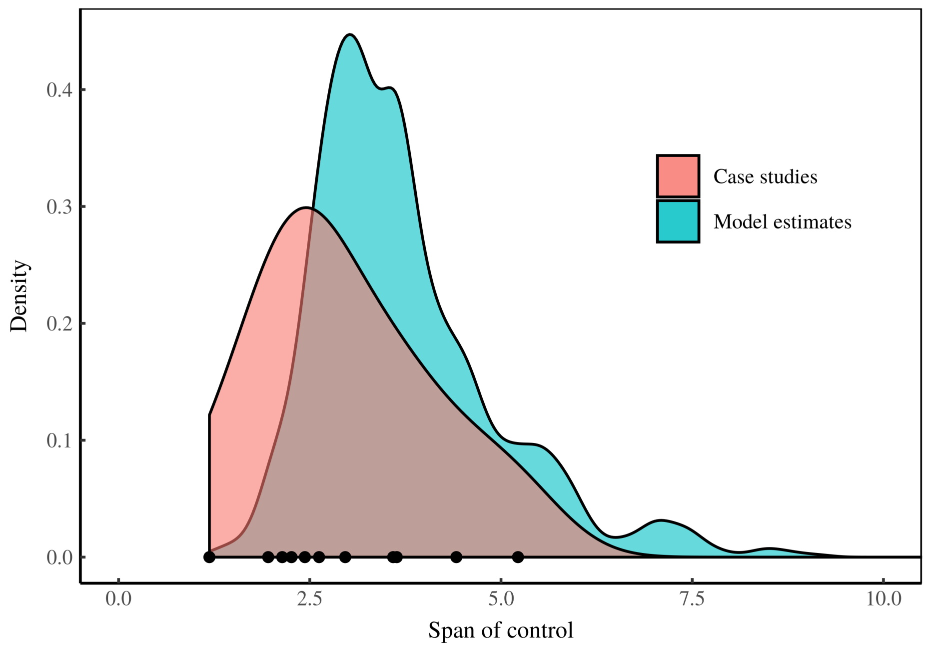

Figure 13: Span of control — empirical data and model estimates

The red distribution shows density estimates for the span of control in the available studies of firm hierarchy. Data is from [54–56, 58–64, 67, 68]. I first average the spans reported by each study, and then plot the distribution of averages. Since the density estimate comes from a small sample, I also plot the individual observations as points on the x-axis. The blue distribution shows density estimates for the span of control fitted by the hierarchy model.

References

[1] Smith A. *An Inquiry into the Nature and Causes of the Wealth of Nations*. Edinburgh: A. and C. Black. 1776.

[2] Mas-Colell A, Whinston MD, Green JR et al. *Microeconomic theory*, volume 1. New York: Oxford University Press. 1995.

[3] Hunt EK. *History of Economic Thought: A Critical Perspective*. Armonk, N.Y.: M.E. Sharpe. 2011.

[4] Keen S. *Debunking Economics: The Naked Emperor of the Social Sciences*. New York: Zed Books. 2001.

[5] Keen S and Standish R. Profit maximization, industry structure, and competition: A critique of neoclassical theory. *Physica A: Statistical Mechanics and its Applications*. 2006; 370(1):81–85.

[6] Lee F and Keen S. The incoherent emperor: a heterodox critique of neoclassical microeconomic theory. *Review of Social Economy*. 2004; 62(2):169–199.

[7] Means GC. *The Heterodox Economics of Gardiner C. Means: A Collection*. ME Sharpe. 1992.

[8] Mirowski P. *More Heat Than Light: Economics as Social Physics, Physics as Nature's Economics*. Cambridge Univ Pr. 1991.

[9] Nitzan J and Bichler S. *Capital as Power: A Study of Order and Creorder*. New York: Routledge. 2009.

[10] Pullen J. *The marginal productivity theory of distribution: a critical history*. London: Routledge. 2009.

[11] Robinson J. *Economic philosophy*. Chicago: Aldine Pub. Co. 1962.

[12] Sraffa P. *Production of commodities by means of commodities: Prelude to a critique of economic theory*. London: Cambridge University Press. 1960.

[13] Veblen T. Why is economics not an evolutionary science? *The quarterly journal of economics*. 1898; 12(4):373–397.

[14] Sober E and Wilson DS. *Unto others: The evolution and psychology of unselfish behavior*. Harvard University Press. 1999.

[15] Wilson DS and Sober E. Reviving the superorganism. *Journal of theoretical Biology*. 1989; 136(3):337–356.

[16] Wilson DS and Sober E. Reintroducing group selection to the human behavioral sciences. *Behavioral and brain sciences*. 1994; 17(4):585–608.

[17] Wilson DS and Wilson EO. Rethinking the theoretical foundation of sociobiology. *The Quarterly review of biology*. 2007; 82(4):327–348.

[18] Wilson DS and Gowdy JM. Human ultrasociality and the invisible hand: foundational developments in evolutionary science alter a foundational concept in economics. *Journal of Bioeconomics*. 2015; 17(1):37–52.

[19] Herbert S. The architecture of complexity. *Proceedings of the American Philosophical Society*. 1962; 106(6):467–482.

[20] Smith JM and Szathmary E. *The major transitions in evolution*. Oxford University Press. 1997.

[21] Margulis L. *Symbiosis in cell evolution: Life and its environment on the early earth*. W H Freeman & Co. 1981.

[22] López-García P and Moreira D. Metabolic symbiosis at the origin of eukaryotes. *Trends in biochemical sciences*. 1999; 24(3):88–93.

[23] López-García P, Eme L and Moreira D. Symbiosis in eukaryotic evolution. *Journal of theoretical biology*. 2017; 434:20–33.

[24] Sagan L. On the origin of mitosing cells. *Journal of theoretical biology*. 1967; 14(3):225–274.

[25] Grosberg RK and Strathmann RR. The evolution of multicellularity: A minor major transition? *Annual Review of Ecology, Evolution, and Systematics*. 2007; 38(1):621–654. doi:10.1146/annurev.ecolsys.36.102403.114735.

[26] Nowak MA, Tarnita CE and Wilson EO. The evolution of eusociality. *Nature*. 2010; 466(7310):1057.

[27] West SA, Fisher RM, Gardner A and Kiers ET. Major evolutionary transitions in individuality. *Proceedings of the National Academy of Sciences*. 2015; 112(33):10112–10119.

[28] Wilson EO and Hölldobler B. Eusociality: origin and consequences. *Proceedings of the National Academy of Sciences*. 2005; 102(38):13367–13371.

[29] Gowdy J and Krall L. The ultrasocial origin of the anthropocene. *Ecological Economics*. 2013; 95:137–147.

[30] Gowdy J and Krall L. Agriculture as a major evolutionary transition to human ultrasociality. *Journal of Bioeconomics*. 2014; 16(2):179–202.

[31] Richerson PJ and Boyd R. The evolution of human ultra-sociality. In *Indoctrinability, ideology, and warfare: Evolutionary perspectives*, New York: Berghahn Books. 1998; pages 71–95.

[32] Turchin P. The puzzle of human ultrasociality: How did large-scale complex societies evolve? In *Cultural Evolution: Society, Technology, Language, and Religion*, Cambridge, MA: MIT Press. 2013; pages 61–74.

[33] Lane N and Martin W. The energetics of genome complexity. *Nature*. 2010; 467(7318):929–934.

[34] Lane N. Energetics and genetics across the prokaryote-eukaryote divide. *Biology direct*. 2011; 6(1):35.

[35] Lane N. Bioenergetic constraints on the evolution of complex life. *Cold Spring Harbor perspectives in biology*. 2014; 6(5):a015982.

[36] Lane N. *The vital question: energy, evolution, and the origins of complex life*. New York: WW Norton & Company. 2015.

[37] Pennisi E. The birth of the nucleus. *Science*. 2004; 305(5685):766–768.

[38] Arendt D, Denes AS, Jékely G and Tessmar-Raible K. The evolution of nervous system centralization. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 2008; 363(1496):1523–1528.

[39] O'Donnell S. Reproductive caste determination in eusocial wasps (hymenoptera: Vespidae). *Annual review of entomology*. 1998; 43(1):323–346.

[40] Shimoji H, Abe MS, Tsuji K and Masuda N. Global network structure of dominance hierarchy of ant workers. *Journal of the Royal Society Interface*. 2014; 11(99):20140599.

[41] Turchin P and Gavrilets S. Evolution of complex hierarchical societies. *Social Evolution and History*. 2009; 8(2):167–198.

[42] Turchin P. Warfare and the evolution of social complexity: a multilevel-selection approach. *Structure and Dynamics*. 2010; 4(3).

[43] Okasha S. Multilevel selection and the major transitions in evolution. *Philosophy of science*. 2005; 72(5):1013–1025.

[44] Wilson DS. Altruism and organism: Disentangling the themes of multilevel selection theory. *The American Naturalist*. 1997; 150(S1):s122–S134.

[45] Wilson DS, Van Vugt M and O'Gorman R. Multilevel selection theory and major evolutionary transitions: Implications for psychological science. *Current Directions in Psychological Science*. 2008; 17(1):6–9.

[46] Wilson DS. *Does altruism exist? Culture, genes, and the welfare of others*. Yale University Press. 2015.

[47] Fix B. The aggregation problem: Implications for ecological and biophysical economics. *BioPhysical Economics and Resource Quality*. 2019; 4(1):1.

[48] Fix B, Nitzan J and Bichler S. Real GDP: the flawed metric at the heart of macroeconomics. *Real-world economics review*. 2019; (88):51–59.

[49] Chaisson E. Non-equilibrium thermodynamics in an energy-rich world. In A Kleidon and R Lorenz, editors, *Non-equilibrium Thermodynamics and the Production of Entropy: Life, Earth, and Beyond*, New York: Springer. 2005; pages 21–31.

[50] Kondepudi D and Prigogine I. *Modern Thermodynamics: from Heat Engines to Dissipative Structures*. Chichester: John Wiley & Sons. 1998.

[51] Schrodinger E. *What is life?: With mind and matter and autobiographical sketches*. Cambridge University Press. 1992.

[52] Boltzmann L. *Populare Schriften*. SEVERUS Verlag. 2011.

[53] Chaisson E. *Cosmic Evolution: The Rise of Complexity in Nature*. Cambridge, Mass.: Harvard University Press. 2002.

[54] Audas R, Barmby T and Treble J. Luck, effort, and reward in an organizational hierarchy. *Journal of Labor Economics*. 2004; 22(2):379–395.

[55] Baker G, Gibbs M and Holmstrom B. Hierarchies and compensation: A case study. *European Economic Review*. 1993; 37(2-3):366–378.

[56] Dohmen TJ, Kriechel B and Pfann GA. Monkey bars and ladders: The importance of lateral and vertical job mobility in internal labor market careers. *Journal of Population Economics*. 2004; 17(2):193–228.

[57] Grund C. The wage policy of firms: comparative evidence for the US and Germany from personnel data. *The International Journal of Human Resource Management*. 2005; 16(1):104–119.

[58] Lima F. Internal labor markets: A case study. *FEUNL Working Paper*. 2000; 378.

[59] Morais F and Kakabadse NK. The corporate Gini index (cgI) determinants and advantages: Lessons from a multinational retail company case study. *International Journal of Disclosure and Governance*. 2014; 11(4):380–397.

[60] Treble J, Van Gameren E, Bridges S and Barmby T. The internal economics of the firm: further evidence from personnel data. *Labour Economics*. 2001; 8(5):531–552.

[61] Ariga K, Brunello G, Ohkusa Y and Nishiyama Y. Corporate hierarchy, promotion, and firm growth: Japanese internal labor market in transition. *Journal of the Japanese and International Economies*. 1992; 6(4):440–471.

[62] Bell B and Van Reenen J. Firm performance and wages: evidence from across the corporate hierarchy. *CEP Discussion paper*. 2012; 1088.

[63] Eriksson T. Executive compensation and tournament theory: Empirical tests on Danish data. *Journal of Labor Economics*. 1999; 17(2):262–280.

[64] Heyman F. Pay inequality and firm performance: evidence from matched employer–employee data. *Applied Economics*. 2005; 37(11):1313–1327.

[65] Leonard JS. Executive pay and firm performance. *Industrial and Labor Relations Review*. 1990; 43(3):13–28.

[66] Main BG, O'Reilly III CA and Wade J. Top executive pay: Tournament or teamwork? *Journal of Labor Economics*. 1993; 11(4):606–628.

[67] Mueller HM, Ouimet PP and Simintzi E. Within-firm pay inequality. *SSRN Working Paper*. 2016; .

[68] Rajan RG and Wulf J. The flattening firm: Evidence from panel data on the changing nature of corporate hierarchies. *The Review of Economics and Statistics*. 2006; 88(4):759–773.

[69] Tao HL and Chen IT. The level of technology employed and the internal hierarchical wage structure. *Applied Economics Letters*. 2009; 16(7):739–744.

[70] Fix B. Personal income and hierarchical power. *Journal of Economic Issues*. 2019; 53(4):928–945.

[71] Fix B. Hierarchy and the power-law income distribution tail. *Journal of Computational Social Science*. 2018; 1(2):471–491. doi: 10.1007/s42001-018-0019-8.

[72] Fix B. Energy and institution size. *PLOS ONE*. 2017; 12(2):e0171823. doi:doi:10.1371/journal.pone.0171823.

[73] Axtell RL. Zipf distribution of US firm sizes. *Science*. 2001; 293:1818–1820.

[74] Gaffeo E, Gallegati M and Palestrini A. On the size distribution of firms: additional evidence from the G7 countries. *Physica A: Statistical Mechanics and its Applications*. 2003; 324(1-2):117–123. doi:10.1016/S0378-4371(02)01890-3.

[75] Newman ME. Power laws, Pareto distributions and Zipf's law. *Contemporary physics*. 2005; 46(5):323–351.

[76] Clauset A, Shalizi CR and Newman ME. Power-law distributions in empirical data. *SIAM review*. 2009; 51(4):661–703.

[77] Simon HA. The compensation of executives. *Sociometry*. 1957; 20(1):32–35.

[78] Lydall HF. The distribution of employment incomes. *Econometrica: Journal of the Econometric Society*. 1959; 27(1):110–115.

[79] Strauss G. The changing role of the working supervisor. *The Journal of Business*. 1957; 30(3):202–211.

[80] Sprules WG and Barth LE. Surfing the biomass size spectrum: some remarks on history, theory, and application. *Canadian Journal of Fisheries and Aquatic Sciences*. 2016; 73(4):477–495.

[81] Hatton IA, Dobson AP, Storch D, Galbraith ED and Loreau M. Linking scaling laws across eukaryotes. *Proceedings of the National Academy of Sciences*. 2019; 116(43):21616–21622.

[82] Mones E, Vicsek L and Vicsek T. Hierarchy measure for complex networks. *PloS one*. 2012; 7(3):e33799.

[83] Nepusz T and Vicsek T. Hierarchical self-organization of non-cooperating individuals. *Plos one*. 2013; 8(12).

[84] Bendix R. *Max Weber: an intellectual portrait*, volume 2. London: Psychology Press. 1998.

[85] Glattfelder JB and Battiston S. Backbone of complex networks of corporations: The flow of control. *Physical Review E*. 2009; 80(3):036104.

[86] Vitali S, Glattfelder JB and Battiston S. The network of global corporate control. *PloS one*. 2011; 6(10):e25995.

[87] Child J. Predicting and understanding organization structure. *Administrative Science Quarterly*. 1973; 18(2):168–185.

[88] Hamilton MJ, Milne BT, Walker RS, Burger O and Brown JH. The complex structure of hunter-gatherer social networks. *Proceedings of the Royal Society of London B: Biological Sciences*. 2007; 274(1622):2195–2203. doi:10.1098/rspb.2007.0564.

[89] Marx K. *Capital, Volume I*. Harmondsworth: Penguin/New Left Review. 1867.

[90] Samuelson PA. Understanding the Marxian notion of exploitation: a summary of the so-called transformation problem between Marxian values and competitive prices. *Journal of Economic Literature*. 1971; 9(2):399–431.

[91] Marx K and Engels F. The communist manifesto (1848). *Karl Marx: Selected Writings*. 1967; :157–186.

[92] Turchin P. *Ultrasociety: How 10,000 Years of War Made Humans the Greatest Cooperators on Earth*. Chaplin, Connecticut: Beresta Books. 2016.

[93] Wilson DS. *Darwin's cathedral: Evolution, religion, and the nature of society*. University of Chicago Press. 2010.

[94] Council SV. Lumen gentium. *Dogmatic Constitution on the Church*. 1964; 21:5–71.

[95] Wood AT. *Limits to Autocracy: From Sung Neo-Confucianism to a Doctrine of Political Rights*. University of Hawaii Press. 1995.

[96] Lewis BE and Churchill BE. *Islam: The religion and the people*. Pearson Prentice Hall. 2008.

[97] Figgis JN. *The divine right of kings*. University Press. 1922.

[98] Collins A. The divinity of the pharaoh in Greek sources. *The Classical Quarterly*. 2014; 64(2):841–844.

[99] Gelfand M. *Rule Makers, Rule Breakers: Tight and Loose Cultures and the Secret Signals That Direct Our Lives*. Scribner. 2019.

[100] Friedman M. *Capitalism and Freedom*. Chicago: University of Chicago press. 1962.

[101] Friedman M and Friedman R. *Free to choose: A personal statement*. Houghton Mifflin Harcourt. 1990.

[102] Mankiw NG. *Principles of microeconomics*. Mason, OH: South-Western, Cengage Learning, 6th edition. 2012.

[103] Brown PG and Timmerman P. *Ecological economics for the anthropocene: An emerging paradigm*. New York: Columbia University Press. 2015.

[104] Dunbar RI. Coevolution of neocortical size, group size and language in humans. *Behavioral and Brain Sciences*. 1993; 16(04):681–694.

[105] Dunbar RI. What makes the Neolithic so special? *NEO-LITHICS*. 2013; 13.

[106] Hayden B. Richman, poorman, beggarman, chief: The dynamics of social inequality. In *Archaeology at the Millennium*, Springer. 2001; pages 231–272.

[107] McNeill JR and Engelke P. *The great acceleration: An environmental history of the Anthropocene since 1945*. Harvard University Press. 2016.

[108] Steffen W, Broadgate W, Deutsch L, Gaffney O and Ludwig C. The trajectory of the anthropocene: the great acceleration. *The Anthropocene Review*. 2015; 2(1):81–98.

[109] Arnsperger C and Varoufakis Y. What is neoclassical economics? the three axioms responsible for its theoretical oeuvre, practical irrelevance and, thus, discursive power. *Panoeconomicus*. 2006; 53(1):5–18.

[110] Backhouse RE. *The puzzle of modern economics: Science or ideology?* Cambridge University Press. 2010.

[111] Heilbroner R. Economics as ideology. In *Economics as discourse*, Springer. 1990; pages 101–128.

[112] Hodgson GM. *Is There a Future for Heterodox Economics?: Institutions, Ideology and a Scientific Community*. Edward Elgar Publishing. 2019.

[113] Hoover KR. *Economics as ideology: Keynes, Laski, Hayek, and the creation of contemporary politics*. Rowman & Littlefield Publishers. 2003.

[114] Hunt EK. *Property and Prophets: The Evolution of Economic Institutions and Ideologies*. New York: Routledge. 2016.

[115] Martin DA. Economics as ideology: on making "the invisible hand" invisible. *Review of Social Economy*. 1990; 48(3):272–287.

[116] Samuels WJ. Ideology in economics. In *Essays on the Methodology and Discourse of Economics*, Springer. 1992; pages 233–248.

[117] Söderbaum P. Economics as ideology. In E Fullbrook, editor, *Pluralist Economics*, Zed Books London. 2008; pages 117–127.

[118] Carter SB, Gartner SS, Haines MR, Olmstead AL, Sutch R and Wright G. *Historical statistics of the United States: millennial edition*, volume 3. Cambridge: Cambridge University Press. 2006.

[119] Gillespie CS. Fitting heavy tailed distributions: the poweRlaw package. *arXiv preprint arXiv:1407.3492*. 2014; :1–16.

[120] Sanderson C and Curtin R. Armadillo: a template-based C++ library for linear algebra. *Journal of Open Source Software*. 2016; 1(2):26.