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A Theory of Community Formation and Social Hierarchy

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Abstract
We analyze the classic problem of sustaining trust when cheating and leaving trading partners is easy, and outside enforcement is difficult. We construct equilibria where individuals are *loyal* to smaller groups – communities - that allow repeated interaction. Hierarchies provide incentives for loyalty and allow individuals to trust agents to extent that the agents are actually trustworthy. We contrast these with other plausible institutions for engendering loyalty that require inefficient withholding of trust to support group norms, and are not robust to coalitional deviations. In communities whose members randomly match, we show that social mobility within hierarchies falls as temptations to cheat rise. In communities where individuals can concentrate their trading with pre-selected members, hierarchies where senior members are favored for trade sustain trust even in the presence of proximate non-hierarchical communities. We link these results to the emergence of trust in new market environments and early human societies.

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Table of contents

1 Introduction

A long-standing puzzle in economics concerns how individuals maintain trust despite short-term incentives to cheat. Almost every type of exchange involves some sort of moral hazard problem, whereby the individual providing a good or a service may shirk on quality or effort, or fail to deliver the good. An enormous literature seeks to use the theory of repeated games to suggest solutions to this problem. In long-term bilateral relationships, the breakdown of future cooperation provides an incentive for cooperation. However, in larger groups, the probability of future interaction with the same individual may be small, and even worse, it may be possible for a cheater to make choices (such as relocating) to actively avoid those he has cheated in the past.

In the face of such fundamental challenges to cooperation in large groups, several natural alternatives can be considered (in Section 2, we review the literature in more depth). The first, which do not consider in this paper, is the *rule of law*. Here, we focus on settings where legal institutions are limited in their ability to enforce trust. The second is *community enforcement*: all individuals in a society agree to jointly punish defectors. This type of approach has limited value when individuals have the opportunity to *cheat and leave*, and the community enforcement technology does not extend across all potential trading partners. A third class of alternatives recognizes the crucial role of *loyalty*: strategies that provide incentives for individuals to concentrate their trust relationships with known partners over time. Our paper fits into this category.

Several perspectives on loyalty exist. One is that individuals differ in their innate propensity for good behavior, and individuals attempt to signal their type by cooperating. Loyalty is engendered because new trading partners are not known to be honest, and the signaling process takes time. In this paper, we set aside unobserved individual heterogeneity, and instead analyze other forces that can support loyal relationships.

We build a very simple model of a large population playing bilateral trust games. We consider several assumptions that enable rich and realistic behavior to emerge. First, we allow players to form *communities*. Technically, we allow players to choose a location, a choice that limits their ability to play trust games to other players that also chose that location in that period. However, individuals can relocate in every period, capturing the idea that players can cheat and leave. Second, we consider various technologies for *record keeping* within a community. The record keeping is limited, however; all current members of a community can see how long others have attended that community, as well as a uni-dimensional *status* which depends on public randomization but not in any way on any individual's trading history.

Third, a key exogenous parameter of the model, which we refer to as *trading selectivity*, is the extent to which a subset of community members can serve all of the trading needs of the community. This parameter is motivated by differences in the kinds of trust exchanges that could occur in the real world. Taking the location analogy literally, in a town or a neighborhood, you sometimes encounter people randomly, and have the opportunity to create value through trust. A neighbor can hold the door for you, help you carry your bags, warn you of a pothole ahead, sign for your package and deliver it to you, or call a doctor if you faint on the street. These trust opportunities arise due to proximity, and individuals cannot easily make choices to only interact within a small set of established relationships. By choosing your location, you inherently choose to interact with community members. A second type of interaction entails more choice in the selection of partners. For example, an individual may need advice or information, or they may need to procure goods or small amounts of labor where quality is difficult to contract upon. Then, an individual might be able to choose to interact with only certain individuals in a community; in such cases some individuals might engage in more trade than others. In our model, the only publicly observed characteristics of individuals are the length of their attendance and their *status* (the outcome of public randomization that depends on their attendance) so it is natural to consider that high status individuals would be selected more often for trade. Our paper analyzes only two polar cases, full trading selectivity and no trading selectivity, where in both cases trade must take place within a community. We compare the types of equilibria that can be sustained and their robustness properties across these two polar cases, noting that most real-world environments entail a range of trust interactions including both types of trading selectivity as well as intermediate cases.

Using our model, we proceed in several steps. First, we examine equilibria of a type that have been considered in the literature in the past in the context of our model. In these *identity investment equilibria*, individuals are forced to make costly (and wasteful) investments of either time or resources in order to start trading in a community. These investments may take a number of forms, including *culture-specific* investments or the costs of traveling to a specific physical location. Identity investment equilibria serve as a benchmark for the novel equilibria we introduce in our paper. Though natural, we critique these equilibria on several grounds. First, focusing on the *no trading selectivity* case, individuals artificially withhold trust from certain agents. They fail to trust certain individuals and thus lose out on valuable opportunities to create surplus, not because the individuals cannot be trusted (that is, not because it is impossible for their *cooperate* rather than *cheat and leave* incentive constraints to be satisfied), but rather to uphold a social convention. Furthermore, upholding that convention does not benefit a community itself: the community as a whole would create more expected surplus if it abandoned the convention of requiring new members to make investments. An individual community sustains trust because *other* communities impose entry costs, not because they play any role in the community itself. Thus, a coalitional deviation where all members of a community abandoned the initial investment requirement would benefit the community. On the other hand, if any single community did that, trade would break down in other communities.

This motivates us to propose several alternative structures for equilibria that sustain cooperation. We begin with the no trading selectivity case. There we develop what we call a *maximal trust hierarchical equilibrium*. In this equilibrium, when a trading opportunity arises between two individuals, trust–which in our model can occur at different scales– is always *maximal*: individuals trust one another up to the point where an agent is just indifferent between working and a cheat and leave strategy. The equilibrium is also *hierarchical*: agents with higher *status* are trusted more. As we will develop in the paper, a key feature of the equilibrium is that advancement to higher status– which can be thought of as *social mobility*– is probabilistic.

Once we have established conditions under which maximal trust hierarchical equilibria exist, we analyze more deeply the structure of the equilibria, as well as compare different equilibria in the class. We analyze the distribution of income, and look at tradeoffs between equality and efficiency.

Next, we turn to analyze the *trading selectivity* case. In this setting, we look at equilibria where trades are concentrated on agents with higher status. Newcomers to a community on average have low status. We show that communities that employ these structures are robust in an interesting and novel way. Even if another community adopts a more *egalitarian* structure, individuals will still choose to join the communities with a hierarchical structure. This contrasts with identity investment equilibria, where the existence of a community that trusts newcomers undermines trust in other communities.

After developing the theoretical results, we then relate these results to three real-world applications. We apply our results to understanding the puzzling emergence of hierarchies among early human societies, to the development of impersonal citizenship, illustrated by the Roman Republic, and to the sustenance of trust in settings as different as marketplaces in modern Nigeria and in online communities. Though separated by time and geography, all our examples share the commonality of a challenging contracting environment, with increasing population sizes and the possibility of cheating and leaving for alternative venues. We trace how hierarchies emerged in each environment, and how hierarchies may be interpreted as providing a means of facilitating trust.

2 Existing Theoretical Perspectives

Our paper builds upon literatures on the importance of trust in economic development, on social networks and in historical political economy. The issue of cooperation based on reciprocity has attracted the attention of both social scientists (e.g. Kranton, 1996b) and evolutionary biologists (see Nowak and Sigmund (2005) for a survey.) The problem of sustaining trust in particular has long been seen as a fundamental question in economic development, and economics more generally (Arrow, 1974, McMillan, 2002).

Beyond the classic folk theorems, theorists traditionally focus on two types of mechanisms that overcome the trust problem: those that signal reputations and those that require third party enforcement. In reputation-based models, players learn about the others' type as honest or opportunistic as the relationship progresses. Equilibria in which more senior individuals are accorded more trust emerge as a result of these inferences (eg Sobel, 1985, Watson, 1999, Ghosh and

Ray, 1996)). Our formulation exhibits an analogous equilibrium dynamic without any unobserved individual heterogeneity. We also differ from an important line of research on cooperation in groups that employs multi-lateral enforcement among delimited coalitions, following Greif (1993) and Kandori (1992), by examining settings where multi-lateral enforcement is not possible and populations can be arbitrarily large.[1]

Dixit's (2003) study of trade expansion and enforcement is similar in motivation to ours. He uses a circular world as a geographical analogy for the costliness of information flows across distances, and examines how much cooperation can be sustained as the circle grows in size. He finds that small and large worlds can sustain greater trust than their intermediate counterparts. In small worlds, partners to a transaction are likely to know third parties in common, and thus are able to share information about defectors. In large worlds, developing a legal system becomes economical. In contrast, our model focuses on the case where information sharing about behavior within bilateral relationships is not possible.

Beginning with Klein and Leffler (1981), the role of specific investments or "cultural capital" has assumed an important role in research into trust. For example, Iannaccone (1992) applies the notion of specific investments to cults that provide club goods. There is an incentive to free-ride upon others' zealousness. In order to limit participation to the truly committed, religious practices, such as stigma and self-sacrifice develop to act as screening devices. Similarly, Fryer (2002) allows for identity-specific investments among African Americans and compares their effects on within-market trust with that of investing in general human

[1]For example, Woodruff (1998) finds that Mexican footwear manufacturers were also able to maintain trust through third party enforcement mechanisms and information sharing. In a manner analogous to Greif (1993)'s classic example of the Maghribi medieval traders, such trust is supported by multilateral enforcement among small, culturally homogeneous groups, underpinned by the threat of ostracism from the community or business coalition.

A feature of such identity-based mechanisms, as we will show, however, is that such groups fail to support cooperation when group sizes are large, there is limited information sharing that prevents third party enforcement and where the availability of alternative trading partners make it easy to cheat and leave, and thenceforth avoid the cheated party.

Furthermore, even when there some random chance of re-encountering a cheated party, such mechanisms require high degrees of coordination to sustain– coordinated barriers to entry in each group are raised to prevent cooperation failing in *other* groups. The relaxation of such barriers by any group coalition will lead to a failure in cooperation in all. Indeed, as Woodruff describes, third party enforcement and cooperation among Mexican footwear manufacturers appeared to break down as new opportunities to trade with the US emerged with trade liberalization, allowing alternative trading partners outside the coalition.

capital or "acting white."[2] These works, however, take both the set of identities and prescriptions to be exogenous.

The intuition underlying the identity-investment equilibrium– using barriers to entry such as costly "gifts" into new relationships to sustain cooperation in old relationships– has been noted by a number of important studies (eg Kranton, 1996a, Carmichael and Macleod, 1997, Ramey and Watson, 2001)). The focus of these studies has however chiefly been two-agent partnerships rather than broad groups.

Research has also begun to examine the role of such conventions for sustaining cooperation in groups. The role of membership fees in engendering loyalty to "insiders" with whom such costs have not been incurred has been explored by Board (2008), and the role played by time in acting as such a membership fee has been explored by Friedman and Resnick (2001) in the context of internet chat rooms. Sobel (2006) analyzes a model where individuals in a large population form bilateral relationships. He contrasts relational contracts with formal contracting as mechanisms for sustaining trust. As in our model, it can be inefficient for partnerships to be exclusive in every period. Sobel's model has relationships that permanently "grow stale."In his model, relationships based on relational contracts may last inefficiently long, because the institutions that support cooperation must entail costs of starting new relationships. In contrast to this model, and the literature on cooperation in social networks, in which ties are based upon individual trading histories (eg Jackson, 2003, Bloch, Genicot, and Ray, 2008), the social hierarchies we construct are "impersonal" in the sense that the actual agents in the hierarchy can change but they inherit the incentives of their rank and thus fully efficient exchange can be sustained. This is a distinct advantage of social hierarchies that has not to our knowledge been explored in the economics literature.[3]

[2]In using the term "identity" we follow Akerlof and Kranton (2000). We differ, however, in the form that identity takes. In their formulation, group "identity" enters into individuals' utility functions. These identities and the associated "prescriptions" for behavior result in individual and group sanctions for violators of the group "code of conduct."

[3]The key distinction between an agent's rank and their personal identity naturally has a long tradition in sociology. In particular, we build on and further work, at least as early as White (1970), on mobility in hierarchical organizations and "chains of vacancies" created by openings at higher ranks of hierarchies (see also Gibbons (2005)). Specific identity investment also has parallels in an important literature, beginning with Kreps (1990), on the role of "corporate culture". Culture can create value for the firm through variety of means, including reducing

Thus, cooperative equilibria based upon the existence of barriers to form new relationships occupy a prominent role in theories of trust.[4] An important focus of our study is to analyze the robustness properties of such identity investment equilibria in environments where some groups adopt social hierarchies and there may be insurgent egalitarian groups that lower barriers to entry entirely.[5] Our analysis also differs from much of the existing literature on trust in its focus on endogenous group formation, hierarchical structures, and the problems associated with increasing population size.[6] It links and contributes instead to important literatures looking at cultural transmission (eg Boyd and Richerson, 1994, Bisin and Verdier, 2011, Doepke and Zilibotti, 2013) and the origins of hierarchy and formation of state-like institutions (Bates, Greif, and Singh, 2002, Besley and Persson, 2009, North, Wallis, and Weingast, 2009, Bowles and Choi, 2013, Seabright, 2013, Dow and Reed, 2013, Boix and Rosenbluth, 2014, Mayshar, Moav, Neeman, and Pascali, 2015), as we describe below.

3 The Model

We take as our departure point the classic Shapiro and Stiglitz (1984) model of moral hazard and unemployment in the job market, a useful benchmark for examining trust in trade relationships (Greif, 1993).

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costs of coordination and communication and improving commitment by managers (see also Hermalin (2010).) Homogeneity within firms can happen through selection and through learning and indoctrination (Van den Steen, 2005) which can also be thought of as specific investments in the firm culture or identity. Thus, though we abstract from the potential productive roles of identity investment, our discussion of the relative robustness of hierarchies and identity investment equilibria can shed light on the relative robustness of trust-enhancing aspects of corporate culture as well.

[4] A notable exception to the focus on entry barriers to sustain trust is work by Lindsey, Polak, and Zeckhauser (2003), who incorporate the notion of itinerant temptations into their study of long-term bilateral, exclusive relationships between individuals where there is "free love": no barriers to a new start. Existing relationships gain value the longer they exist. This makes them robust to break-ups. However, this occurs for different reasons in our model: in the social hierarchies we construct, senior agents engender more trust.

[5] In comparing the competitiveness of alternative forms of social organization, our paper has natural links to research in organizational ecology (e.g. Hannan, Polos, and Carroll (2007)) as well as reciprocity in traditional societies exposed to the market (Kranton, 1996b).

[6] The role played by subgroup defection in limiting patterns of cooperation in larger communities has also been studied by Genicot and Ray (2003) in the context of risk-sharing. We abstract from the risk-sharing advantages of having larger groups in our study.

The game takes place over an infinite horizon with periods indexed by t. There is a stationary population of P players, with P even. Each individual survives with probability δ every period, where survival is independent across individuals. When a player dies a new player inherits his index with a null history. Trade among individuals takes place within M communities which can be thought of as actual geographical marketplaces, virtual communities or simply groups of people who recognize each others' affiliation. At the beginning of each period, all surviving individuals select a community. For simplicity, we assume that newly-born individuals select communities only after the survivors make their selection, and that individuals choose in sequence so that we can find strategies that guarantee that all communities have equal size. Furthermore we assume that P is so large that moving to a different community is always an option.[7]

Individuals engage in trading in pairs. At the beginning of each period individuals are randomly matched to each other. Each pair has a principal and an agent. For simplicity, all individuals are assumed to play both roles every period. Therefore P trust games are played in every period (or $N := P/M$ trust games within each equal-sized community). The randomization ensures that each individual is an agent to no more than one principal and a principal to no more than one agent. After being matched, the principal chooses how much to trust the agent, offering a scale of trade $\lambda \in [0, 1]$ to the agent. Then, if the agent works, payoffs are $(\lambda R, \lambda w)$ to the principal and agent, respectively. If an agent shirks, payoffs are $(-\lambda r, \lambda s)$. We assume $w < s$, $r > 0$ and $R + w > s - r$, so shirking is inefficient. R gives principals an incentive to trust *as much as possible*. To simplify the analysis we assume that R is positive albeit arbitrarily small. Formally this is $R = 0$.[8]

Each player observes personal bilateral trade histories between themselves and any other player from birth to the current period, but does not observe trades to which they are not a party. In addition, we allow the players to employ several

[7]Formally, when we consider incentive constraints that specify that an individual prefers to cooperate than to *cheat and leave*, we ignore the possibility that other communities cannot accommodate an agent who seeks to leave their current community. This is a conservative treatment of the incentive constraints.

[8]Keeping the reward to the principal arbitrarily low in this way is beneficial for algebraic tractability: we can avoid carrying a constant term R around. When analyzing hierarchical equilibria, this assumption also allows us to avoid the need to iteratively determine the distribution which is appropriate for a given advancement process, since the equilibrium distribution of individuals over seniority levels is endogenous.

different kinds of public randomization devices, which we will describe in more detail below. These randomization devices map from each members' histories of *status* to their current *status*, with both status histories and each member's status observed publicly within each community. Note that this randomization device does not add anything to the observability of trading histories, but instead simply introduces a public history with public randomization. We will provide more details when those are used, and in environments where public randomization is payoff-irrelevant, we simply omit reference to the realization of these devices, implicitly assuming that players simply ignore them.

A *period trading strategy* is a mapping from the set of all possible bilateral trading histories, and set of all possible status histories to the following choices: (i) which community to attend today, (ii) as principal how much to trust each agent, and (iii) as agent whether to shirk or work for each potential principal as a function of the trust level granted.

Since we are interested in robust institutions, we focus our attention on incentive provision via one period punishments. By limiting our attention to punishments that last one period, rather than grim trigger or other more extensive punishments, we naturally make it *harder* to support cooperation for a given level of patience and group size.[9] We will use the same simplification in all of the different strategy profiles we study, allowing us to compare outcomes across different types of equilibria faced with similarly challenging conditions for enforcing contracts.

'Institution-Free' Equilibria

To benchmark the importance of institutions, we first consider classes of (potential) sequential equilibria that are *institution-free* in the sense that individuals condition only on their bilateral trading history when determining trust. Not surprisingly, the combination of repeated interaction and a sufficiently high de-

[9]This simplification also allows us to avoid a technical complication: when players punish one another by refraining from trade forever, in some cases we analyze they might contemplate fairly complex strategies, where they accumulate a set of "enemies" in one community (principals they cheated in the past) before leaving for another community. By focusing on one-period punishments we avoid this complication.

gree of patience enables cooperation despite a large number of individuals and alternative trading partners.

Consider institution-free strategies, which specify that traders randomize uniformly over communities in every period. Players perceive it as equally likely to be matched with all other individuals in the population, as if there were no communities at all. On the equilibrium path, principals maximally trust, and agents work if and only if they are maximally trusted. Deviations from the strategy above at any time t trigger a one period reversion to the static equilibrium of shirk and zero trust in period $t+1$.

It is straightforward to show that these strategy profiles constitute an equilibrium if and only if:

$$(s-w) \leq \frac{\delta^2}{P-1} w. \tag{1}$$

The left hand side is the maximum short term gain from deviating. The right hand side is the expected lost stream of trading surplus due to the breakdown of bilateral cooperation in $t+1$. This loss from deviating is the lost payoff w from serving as an agent, discounted by the probability that both individuals survive in the next period, multiplied by the (subjective) probability that the two individuals will be randomly matched to one another in the sub-game starting after the deviation occurred.[10]

Equilibria Based On Identity Investments

As discussed above, one way of sustaining cooperation as populations grow is to require individuals to make *specific* investments in a cultural identity that marks them as members of a community. Such investments can take a number of forms, depending on the exogenous dimensions available through which groups may assert distinction between one another and conformity within themselves (e. g. ethnic or racial markers, language, culture, physical location, religious or ethical codes). Such investment can be either publicly observable or simply required to

[10]Note that the condition above could have been maximally weakened had we considered equilibrium profiles in which a one time deviation leads to a 'grim trigger'– an infinite replication of the stage-game equilibrium with shirking and no trust forever thereafter. In that case, the right side of (1) should be replaced by $\frac{\delta^2}{1-\delta^2}\frac{1}{P-1}$, i.e. the lost stream of future trading surplus due to the permanent loss of reciprocal trust.

join existing communities. Suppose that in order to start afresh in a new group individuals are required to make an investment m. Identity investment strategies are defined as follows: in $t = 1$ individuals pay m and select communities to equalize size ($N := P/M$); at the beginning of each $t > 1$ individuals come back to the same community if neither $t-1$ partner deviated in past play. On the equilibrium path individuals are fully trusted ($\lambda = 1$) and work when trusted. The punishment phase triggered by a deviation to the above is a one period *Nash reversion* to the *static* equilibrium of no trust and shirk if the cheating agent were to be paired once more with the cheated principal in the following period.

Proposition 1. *An equilibrium in identity investment strategies exists if and only if*

$$s - w \leq \delta m, \tag{IC_L}$$

$$s - w \leq \frac{\delta^2}{N-1} w \quad \text{and} \tag{IC_R}$$

$$m \leq \frac{w}{1-\delta}. \tag{IR}$$

(See the appendix for a formal argument.) The (IC_R) provides incentives to cooperate *within* groups. It is the analogue of (1) at the group (rather than at the population) level. The (IC_L) requires the short term gain to be lower than the future loss incurred due to individuals migrating to different groups to avoid their current trading partners.

Notice that (IR) and (IC_L) imply $s \leq w/(1-\delta)$. If the short term gain from deviating exceeds the maximum long term loss (that is an expected payoff of zero after deviating) then cooperation cannot be supported. The minimum investment required to guarantee cooperation is $(s-w)/\delta$, and cooperation can be sustained for lower degrees of patience as the groups shrink in size, with minimal patience required for groups of size two: there are no gains from having larger groups.

In an identity investment equilibrium, a reduction of distance between communities may make the assertions of ethnic or cultural differences become *more* desirable as they allow the creation of entry barriers and investments that sustain cooperation. Thus the need to sustain cooperation within communities can lead to increased cultural separation between them. Indeed, Fryer (2002) provides a compelling account of the costs of African Americans of being perceived to be

“Acting White” in mixed neighbourhoods, and how overt cultural markers of identity are used to sustain cooperation in those communities.[11]

Though identity investment equilibria have real-world analogues, it is important to note that they also have several unattractive robustness features. First, they are not robust to coalitional deviations of a particular kind. Specifically, the role of the investments required by one group is to sustain cooperation in *other* groups. The fact that other groups require investments to join makes it unattractive to cheat and leave. But a given community could simply stop requiring investments, and it would not be affected as long as all other communities do. And indeed, if an individual arrived in a community and did not make the required investment, the identity investment strategies require individuals to withhold trust from the individual, incurring a loss of potential surplus, even though that individual could be deterred from cheating given that all other communities require investments.

This highlights the second unattractive feature of this class of equilibria: the strategies require withholding trust from *trustworthy* individuals. By this we mean that the individual would find it more profitable to work when trusted than to cheat. Indeed, the individual can only be induced to cheat when trusted in this scenario (as required by the identity investment strategies) by the threat of withholding future trust if the player does not cheat. In the rest of the paper, we develop alternative equilibria that also induce loyalty, but that address at least the latter concern, and in some cases the former concern as well.

Hierarchical Institutions

A hierarchical structure consists of three elements: a number of members, a set of labels that describe the seniority levels of new and existing members and a stochastic *advancement process* that describes how these labels evolve over time.

Formally, a “hierarchical structure” is defined as a tuple $(N, [0, 1], g)$. The

[11] It is also possible to study a closely related set of strategies, whereby players refrain from trading with newcomers when matched with them, or reduce their level of trade with newcomers (as in Friedman and Resnick (2001)). The incentives created by this type of *initiation* requirement are similar, but they also impose costs on senior members of a community who are matched with newcomers, creating additional inefficiency.

interval $[0,1] \subset \mathbb{R}_+$ is the set of seniority labels. $g : [0,1] \times [0,1] \to \mathbb{R}_+$ is a functional that describes the process of advancement between levels of seniority: $\int_{l'}^{l''} g(\tilde{l}, l) d\tilde{l}$ is the (subjective) probability that an individual who attained seniority l in the previous period acquires a new seniority in $[l', l'']$ conditional on surviving. Communities keep a public record of members' seniority levels. At the beginning of every period new seniorities are drawn according to the above process and the public record is updated. For those individuals with no previous record (newcomers) their initial level is drawn according to density $g(l, 0)$. That is, it is as if their previous period seniority were zero. Note that the advancement process g is specified as part of the equilibrium. We, however, restrict attention to those advancement processes that have the following features:

$$g > 0 \text{ at all } (\tilde{l}, l) \text{ with } l \leq \tilde{l} \text{ and } 0 \text{ otherwise,} \tag{2}$$

$$g(\tilde{l}, \cdot) \text{ monotone increasing,} \tag{3}$$

$$\lim_{l \to 1} \int_{l}^{1} g(\tilde{l}, l) d\tilde{l} = 1, \tag{4}$$

$$g \text{ continuous and differentiable at all } (\tilde{l}, l) \text{ with } l < \tilde{l}. \tag{5}$$

(2) restricts the advancement process between levels to only allow individuals to move upward or stay where they are.[12] (3) requires that individuals with higher seniority enjoy an advantage over lower ranked individuals in their prospects for promotion to a rank further up the ladder. In other words, the larger the gap between the current level and the new level, the lower the chances of making it to the new level. (4) is a weak technical requirement. It captures the idea that an individual at the top level ($l = 1$) remains at the top with probability one if they survive. (5) disallows discontinuous or non-smooth jumps in the probability of promotion.

It is important to note that the stochastic process that describes how seniority evolves over time is memoryless and anonymous. Further, the probability of moving from level l to some level l' does not depend on past realizations or on the individual's identity and trades. This concept of hierarchy therefore differs from one of centrality within social networks, that is based upon past trades or ties that link specific individuals.

[12] We also allow individuals to *fall from grace*– descend the hierarchy– in a limited sense, by allowing them to start anew in a different community.

Define *maximal trust hierarchical strategies* as follows: individuals select communities so that the communities are symmetric in size (i.e. $N := P/M$). On the equilibrium path, individuals always come back, l types are trusted at scale l and work. All $l < 1$ individuals are indifferent between working and shirking, so trust is maximal.[13] In the continuation game after any one stage deviation to the above, the principal always returns and the agent always leaves. The punishment phase triggered by a deviation from the above by either individual in $t-1$ or t is a one period reversion to shirk and no trust in period t provided the individuals are matched once more with each other.

A *maximal trust hierarchical equilibrium* (abbreviated HE) is a function g and a set of *maximal trust hierarchical strategies* such that: (i.) given g, the strategies constitute a sequential equilibrium of the underlying game; (ii.) group size is as large as possible to preserve equilibrium existence given the exogenous parameters of the environment; (iii.) g satisfies requirements (2) – (5).

Let $v(l)$ be the optimal value functional on the equilibrium path for an individual of seniority l in a particular community after they have chosen to go to that community but before the random advancement process and trust transaction takes place. If a HE exists, an individual of seniority l's period payoff along the equilibrium path is simply lw. Thus we can express $v(l)$:

$$v(l) = \int_l^1 g(\tilde{l}, l)(\tilde{l}w + \delta v(\tilde{l}))d\tilde{l} \tag{6}$$

The following proposition characterizes a HE as the solution to a system of functional equations.

Proposition 2. *A HE exists if and only if there is a triplet* $(N, g(\cdot), v(\cdot))$ *such that for all seniority levels* $l \in [0, 1]$*, the following conditions hold:*

$$l(s-w) \leq \delta(v(l) - v(0)), \qquad \textit{with equality if } l < 1. \tag{IC_L}$$

$$l(s-w) \leq \frac{\delta^2}{N-1} w \int_l^1 g(\tilde{l}, l)\tilde{l}\, d\tilde{l}, \qquad \textit{with equality if } l = 1, \tag{IC_R}$$

The left hand side of both (IC_L) and (IC_R) is the period gain for an individual

[13] Type $l = 1$ is already granted maximal trust by definition and therefore there is no need to worry about the agent's incentives if she were to be trusted 'more' off the equilibrium path.

trusted at seniority level l from cheating over cooperation. The (IC_L) constraint ensures individuals prefer cooperation to strategies where they *cheat and then leave*, starting anew elsewhere.

The (IC_R) rules out cheat and return defections. The right hand side is the expected punishment conditional on returning, which depends on the probability of both parties surviving and being rematched, and an individuals' expected trust the next period. Notice that it is hardest to satisfy for the most senior $(l = 1)$ types, as for them the ratio of current to future trust is highest (it equals one), and thus the temptation to defect today is greatest relative to the expected loss in future trust in the punishment phase. Our focus on equilibria without any artificial withholding of trust is captured by the requirement that the (IC_L) binds for all types $l < 1$. Similarly, the focus on maximal size communities implies that (IC_R) must be binding whenever $l = 1$.

To allow us to solve for the equilibrium, we further restrict g to belong to the following family of advancement processes, parameterised by $b \in (0, 1)$:

$$g(\tilde{l}, l) = \frac{1 - b}{b} \times \frac{(1 - \tilde{l})^{\frac{1}{b} - 2}}{(1 - l)^{\frac{1}{b} - 1}}. \tag{7}$$

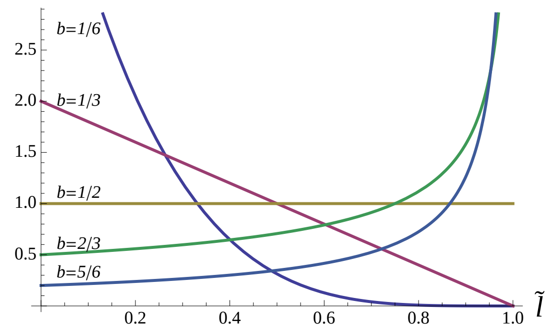
This parametrization allows us to capture *social mobility* within the community in a straightforward way. Let $\mu_{\tilde{l}|l}$ denote the expected seniority $\tilde{l}$, given current seniority l:

$$\mu_{\tilde{l}|l} = \int_l^1 g(\tilde{l}, l)\tilde{l}\ d\tilde{l}$$

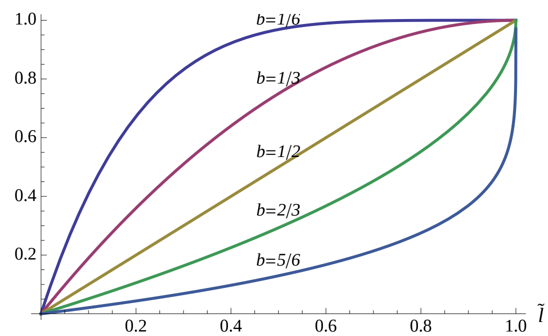
Observe that:

$$\mu_{\tilde{l}|l} = l + b(1 - l) \Leftrightarrow b = \frac{\mu_{\tilde{l}|l} - l}{1 - l}. \tag{8}$$

Although imposing a functional form for g is obviously restrictive, the form still allows for a rich family of advancement processes. The parameter b can be interpreted as the proportion of the remaining gap an individual faces between current seniority and the highest possible level of seniority that the individual expects to cover in one period, conditional on surviving. Recalling that l is normalized so that it indicates the level of trust in the HE, it is thus it is a gauge of *social mobility* (see Figure 1). When $b \to 1$, all individuals expect to get to the top in one period– i.e. there is extreme mobility, and individuals are trusted fully after their initial period. When, $b \to 0$ for all $\tilde{l} > l$, then $g(\tilde{l}, l) \to 0$, i.e. there is



(a) Density $g(\tilde{l}, 0)$

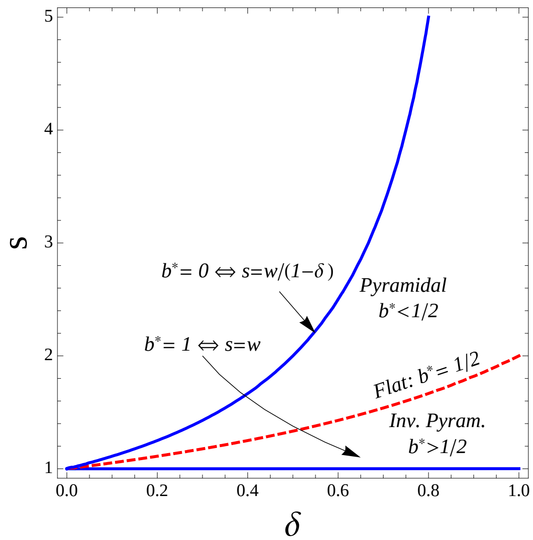


(b) Cumulative density $\int_0^{\tilde{l}} g(x, 0)dx$

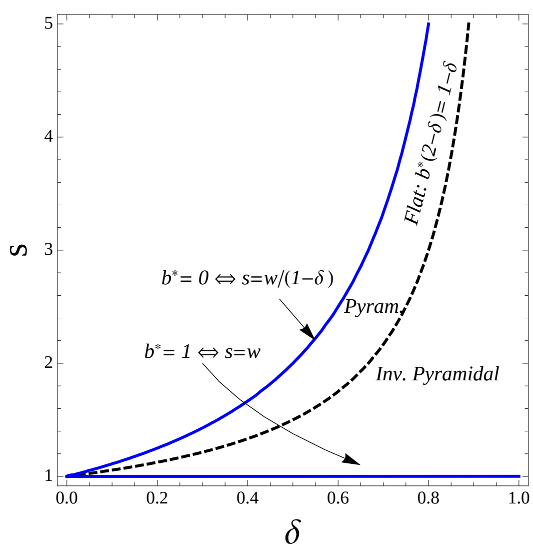
Figure 1: **Advancement Probabilities as Seniority Rises, by Social Mobility**: The figure shows how the advancement probability and cumulative distribution changes at different levels of seniority $\tilde{l}$ for different levels of social mobility b. Notice that for $b = 1/2$, the graph is flat: advancement is independent of current seniority. For $b > 1/2$, there is *higher social mobility*: newcomers advance faster, and advancement slows as they become more senior. With $b < 1/2$, there is *limited social mobility*: newcomers advance more slowly, and advancement accelerates with seniority.

no mobility. An intermediate case is $b = 1/2$. In this situation, the probability of advancement for an individual of seniority l is uniform between l and 1, and thus each period, each individual expects to cover half the distance between their current seniority and the top rank of $l = 1$.

Next we characterize the b^* (and the associated equilibrium) that satisfies the requirements of an HE. Recalling that we define an HE to have maximal group size such that the other requirements are satisfied, this b^* is unique.



(a) HE Existence region in the (δ, s) space (enclosed by solid blue lines) and shape of the equilibrium advancement process g^* $(w = 1)$.



(b) HE Existence region in the (δ, s) space (enclosed by solid blue lines) and shape of the steady state distribution f^* for $(w = 1)$.

Figure 2

Proposition 3. *If and only if* $s < \frac{w}{1-\delta}$, *a HE exists and is unique with:*

$$v^*(l) = \frac{w}{1-\delta} - (1-l)\frac{s-w}{\delta} \tag{9}$$

$$b^* = 1 - \frac{s-w}{\delta s} \tag{10}$$

$$N^* = \frac{\delta^2 w}{s-w} + 1. \tag{11}$$

First, observe that, perhaps surprisingly, the existence regions for HE and the identity investment equilibrium coincide. Both require $s < w/(1-\delta)$, which requires that shirking can be deterred with a maximal punishment of no trade in future periods. In the HE, when s is close to $w/(1-\delta)$, the hierarchical structure has very low mobility ($b^* = 0$), so that starting over in a new community is very unattractive. The HE has a number of attractive features relative to the identity investment equilibrium (such as not requiring trust to be denied to trustworthy individuals), so it is useful to know that these properties do not come at the expense of more restrictive conditions for existence.

Figure 2 illustrates the existence regions for a HE as a function of δ and s, and relates them to the characteristics of the equilibrium. The blue curves indicate the boundary of the region; note that existence depends on three parameters, s, δ, and w; in the figure, we normalize $w = 1$. The region is defined by whether it is possible to find an advancement process (parameterized by b) that supports an HE; thus, the upper and lower bounds represent the solution to (10) when $b^* = 0$ and $b^* = 1$, respectively. When s is close to the maximum long-term loss from deviating, $w/(1-\delta)$, then to support trust with the maximum group size, we need b^* close to 0, so that newcomers are likely to remain low in the hierarchy and are thus trusted at a low level. This yields low surplus from a cheat-and-leave deviation, since starting over is particularly unattractive in this scenario. On the other hand, when s is close to w and both are close to 1 (so that it is also possible to satisfy $s < w/(1-\delta)$), there is no incentive to shirk and so cooperation can be sustained for all δ. Then, the HE has b^* close to 1 (in order to ensure that IC_L binds), so that newcomers advance to full trust very quickly. The red dotted line in the figure illustrates the boundary between "high mobility" and "low mobility" advancement processes. Higher values of the incentive to shirk require more patience to sustain high mobility scenarios.

We can also characterize the steady state density of the seniority level of individuals, denoted f^*, in this equilibrium.[14] This density is determined jointly by the survival rate δ and the advancement process (b^*), which also depends on δ. Since seniority is normalized to correspond to the level of trust, the shape of f^* describes the distribution of trustworthiness in the community. f^* solves the

[14]More precisely, $\int_{l'}^{l''} f(l)dl$ equals the probability that an individual sampled at random at some arbitrarily large time t has seniority between l' and l'').

following functional equation for $l \in (0,1)$.

$$\overbrace{f(l)(1-\delta)}^{\text{\# individuals dying}} + \underbrace{f(l)\delta \int_l^1 g^*(\tilde{l},l)d\tilde{l}}_{\text{\# ind. promoted to upper levels}} = \overbrace{\delta \int_0^l g^*(\tilde{l},l)f(\tilde{l})d\tilde{l}}^{\text{\# ind. promoted from lower levels}} + \underbrace{(1-\delta)g^*(0,l)}_{\text{\# newcomers landing at level } l} \quad (12)$$

The above has exactly one solution given by:

$$f^*(l) = \frac{1-b^*}{b^*}(1-\delta)(1-l)^{\frac{1-b^*}{b^*}(1-\delta)-1}. \quad (13)$$

Taking the derivative with respect to l and rearranging, one can show that $f^*(l)$ decreases with seniority l if and only if:

$$\frac{s-w}{s} > \frac{\delta}{2-\delta}. \quad (14)$$

Communities have pyramidal structures– meaning that there are more individuals at the bottom than the top–when either the incentives to cheat are large $(s-w)$ or if patience is low. Conversely, higher social mobility and more *egalitarian* inverse-pyramidal communities are sustained in maximal trust hierarchies when these incentives to cheat and defect are weaker (see also Figures 2a and b).

Notice also that the black dashed line in Figure 2b (representing a uniform distribution over seniority) would fall to the left of the red dashed line if superimposed on Figure 2a (representing a uniform advancement process), and the wedge between them increases with δ. Intuitively, when individuals are long-lived, even with low social mobility, they will mass at the top of the distribution. So an equilibrium advancement process with low social mobility does not imply a pyramidal hierarchy in the steady state. However, a pyramidal steady state distribution does imply the presence of low social mobility.

We can also examine aggregate welfare. The closed form expression for aggregate average per period surplus is:

$$(1-\delta)\int_0^1 \tilde{v}(\tilde{l})f^*(\tilde{l})d\tilde{l} = \frac{(w-(1-\delta)s)((1-\delta)s+2\delta w-w)}{\delta^2 w}$$

Naturally, average per period surplus decreases with temptation to cheat $s-w$

and increases with patience δ, Further, average surplus approaches $\frac{w}{1-\delta}$ whenever s approaches w and approaches 0 whenever s approaches $w/(1-\delta)$.

Hierarchies with Trading Selectivity

Up until now we assumed that having chosen a community, individuals are randomly matched with all other community members. We also have implicitly assumed that there are capacity constraints on individuals' ability to work for others– each player was limited to be trusted at most once, and thus their period payoff was capped by w. We now consider a setting where individuals can choose whom to interact with, even within a community, and we relax the capacity constraints so that individuals can be entrusted as an agent by more than one principal. We keep the total number of potential trades in the community the same (equal to N), but allow the distribution of trades to change. Thus higher rank individuals may become the focuses of trust to the extent that they are in fact trustworthy, and obtain on average more than w per period in equilibrium. One extreme example is a community in which the highest in rank works as an agent for everyone else, and the lowest ranked community members, or newcomers, may act as principals for others but may not themselves be selected as agents.

Though conceptually straightforward, permitting trading selectivity within hierarchies raises a number of modelling challenges. A key issue is that an individual's incentive to cooperate depends on seniority *relative* to other individuals, and thus the entire realization of individuals' seniorities $\{l_i\}_{i=1}^{N}$ is relevant for incentives. For this reason we focus on studying the simplest hierarchy– one with three individuals– and rely on numerical methods to characterize the key equilibrium objects.

The hierarchical setting with trading selectivity is the same as the hierarchical setting with random matching, but with the following modifications: $N = 3$. Individuals can choose whom to trust among those present with a community. For convenience, given an arbitrary vector of seniorities (l_1, l_2, l_3) (from now on referred to as the 'state'), we call those individuals endowed with the highest, second-highest and lowest seniority as (S)eniors, (J)uniors and (F)reshmen, re-

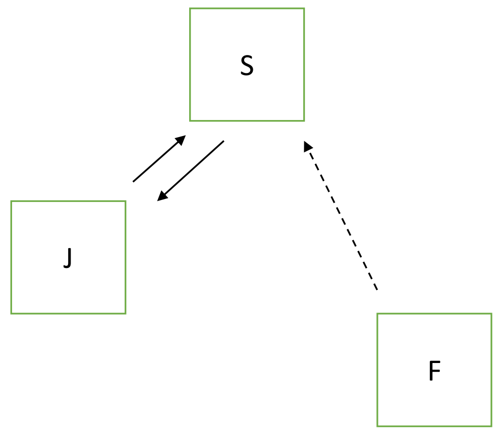


Figure 3: **Example: One-sided trust relationships in a three person hierarchy with trading selectivity before a newcomer (F) decides to leave or stay.**

spectively.[15] As before, let seniority ranks be determined at the beginning of every period by a public randomization process that is i.i.d. according to the family (7) parametrized by the social mobility level b. We also keep that the initial seniority of newcomers is drawn right after joining according to density $g(l, 0)$. That is, it is drawn as if their previous period seniority were zero. Notice that a community's seniority rank ordering can differ every period: while there is a Senior every period, her identity (i.e. index) can change depending on the realization of the advancement process, the survival of other individuals and their choices to stay in the community. Further observe that new members are not necessarily Freshmen although are ex-ante more likely to wind up as such.

Define the maximal *Hierarchical Equilibrium with Trade Selectivity* (HE-TS) to be the same as a HE with the following amendments. On the equilibrium path J trusts S at full scale and returns. S trusts J at full scale and returns. F either fully trusts S and returns or trusts no-one and leaves. F leaves if and only if the state is such that the continuation payoff from remaining on the equilibrium

[15]This involves a slight abuse of notation as if one or more individuals have the same seniority (a probability zero event), then we assume that seniority is randomly assigned. So $l_i = l_S$ is, strictly speaking, necessary but not sufficient) for i to be senior.

path falls below that of starting afresh in the average community. S and J work if trusted (see also Figure 3). The punishment phase triggered by a deviation to the above in $t-1$ or in t is a one period Nash reversion to no trust/shirk in period t within the relevant parties. In the continuation game after any one stage deviation to the above, the principal(s) always returns and the agent always leaves. Allowing for the possibility that cooperation breaks down between F and S is a key difference with the HE setting.

To define the HE-TS formally, new notation will help. Redefine $l \in [0,1]^3$ to denote a vector of seniorities. Let $\pi(l_i, l_{-i})$ denote the number of tasks carried out by agent i in state l according to the candidate strategies which define the equilibrium.[16] Let the subscripts S,J and F denote the indexes of the respective types. Note that F is assigned no tasks even if he stays given the current realization ($\pi(l_F, l_{-F}) = 0$). S does one or two tasks depending on whether F stays or leaves for a new community given the current realization- i.e. $\pi(l_S, l_{-S}) \in \{2, 1\}$. J acts as an agent to S: $\pi(l_J, l_{-J}) = 1$.

The fact that some individuals may leave on path requires further adaptations of the analysis relative to the HE setting. A first issue is that the transition density from l_i to $\tilde{l}_i$, denoted $\mathcal{G}$, is state dependent.[17] Specifically, suppose v_0 denotes the expected payoff of starting afresh in a new community[18] and $v(l_i, l_{-i})$ the value of returning of individual i. The transition density is equal to:

$$\mathcal{G}(\tilde{l}_i, l_i, l_{-i}; v, v_0) = \begin{cases} (1-\delta)g(\tilde{l}_i, 0) + \delta g(\tilde{l}_i, l_i) & v(l_i, l_{-i}) \geq v_0 \\ g(\tilde{l}_i, 0) & v(l_i, l_{-i}) < v_0 \end{cases}. \tag{15}$$

v_0 in turn depends on the stationary density of the state variable, denoted $\mathcal{F}$ which, being induced by $\mathcal{G}$, is itself endogenous. $\mathcal{F}$ is a solution to the following

[16]Note that the first argument denotes one's 'own' seniority. As the game is symmetric, any permutation of the other two reals l_{-i} leaves the function unchanged.

[17]Differently form the previous section this object describes the transition density of the i-th component of the state vector. This should not be confused with the related but different object describing the individual's transition density from seniority l_i to $\tilde{l}_i$. These two objects coincide only if individuals never leave or die.

[18]We implicitly assume that the public record of community members can be accessed only after joining so the expectation is taken over the unknown state of the new community.

functional equation

$$\mathcal{F}(l; v, v_0) = \int_{[0,1]^3} \mathcal{G}(\tilde{l}_1, l, v, v_0)\mathcal{G}(\tilde{l}_2, l; v, v_0)\mathcal{G}(\tilde{l}_3, l; v, v_0)\mathcal{F}(\tilde{l}; v, v_0)\, d\tilde{l}. \tag{16}$$

In addition, the extent of the punishment in the period after a deviation, say $t+1$, depends on relative seniority. The most tempted to cheat and return are senior individuals matched with two fully trustworthy agents. Let π^C denote the number of tasks that such senior individual carries over in period $t+1$ in the subgame after cheating in t. Given the above description of the candidate strategies, the value of π^C depends on the realization of the state as well as on the realization of the survival process. So to simplify the notation, in what follows we let $\pi^e(l_S, l_{-S})$ denote the expected number of tasks a senior cheater expects to carry out in $t+1$ conditional on returning, which is what matters for incentives. The expectation operator accounts for the possibility that the cheated principal(s) do not return in $t+2$ and for the possibility that the parties involved transition to different ranks.[19] We provide a full description of π^C in Appendix A.3.

We define a *Hierarchical Equilibrium with Trading Selectivity* (HE-TS) as a set of strategies such that there exists a tuple $(b, v, \pi, \pi^C, \mathcal{G}, \mathcal{F})$ that satisfies (15), (16) and the following conditions:

$$v(l_i, l_{-i}) = \mathbb{E}_{\tilde{l}|l}\, \pi(\tilde{l}_i, \tilde{l}_{-i})w + \delta \max\{v(\tilde{l}_i, \tilde{l}_{-i}), v_0\} \tag{17}$$

$$v_0 = \int_{[0,1]^2} v(0, x, y) \left(\mathcal{F}(0, x, y; v, v_0) / \int_{[0,1]^2} \mathcal{F}(0, \tilde{x}, \tilde{y}; v, v_0)\, d(\tilde{x}, \tilde{y})\right) d(x, y) \tag{18}$$

$$\pi(l_S, l_{-S}) = 2 \text{ if and only if } v(l_F, l_{-F}) \geq v_0 \tag{19}$$

$$\pi(l_i, l_{-i})(s - w) \leq \delta(v(l_i, l_{-i}) - v_0) \tag{IC_L}$$

$$\pi(l_i, l_{-i})(s - w) \leq \delta \left(v(l_i, l_{-i}) - \pi^e(l_i, l_{-i})w - \delta\, \mathbb{E}_{\tilde{l}|l}[v(\tilde{l}_i, \tilde{l}_{-i})]\right) \tag{IC_R}$$

(17) specifies that the value of each agent depends on the expectation over the next state $\tilde{l}$. The operator $\mathbb{E}_{\tilde{l}|l}$ averages over the convolution of the processes that

[19] Again recall that the candidate strategies allow F leave on path. So when computing the period payoff in the punishment period $t+1$ we need take into account that in some states F is not trustworthy despite the cooperation phase restarting in $t+2$.

determine the future states: the survival process and the advancement process. (18) defines v_0: the expected value of starting afresh in a new community whose state is unknown prior to joining.[20] (19) requires that the agent with the most seniority in the three person hierarchy receives two trades whenever the newcomer (F) prefers to stay. (IC_L) and (IC_R) represent the no 'cheat and leave' and no 'cheat and return' requirements.

Let us interpret how the equilibrium works. Trading selectivity allows the redistributing of period surplus from lower ranked individuals to higher ranked (and more trustworthy) individuals. This makes it more costly for high ranked individuals to cheat and start anew in a different community, rendering cheat and leave deviations more costly and increasing the trustworthiness of high ranked individuals, where their trustworthiness creates the incentive for others to choose them for trade. In contrast, lower ranked individuals have less to lose by leaving, and thus would in fact cheat and leave if trusted. Further, some low ranked individuals actually move between hierarchical communities on the equilibrium path, where higher status individuals remain in a community. So the equilibrium has the feature that more senior individuals are more trustworthy because they have the incentive to stay, and would thus suffer more from cheating someone they may encounter again.

Notice that by focusing trades among individuals with higher levels of seniority, hierarchies with trade selectivity also increase the fraction of the period surplus which is appropriated by the returning members of the community. This allows for two key robustness features of hierarchies relative to other institutions (such as those based upon identity investment).

First, hierarchies can exist in the presence of other groups that follow different strategies, including, in the extreme, a community that lowers its barriers or removes its institutions completely, and trusts newcomers fully and from the start. This is because if social mobility is high enough, the sharing of the future surplus that accrues to returning individuals if they rise in status can more than compensate for the losses that individuals with low seniority incur in hierarchies due to the fact that they may experience an initial period without being selected for trade. Formally, all individuals find it more attractive to start afresh in

[20] Again note, that unlike in an entry barrier model, starting afresh does not imply a period of 'purgatory' with no trust, but could, in principle, involve being trusted.

hierarchical community than in a hypothetical institution-free community with full cooperation if:

$$v_0 \geq \frac{w}{1-\delta}. \qquad (IF)$$

Although it may seem surprising that it is possible for an agent to expect, on average, more than the full per-individual surplus (discounted to factor in survival), our model has the flavor of an overlapping generations model. Each individual expects other members of the community to die with positive probability, and when they do, their replacements will on average have lower seniority. (IF) also implies that cheating within a hierarchy and then leaving for an institution free community with full cooperation cannot be optimal.

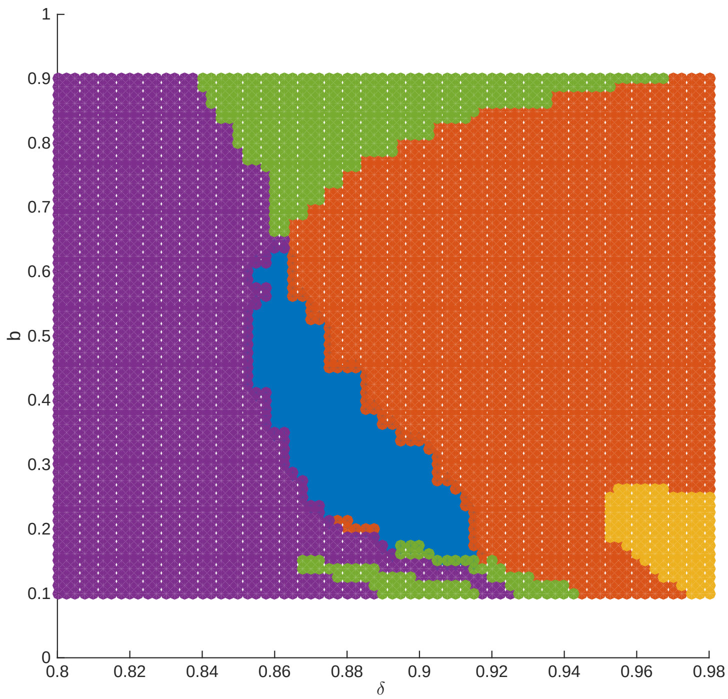
Second, hierarchical communities with sufficient social mobility can in fact, lead to defection from and thus the breakdown of cooperation in institution-free communities. Individuals belonging to a hypothetical institution free community with full cooperation find it profitable to cheat and leave for the hierarchy if and only if

$$s + \delta v_0 \geq w + \delta \frac{w}{1-\delta} \qquad (20)$$

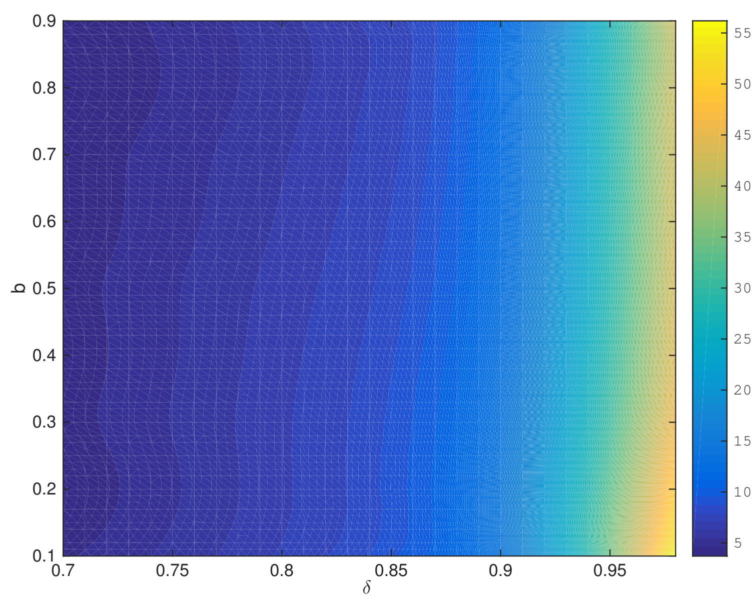
Since $s > w$, this condition is implied by (IF). Using numerical methods, we show that the hierarchical equilibrium exists and, in addition, can satisfy the robustness conditions (IF) and (20) (see Appendix A.3 for details.)

Figure 4a shows the existence region of the hierarchical equilibrium, depending on the level of patience δ and the extent of social mobility b. Notice that there are two main regions, corresponding to the two main incentive constraints (IC_L and IC_R). First, (IC_L) is satisfied for high degrees of a patience, as one might expect, but also at intermediate levels of social mobility (the red and blue regions). Recall that the binding constraint to not cheat and leave is on higher status agents being trusted by multiple partners of lower status. The presence of some social mobility that allows these partners to be promoted in the future makes them less desirable marks for a higher status cheater to exploit.

In contrast to (IC_L), (IC_R) is satisfied for lower levels of patience (blue and purple). This is because if the agent is patient, he can more easily tolerate the one-period punishment. The resulting existing region is the blue area sustained by intermediate levels of both patience δ and social mobility b. Notice that



(a) Existence region. Horizontal axis is patience (δ), vertical axis is social mobility (b), $w = 1$. Blue diamond: equilibrium exists for some $s > w$. Red: (IC_R) is violated; purple: (IC_L) is violated); green: (IC_L) and (IC_R) are violated; yellow: (IC_R) and (IF) violated.



(b) Payoff of an average member of a hierarchical community with trading selectivity in (δ, b) space.

Figure 4

violations of the condition IF (in orange) are nested inside the same parameter space that also violates IC_R– so there is no additional restrictions on patience or social mobility to obtain institutional robustness.

Thus, hierarchies can not only be robust to other institutions, but their presence can also make it impossible to sustain alternative institutional arrangements, when agents have the option to cheat and leave.

Finally, Figure 4b shows how the value for an average member of the hierarchy changes with social mobility and patience.[21] The long-term payoff is higher for longer lived members with lower social mobility (low b).

Applications

Our model may be applied to shed new light not only on the design and robustness of institutions that can sustain cooperation across a range of challenging contracting environments, but also on a number of puzzles related to early human economic and political development. In the Online Appendix, we describe several applications in detail; here, we highlight the main points of three of these applications before analyzing a fourth in greater depth.

A first application of our model is in explaining the emergence of hierarchy in early human societies. A literature on this emergence focuses on the technological change from pastoralism to agriculture, the advantage of first movers in acquiring geographically desirable locations or the storability of crops in allowing coercion (eg Dow and Reed, 2013, Boix, 2015, Mayshar, Moav, Neeman, and Pascali, 2015). Our model suggests an alternative, though potentially complementary, explanation: as population density increases, "cheat and leave" defections become easier, and social hierarchy provides a way to sustain cooperation in the face of this. In the Appendix, we use data from Binford's 2001 study of 339 non-agrarian hunter-gatherer societies, described at first contact with anthropologists. We define *egalitarians* to include all societies classified as "generic hunter-gatherers" or "generic hunter-gatherers with institutionalized leaders," while *hierarchical* societies include all societies classified as "wealth-differentiated hunter-gatherers"

[21] That is, the average value $v(l)$ where the expectation is taken over the stationary distribution of l's.

or "stratified or characterized by elite and privileged leaders." We show that as population density increases, hierarchical societies become much more prevalent than egalitarian ones.

Another implication of our model is that hierarchy can help sustain trust in larger groups, so long as seniority confers higher levels of trust. As long as there is common knowledge of seniority, it is not necessary for individuals to keep track of individual trading histories. The example of the ascendance of the Roman Republic over the ethnically-delimited organization among the city-states of Carthage and Greece illustrates how seniority-based systems can achieve greater scale and trade. Citizenship in "egalitarian" Athens, for example, derived from ethnic descent from one of four tribes. While citizens had special privileges, "foreigners" were excluded from economic opportunities. Rome, in contrast, allowed many different ethnic groups to become members. Roman society was hierarchical, with ranks including slaves, citizens, junior and senior office holders, and senators. There was mobility across ranks, including for slaves, so much so that by the second century CE, most citizens had slave ancestry. While both contemporaries and modern historians have contended that the growth of the Greek city-states was constrained by their institutions, Rome's hierarchy arguably sustained trust and cooperation at very large scale.

A third example concerns the ability to sustain trust in online communities, such as open source software development and online forums. Many such communities have hierarchies; for example, more senior members have voting rights and help determine the direction of projects. Online forums typically note some form of seniority for experienced members. As in our model, more senior members are trusted more, and as such have greater incentives to return, which in turn makes them more trustworthy.

Pastoralist and Agriculturalist Hausa in Nigeria The case of the Hausa in Nigeria further illustrates how emergent hierarchies sustain trust in a modern society with weak legal institutions while undermining cooperation in nearby egalitarian communities.[22]

[22] Of the 20 sub-Saharan African states surveyed by Afrobarometer in 2008, Nigerians ranked last, with only 9.50% stating that they trusted non-relatives they knew "a lot", compared to 25.50% of other sub-Saharan African respondents. Formal third party enforcement is also perceived to be among the weakest in sub-Saharan Africa.

Among the Hausa, it is religious identity– particularly Islam– that plays an important role in shaping access to commercial opportunities. However, Hausa Muslims and non-Muslims (known as Maguzawa) have common ethnic origins and have lived inter-mixed historically, with Maguzawa seen by Muslims as being the "original" Hausa (Last, 1999).[23] Though Maguzawa now constitute fewer than 2% of the 50 million modern Hausa-speakers, mass conversion to Islam is relatively recent: in 1900, only 5% of contemporary Hausaland were Muslim (Salamone, 2010).

Yet, despite their similarities, and the ability of individuals to move relatively freely between Muslim and Maguzawa groups within the Hausa, there remain remarkable differences in their social organization and levels of trust. The Muslim Hausa have a well-developed hierarchical structure that transcends lineage, while the Maguzawa have well-established norms of egalitarianism (King, 2006, Last, 1979, 1999, Barkow, 1974, Salamone, 2010). As in the hierarchical equilibrium, access to enhanced trading opportunities is directly related to the extent to which the agent is embedded in a network of trust-based relations. Those with the highest status include long-distance Muslim traders, who traded along pilgrimage routes across the Sahara (King, 2006, Barkow, 1974, Cohen, 1969). Those involved in smaller-scale commerce or professions involving less trust also have lower perceived status (Barkow, 1974). Qualitative accounts stress how among the Hausa, "a good deal of business is conducted with handshakes and one's word" (Salamone, 2010)[p.3].

In contrast to the Muslim Hausa, the Maguzawa are a good example of an 'institution-free' competing group. Maguzawa have strong norms of egalitarianism and reciprocal obligation (King, 2006, Last, 1979, 1999, Barkow, 1973, Salamone, 2010). They are also perceived as being completely open and welcoming to new entrants (Barkow, 1973, Last, 1999). Though, the Maguzawa have lived in close proximity to the Muslims for centuries, there is no ambiguity in classification: both groups maintain clear (though reversible) visual symbols of distinction, including different styles of clothing and restrictions on women (Barkow, 1973, Last, 1999).

[23] As Last (1979)[239] notes, the Maguzawa were "considered one of "us", therefore not targets for jihad even in the early nineteenth century ... There was apparently, and still is, no urge among the Muslims to convert the non-Muslims among their neighbors and subjects ..."

Hausa thus have had the option of choosing to be Muslim and thus joining the hierarchical structure of the Muslim Hausa, or choosing to remain or even switch to being Maguzawa (Last, 1979).[24] Consistent with the model, new converts to Islam are *actually poorer* than non-Muslim Hausa (Last, 1979, 1999, Barkow, 1974).[25] Yet, despite the drop in wealth, it appears that it is the possibility of advancement in the Muslim hierarchy (and thus of being the focus of coordinated trades and thus increased wealth in the future), that drives individuals to convert.[26]

Further, despite common ethnic, linguistic and geographic endowments, and the relative lack of barriers to conversion to Islam (Last, 1979), the differences in the degree of trust between Hausa religions are remarkable. Table 1 shows the proportion of Nigerian respondents to the Afrobarometer survey who reported their willingness to trust others from their country "a lot" or "somewhat". As the table suggests, while both non-Muslim and Muslim Hausa tend to report a greater willingness to trust others in general compared to non-Hausa Nigerians, there are remarkable differences within the Hausa according to the degree they trust people within and outside their own families. While a greater proportion of non-Muslim Hausa show a willingness to trust relatives, Muslim Hausa are more likely to report that they trust both non-relatives that they know and strangers more generally.

Consistent with our model, rather than the 'institution-free' community undermining cooperation among the Muslim Hausa, the Muslim community has attracted more converts, despite the fact that converts tend to be poorer on average, and it has been cooperation among the Maguzawa that has largely broken down. Once living in close proximity to Muslims in the towns of Hausaland, the remaining Maguzawa have become specialized economically in largely autarkic farming activities, and have become more geographically dispersed, both from Muslims and from each other (Greenberg, 1947, Last, 1979, 1999).[27]

[24] In fact, consistent with the model, new Muslim converts who "fail" in trade can and do change their identity to Maguzawa (Last, 1999).

[25] Ironically, in the early years of independence, due to their relatively high wealth, the agriculturalist Maguzawa were classed as "merchants" and taxed at a higher rate on average (Last, 1999).

[26] Last (1979) describes: "Though it is clear to non-Muslims that the Muslim is often poorer and lives a more constricted social life, the prospect is of wealth through trade . . . (239)"

[27] In the 1970s, virtually all Hausa in areas with population densities above 200 per square mile had become Muslim (Last, 1979).

		Non-Muslims	Muslims	All
Proportion claiming to trust:				
Non-Hausa	Relatives	0.678	0.741	0.692
	Others they know	0.386	0.464	0.403
	Other Nigerians	0.247	0.289	0.257
	Observations	1,394	401	1,795
Hausa	Relatives	0.918	0.852	0.858
	Others they know	0.469	0.635	0.620
	Other Nigerians	0.367	0.469	0.459
	Observations	49	480	529

Table 1: **Trust in Nigeria by ethnicity and religion**
Proportion of population that trust other Nigerians "somewhat" or "a lot" (as opposed to "not at all" or "just a little".) source: Afrobarometer 2008-2009

Conclusions

This paper has analyzed the endogenous formation of groups that enable their members to sustain trust in environments where there are many possible partners, outside options are strong and legal enforcement is not available. An important set of "identity investment" institutions sustain loyalty to a group and cooperation within groups by creating barriers to starting anew. Seniority structures, however, can support loyalty and within-group cooperation without requiring artificial barriers to entry or withholding of trade. In fact, in environments where individuals can choose their trading partners, seniority structures can be designed that are robust to the entry of institution-free groups that would lead to the failure of trust in groups that are sustained by entry barriers. In fact, such seniority structures can actually undermine cooperation in institution-free groups.

The resilience of seniority- based cooperative hierarchies and the corresponding decline of trust and cooperation in institution-free groups appears to mimic a number of environments where new venues for exchange have emerged, from open source software communities to early human societies. But it also hints at the dynamics of spontaneous order to expect in both historical and contemporary settings where no institutions exist. Though the formation of entry barriers based upon "cultural" distinction can sustain cooperation among sub-groups, these will be undermined by the continued presence of institution-free groups. Social hierarchies, in contrast, may survive. In the absence of third-party enforcement, hierarchies may thus emerge as a common early organizational form in new venues for trade.

We are also able to explain an important paradox, how absent coercive power supportive of secure property rights, that small inequalities that underpin the historic emergence of elites in human societies might persist and grow rather than being simply expropriated in societies with strong egalitarian norms (Sterelny, 2013, Bowles and Choi, 2013). In our hierarchical equilibria, it is increased bilateral trust that provides the wealth associated with status, and being intangible, such trust cannot be expropriated. Further, unlike social networks which are often person-specific, social hierarchies are "impersonal". Individuals can trade with and trust others that they have never met, with rank providing sufficient information for trust, and the patterns of cooperation in a social hierarchy can survive beyond the individuals that populate them. Rank indicates that individuals benefit from remaining in a community, and thus are more trustworthy.

A Appendix: Proofs and Numerical Solutions

A.1 Proof of Proposition 1

First, we show that if an Identity Investment Equilibrium (IIE) exists then (IC_L), (IC_R) and (IR) must each be satisfied. If (IC_L) is violated, an agent would have an incentive to defect and leave the community, starting anew in a new community, thus the equilibrium cannot be sustained. Similarly, if (IC_R) is violated, an agent is better off defecting and staying in the community than to play his equilibrium strategy of working when no trust had been breached before. If (IR) is violated, an agent would not enter the community in the first place. Thus if the IIE exists, the three conditions (IC_L), (IC_R) and (IR) must be satisfied.

Second, we show that if ((IC_L), (IC_R) and (IR) are all satisfied, then the IIE must exist. First we will fully describe a candidate equilibrium strategy, and then we will show that given the other players' candidate strategies, no individual has an incentive to deviate. In the first period, individuals randomly select a community and, on the equilibrium path, stay in that community for all future periods. An agent works and a principal trusts fully if neither have defected before, or if they have already punished a defection with one-period Nash reversion. An agent shirks and the principal gives no trust if the pair had met in the previous period and either party defected.

Notice that there can be no equilibrium in which the principal leaves following a defection in $t-1$ by the agent as there would be no punishment. So only agents may leave off the equilibrium path. There is no need to worry about the principal's incentives to come back in t as depending on the primitives either (i.) the agent leaves in t or (ii.) they both come back (as they face the same continuation payoffs).

First, we examine whether an agent has an incentive to shirk if the either partner has never defected before, or has regained trust after one-period punishment. (IC_L) guarantees that under such circumstances the agent has no incentive to defect and leave, since starting anew with an investment m is more costly than the potential gain from defection. (IC_R) guarantees that the agent has no incentive to defect and return when the cheated upon principal returns the next period. Finally notice that there is no profitable deviation for an agent to defect for a few periods and then leave, since the punishment only happens in the next period, and in subsequent periods the agent has the same continuation value in their home community but without incurring a new membership fee. Second, if in the last period the agent has just defected and the agent is re-matched with the cheated upon principal, his optimal strategy is to defect once more as the principal will place no trust on him this period, and his behavior in this period will also not affect future trust. Thus, if the conditions hold, no player has an incentive to deviate from the prescribed candidate strategy when other players are also playing the candidate equilibrium, i.e. the IIE exists.

A.2 Proof of Proposition 2 and 3

(IC_L) and(IC_R) are definitionally necessary for a HE to exist. We now show that they are also sufficient. We first show that $v(l)$ is well defined. Recall the functional equation:

$$v(l) = \int_l^1 g(\tilde{l}, l)(\tilde{l}w + \delta v(\tilde{l}))d\tilde{l}. \tag{21}$$

which defines an operator T that maps the set of bounded functions into itself. It satisfies the monotonicity and discounting conditions of Blackwell's theorem and therefore T is a contraction with modulus δ. By the contraction mapping theorem there exists a unique fixed point. Since the set of bounded continuous functions is closed and the operator preserves continuity, it follows that the unique fixed point is bounded and continuous. Continuity implies that the (IC_L) constraint holds as well for $l = 1$. To see this notice that if the right hand side is continuous and equal to the left hand side for all $l < 1$ then the relation must be preserved for $l = 1$ as well. Combining the constraints, it follows that $(s-w) = \delta(v(1)-v(0)) = \frac{\delta^2 w}{N-1}$. So for all types the payoff from cheating and leaving is weakly larger than that of cheating and returning. So, in order to support a HE, one can rely on strategies where agents always leave and principals always return in the period after cheating. Given this, the argument proceeds along lines identical to those of Proposition 1, and is therefore omitted.

Proposition 3 solves for an equilibrium as follows. First solve (IC_L) for $v(l)$ which yields $v(l) = l(s-w)\delta^{-1} + v(0)$. It follows that $v^*(1) = (s-w)\delta^{-1} + v^*(0)$. In addition (21) implies $v^*(1) = w/(1-\delta)$. Combining these observations yields $v(0) = w(1-\delta)^{-1} - (s-w)\delta^{-1}$. Therefore if an equilibrium exists the associated value function should satisfy: $v^*(l) = \frac{w}{1-\delta} - (1-l)\frac{s-w}{\delta}$ which is (9). Finally, substituting v^* into (21) allows us to recover a unique $b^* = 1 - \frac{s-w}{\delta s}$, which is (10). Note that b^* is greater than zero if and only if $s \leq w/(1-\delta)$. Finally, N^* uniquely solves (IC_R) when $l = 1$, yielding $N^* = \frac{\delta^2 w}{s-w} + 1$, or (11).

A.3 Existence of Hierarchical Equilibria with Trading Selectivity

In this section we provide an algorithm we used in Matlab to numerically solve for Hierarchical Equilibria with Trading Selectivity (HE-TS). Computationally, it helps to break the optimization problem into the two cases where the newcomer (F) stays, and where (s)he leaves. Let $L_F \subset [0,1]^3$ be the set of hierarchies where the first player is F and leaves to start anew in alternate community (with expected value v_0) (i.e. $L_F := \{l \in [0,1]^3 \colon l_1 = l_F, v(l_1, l_{-1}) < v_0\}$.)

The allocation of trade in the punishment one-stage phase, given realization l is given by

$$\pi^C = \begin{cases} 0, & l_1 = l_F \\ 1, & l_1 = l_J, \text{ and } S \text{ is a newcomer} \\ 0, & l_1 = l_J, \text{ and } S \text{ not a newcomer} \\ 2, & l_1 = l_S, \ J \text{ and } F \text{ are both newcomers, and } l_F \notin L_F \\ 1, & l_1 = l_S, \ J \text{ and } F \text{ are both newcomers, and } l_F \in L_F \\ 0, & l_1 = l_S, \ J \text{ is not a newcomer, } F \text{ is a newcomer or } l_F \in L_F \\ 1, & l_1 = l_S, \ J \text{ is newcomer and} F \text{ is not} \\ 0, & l_1 = l_S, \ J \text{ and } F \text{ are not newcomers} \end{cases}$$

We used the following method to solve for HE-TS: first, we solve for v in (17) forcing the senior (S) and junior (J) members to work; second, we check that S and J are indeed incentivized to stay and work. The key part of the Matlab code solves the dynamic problem (17), (18), (19) by discretizing the state space. Each dimension $[0,1]$ gets $\texttt{nd} = 15$ knots, so there are 3375 states in the state space. On the grid of (b, δ) ($b \in [.1, .9]$ with step .1, $\delta \in [.7, .98]$ with step .02), we do the following:

1. Construct state transition probability matrix `P` from g on the grid with $\texttt{nd} = 15$. For each action, `P` is 3375×3375.

2. Construct the initial stage reward matrix `R`: it assigns stage payoff $2w$ to S and stage payoff w to J, and stage payoff zero to F.[28]

3. Solve the dynamic optimization problem (17) by iterating the value function.

4. Update `R` to take into account that S's stage payoff is w in a state where F leaves. Update `P` to take into account that F leaves in some states of the world. Go to step 3 if new `R` and `P` are different from the old `R` and `P`; otherwise, go to step 5.

[28]Note that here we force S and J to work on the equilibrium path.

5. Check whether agents in an institution-free community prefer to cheat defect to the hierarchy $(v_0 \geq \frac{w}{1-\delta})$ (note that this turns out not to be restrictive.)

6. Check if IC conditions (IC_L) and (IC_R) hold for any s. If any of the conditions fail, record the non-existence of HE-TS.

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B Online Appendix: Additional Applications

The Birth of Hierarchy in Early Human Societies Prior to the introduction of settled agriculture around 12,000 years ago, human societies consisted of small groups and population densities as a whole were relatively low (Boix and Rosenbluth, 2014, Keeley, 1988). They also tended to be egalitarian (Boix and Rosenbluth (2014)). Inequality increased, and average health appeared to worsen, however, after the introduction of agriculture (Boix and Rosenbluth, 2014, Bowles and Choi, 2013), a period that also saw an increase in population densities and the emergence of social hierarchies (eg Boehm, 1999, Price and Brown, 1985).[29] Some scholars argue that egalitarianism was pinned down by the "countervailing power" of weaker individuals– particularly their ease of exit, should any 'self-aggrandizing' individual seek to dominate (Woodburn, 1982, Knauft, 1991, Boehm, 1999, Nowak and Sigmund, 2005, Sterelny, 2013, Seabright, 2013, Bowles and Choi, 2013).

An important body of work links the emergence of hierarchies and within-group inequality to the development of settled agriculture. Many existing explanations relate to heterogeneity among individuals. For example, Dow and Reed (2013) present a theoretical model where geographical heterogeneity in agricultural suitability generates inequality, as early movers to desirable plots of land collude to exclude latecomers from property ownership.[30] In contrast, our model suggests that such heterogeneity is not necessary for inequality to develop. Any exogenous change that makes it more attractive to cheat and leave, *even if this affects all individuals equally*, could lead to the development of hierarchies. For example, hierarchies might simply emerge from technological improvements that reduce travel costs, or increases in population density, that make alternative trading partners and communities more accessible and thus make it easier to cheat and leave any particular individual or group. Going back to the model, if we think of the membership fee in the identity investment equilibria m as being the determined by the distance needed to travel between them, having a cheated a partner, increased proximity then between markets (an m lowered below $\underline{m}$) can lead to a breakdown of cooperation in those internally-egalitarian communities. In contrast, as we have seen, cooperation in hierarchical communities could survive the reduction, or even the elimination of the costs of inter-community

[29]Summarizing a large body of anthropological and archaeological work, the anthropologist Robert Boehm (1999)[pg3-4] states: "before twelve thousand years ago, humans basically were egalitarian. They lived in what might be called societies of equals, with minimal political centralization and no social classes. Everyone participated in group decisions and outside the family there were no dominators."

[30]See also Boix (2015), who argues that agricultural technology favoured some agents more than others, leading the latter to become bandits and then specialists in violence. Mayshar, Moav, Neeman, and Pascali (2015) point to the extent to which agricultural staples in some places required storage and thus were appropriable in leading to the potential for hierarchies and state formation.

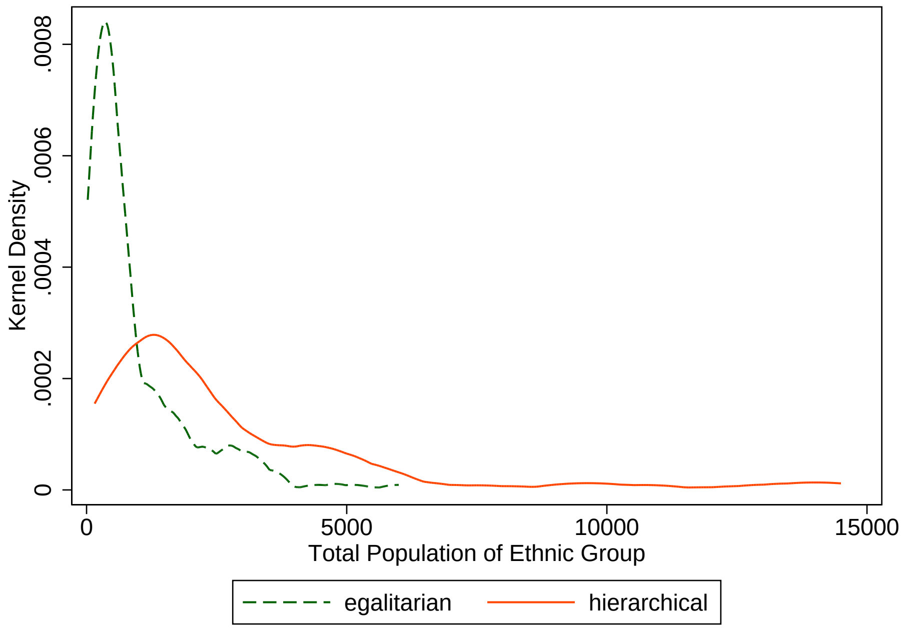

Figure 5: **Egalitarian Hunter-Gatherer Ethnic Groups are Smaller**
Kernel densities of ethnic group size are based upon the Binford (2001) dataset of 339 hunter-gatherer societies described at first contact with anthropologists. This viewed as a comprehensive and expanded version of those mentioned in Murdock's *Ethnographic Atlas*. *Egalitarians* include all societies classified as "generic hunter-gatherers" or "generic hunter-gatherers with institutionalized leaders". *Hierarchical* are all societies classified as "wealth-differentiated hunter-gatherers" or "stratified or characterized by elite and privileged leaders".

travel.

Figures 5 and 6 reveal a positive relationship between hierarchy and population density in a "comprehensive" dataset of modern (non-agricultural) hunter-gatherer societies, as observed upon their first contact with Europeans (Binford, 2001)[pg.117]. Consistent with our theory, egalitarian hunter-gatherer ethnic groups tend to be much smaller, even if we include within them those with some form of institutionalized leadership (Figure 5). Further, while egalitarian institutions survive with low population densities, even among hunter-gatherer societies, ethnic groups with wealth distinctions and social stratification begin to be more prevalent when population densities exceed as little as 1 person per square kilometer.

Our model also sheds new light on a lingering paradox: that hierarchies and inequalities *precede* the development of early states with coercive power that might justify having large groups for mutual defence, or indeed might result in the security of property rights that would allow 'self-aggrandizing' individuals to

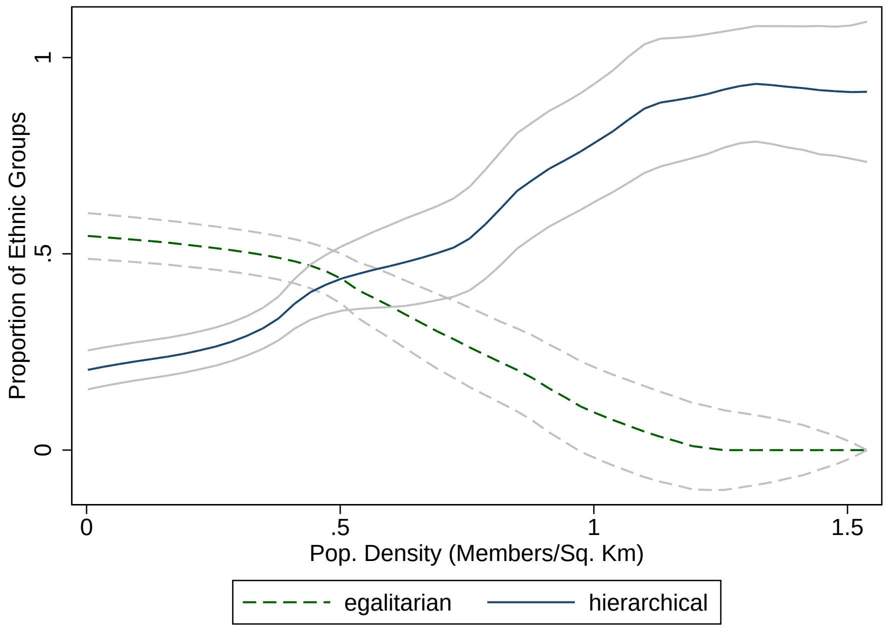

Figure 6: **Egalitarian Groups Do Not Survive as Population Densities Rise**

Local moving averages (epanechnikov kernel, ROT bandwidth) showing the proportion of societies that are egalitarian or hierarchical at different levels of ethnic group population densities. These are based upon the Binford (2001) dataset of 339 hunter-gatherer societies described at first contact with anthropologists. This viewed as a comprehensive and expanded version of those mentioned in Murdock's *Ethnographic Atlas*. *Egalitarians* include all societies classified as "generic hunter-gatherers" or "generic hunter-gatherers with institutionalized leaders". *Hierarchical* are all societies classified as "wealth-differentiated hunter-gatherers" or "stratified or characterized by elite and privileged leaders".

assert economic distinction in the first place (Seabright, 2013).[31] The hierarchical equilibria that emerge in our model address the question of why elites emerge: while egalitarian societies are favoured when distances or travel costs are great and when the tasks individuals can perform for one another are also extremely limited, hierarchies are favoured when these capacity constraints are relaxed. Furthermore, in environments where trade can be concentrated with senior members, hierarchies can be designed that are better able to sustain cooperation in large groups, and are robust to *countervailing power*- coalitional deviations. The de-

[31]In his survey of archaic states, Norman Yoffee (2005)[pg.35], based upon archaeological evidence such as differing sizes of residences, the distribution of artifacts, and mortuary furnishings, concludes that"no prehistoric trajectory to any state fails to contain indications of significant economic inequality or the potential of such inequality well before the appearance of anything that might be called a state."

velopment of social distinction also appears natural and intuitive- the hierarchies that emerge transfer surplus from newcomers to incumbent (returning) members of society, yet sustain incentives for newcomers to themselves return. Our model also explains the key question of institutional selection: hierarchies can emerge spontaneously that dominate and lead to the breakdown in other institutional arrangements, and even undermine groups that had previously been able to maintain such cooperation without institutions. Thus, even without any additional assumptions that hierarchies enjoy a technological advantage in coercive organization, hierarchies may emerge spontaneously that sustain cooperation, and may have provided the seed of early political states.[32]

Citizenship in the Roman Republic, Carthage and Hellenistic Greece Another novel aspect of our model is that, unlike social networks which are often person-specific, social hierarchies are *impersonal* and the patterns of cooperation in a social hierarchy can survive beyond the individuals that populate them. In endogenous social network theory (eg Jackson, 2003, Bloch, Genicot, and Ray, 2008)), ties are based upon an individual's trading history. Instead, in our framework, centrality in the network derives from an individual's office or status. Agents *salute the rank* and can trust senior individuals even if they have never met before. Thus, the social structure can out-live an individual agent or hereditary lineage. Indeed, the development of institutions that support such impersonal relations has been seen as critical for the historic expansion of trade (Greif, 2000).

Furthermore, the impersonal hierarchy in our model is akin to a concept of citizenship which was also novel in the classical world, that of the Roman Republic (ca. 2nd-3rd centuries BC).[33] Rome's contemporaries, like Carthage and the Greek city-states, were organized along traditional ethnic lines that mimic the identity investment equilibrium. Citizenship derived mainly from ethnic lineage. Citizenship in Athens, for example, originally derived from membership in one of four tribes (Aristotle, 335BC)[pg.56,65]. Citizens had specific privileges, many that built upon trust and specialization, that included relatively equitable economic opportunities and political rights, including in a number of prominent cases like Athens, democracy (Ober, 2015)[chp 1]. However, there was systematic exclusion from these rights and opportunities of all outside the specific ethnic group of the city, with 'foreigners' including citizens of other city-states, ex-slaves and, in the case of colonies, even the original inhabitants.

[32]The question of how property rights, inequalities and ultimately coercive elites emerged and were sustained despite strong egalitarian norms and the possibility for coalitions to seize and redistribute any unequal capital accumulation has long been a puzzle (Sterelny, 2013). Among the other ways that this issue has been addressed has been the assumption of a behavioural 'lag' in cooperative social norms– that individuals cooperate with the nascent elites and allow them to take advantage of this (Seabright, 2010, Richerson and Boyd, 2001, Sterelny, 2013).

[33]We are grateful to Ian Morris for pointing out these parallels with our model.

Incentives in the towns of the Roman Republic, in contrast, arguably paralleled the hierarchical equilibrium. They were remarkable for the time by allowing ethnic groups with no genetic relations to Rome, and living far away from the mother city to become *Roman citizens*. There were a number of ranks: slaves, citizens, junior and senior office-holders, culminating in senators, each enjoying higher levels of trust and privileges. Remarkably for the time, there was also gradual but probabilistic advancement at each rank. Many slaves had a good chance of gaining freedom and full Roman citizenship in their lifetime, so much so that by the second century CE, the majority of citizens are believed to have had slave ancestry (Beard, 2015)[pg.67]. This mobility extended to the top: the elite senatorial class itself became a multi-ethnic body (Beard, 2015)[pg.68].

This impersonal institutional structure did not limit Rome by the size of any particular ethnic group and instead allowed Rome to accommodate a large, geographically dispersed and rapidly expanding population. In fact, the comparison between the "avaricious" Greeks and the "generous" Romans in their bestowal of citizenship has been credited both by contemporary observers and modern historians for Rome's relative ability to scale, and its ultimate dominance over the Hellenistic Mediterranean (Gauthier, 1974, Eckstein, 2008, Beard, 2015).[34]

Our model suggests that the Carthaginians' and Greeks' unwillingness to admit members that could have been trustworthy and their attendant inability to scale relative to the Romans may have reflected the historic incentive problems they faced in maintaining cooperation given the presence of other proximate city-state communities in the Hellenistic Mediterranean. In contrast, the adoption by the Romans of a system of *impersonal* hierarchy with social mobility may have been a contributing factor in the Republic's rapid ascendancy and subsequent dominance.[35]

[34] A famous stelae from 215 BC illuminates a contemporary Greek perspective on Roman institutions. It records an exchange to King Philip V of Macedon and the semi-independent Greek city of Larisa in Thessaly. In response to a previous letter suggesting that the Larisans should overcome their recent war-related depopulation by admitting new citizens from among its inhabitants, the Larisans had first admitted and then revoked the citizenship of more than 200 new inhabitants, the majority from Thessaly itself. In response, the King wrote:

> I hear that those who were granted citizenship in accordance with the letter I sent you and your decree, and whose names were inscribed (on the stele) have been erased. If this has happened, those who have advised you have ignored the interests of your city and my ruling. That it is much the best state of affairs for as many as possible to enjoy citizen rights, the city to be strong and the land not to lie shamefully deserted, as at present, I believe none of you would deny, and one may observe others who grant citizenship in the same way. Among these are the Romans, who when they manumit their slaves admit them to the citizen body and grant them a share in the magistracies, and in this way have not only enlarged their country but have sent out colonies to nearly 70 places." (Austin, 2006)[pg 157-159].

[35] A traditional historical view credits Rome's military-oriented culture, including the glo-

Online Communities Open Source Software (OSS) communities and internet discussion groups are increasingly important venues for exchange Raymond (2001), Lerner and Tirole (2005), Shah (2006). As early as 2006 there were over one hundred thousand open source projects with over a million registered users. A central feature of online communities at first seems surprising from the perspective of standard incentive theory: individuals regularly contribute to a public good despite the lack of monetary incentives, large group size and the relative anonymity of the interactions. A closer look at these communities reveals that it is not purely public-spiritedness that motivates users however. Many groups have formal or informal hierarchies. In OSS communities, there is often a group of senior members known as "committers" who have the authority to incorporate both their own code into the project, as well as that of others. In addition, there is often an informal hierarchy, where more senior members will help answer questions for other senior members, but not junior members. In other internet discussion groups, it is common to show the date a user joined beside their posts.[36] Other types of designations (such as top reviewers for Amazon.com, or Most Valuable Professionals on Microsoft Forums) also help distinguish the senior members of a community. Our analysis helps to understand these phenomena.

Consider how OSS projects fit into the model. Even though in principle individual contributions may be publicly observable in many online communities, in practice it requires a substantial investment to learn about the quality of their work. One might need to carefully read a programmer's code. Some aspects of support and collaboration in OSS projects take place in private correspondence. It may thus be difficult for outsiders to ascertain the quality of interactions others are having in the community, and one may only learn about an individual's behavior by trying to adopt the code or otherwise having a close interaction with someone.

Our model applies to a setting where programmers select whether to become involved in a particular project. Programmers may write code for different purposes. Individuals associated with the project have needs arise which may be met using code that others have written, and they may choose whether or not to invest in reading and trying to use the code (as opposed to writing from scratch or finding other sources). They may then have support questions. The author of the code can then choose whether to support the user, answer questions, etc.[37] The "scale" of trust on the part of the user can be interpreted in several ways:

rification of warfare. As Eckstein (2008) points out, however such cultures were pervasive among contemporary states, particularly amongst the successor-states of Alexander's empire, and military advances were rapidly shared and adopted across communities.

[36]As Microsoft's Office Forum web page indicates, "the information about your activity in the Community (such as how many posts you have contributed...) gives others a sense of your trustworthiness and a way to gauge how valuable your comments might be."

[37]Some of the author's choices may be made *ex ante*, such as deciding on the extent of documentation and code quality, modularity/adaptability, etc.

for example, the user might make use of only the basic features of the code, or the user might invest rewriting portions himself. The user observes whether the ex ante quality was high, and also observes whether support was provided. The author gets higher utility the more the user relies on the author's original code (rather than rewriting it), because competing versions of the same code are thereby avoided. In such settings, the observed seniority-based hierarchies of trust and support can be understood as institutions that engender cooperation, and perhaps the puzzle of how OSS and online discussion groups incentivize trust is less puzzling in light of the finding that hiearchies can be powerful forces in favor of cooperation.