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Cheating Because They Can:
The Role of Networks in Informal Governance

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Abstract

Settlers flocking to "boomtowns" on the American western frontier were faced with the same task that communities in weak states across the globe face: self-governance. Peer sanctions can enforce cooperation in these environments, but their efficacy depends on the social networks that transmit information from peer to peer. Peripheral network positions can generate such strong incentives to misbehave that persistent cheating obtains in equilibrium. Groups maintaining high levels of cooperation that face shocks to their strategic environment or to their network can ratchet into less-cooperative equilibria in which the most peripheral become ostracized. Furthermore, population change that features rapid growth, high turnover, and enclave settlements can undermine cooperation. These insights help explain the trajectory of cooperation in mining towns in the "wild west" in which high levels of cooperation deteriorated as the population surged, and help make sense of why only certain non-white settlers were targets of hostility and racism.

Informal Institutions | Social Networks | Cooperation | Community Enforcement | Wild West

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1 Introduction

Informal institutions– unofficial, socially-shared rules– are ubiquitous. While they play an important role in well-functioning states enforcing extra-legal norms and mediating the effects of formal institutions (Helmke and Levitsky, 2004), the stakes are highest when formal institutions are ineffective or absent. In weak or failed states, informal institutions can be the primary check on behavior; the efficacy of these institutions determines whether whole groups of individuals will coexist in peace and productivity or in conflict and inefficiency (Dixit, 2004).

A large body of empirical work has documented that informal rules can enforce good behavior in both weak and strong states, with applications ranging from 11th-century Maghrebi traders (Greif, 1993) to modern-day resource sharers (Ostrom, 1990) to ethnically homogeneous African villagers (Miguel and Gugerty, 2005), and theoretical work has demonstrated that arrangements threatening peer sanction for misbehavior can support cooperation under a range of conditions.

Existing theory provides the conditions under which peer sanction enforces cooperation perfectly– in equilibrium, no one misbehaves. Realistically, though, success stories are those in which cooperation is the *norm*, but some misbehavior occurs now and then. There were *very few*, but not 0, cases of Maghrebi traders cheating (Greif, 1993, footnote 8 p. 598); contributions to public goods in ethnically homogeneous villages are *high*, but some still under contribute (Miguel and Gugerty, 2005, p. 2327); in the case discussed below, relations among settlers in mining towns were *mostly* civil, except for a few exceptions, which turned into many systematic exceptions. To explain persistent misbehavior, to identify the perpetrators and targets of misbehavior, and to understand the trajectory of cooperation breakdown, we need richer theory.

This paper establishes one source of persistent misbehavior in informal institutions: social network position. If gossip about behavior spreads through a social network, one's position within a network determines how many others hear the news quickly, which determines how many others could act on the news and punish when necessary. Peripheral network positions– those from which news does not reach many others quickly– generate incentives to misbehave, sometimes to such an extent that the most cooperative equilibrium that can be enforced by peer sanctions entails perpetual defections by and against those in peripheral positions. Furthermore, shocks that make cooperation more difficult, like a disaster that increases the gains from cheating in market exchanges, or the exodus of those most central in the network, can result in a group ratcheting into a less cooperative equilibrium in which the most peripheral cheat and are cheated against in perpetuity.

After introducing a theory that makes this logic precise and deriving testable hypotheses about cooperation breakdown and persistent cheating, the paper presents an empirical case which offers a unique opportunity to classify perpetrators and victims of some misbehavior in a weak state context, and to observe the consequences of a changing environment.

The case is one that has been largely ignored by the informal institutions literature: mining towns in the American West that grew so rapidly during the 19th century gold rush that they were dubbed “boomtowns.” Formal governance was largely absent in these towns, so miners were left to their own devices to coexist with each other and the nearby native populations. Arguably due to their ability to threaten peer sanctions for misbehavior, settlers experienced a long period in which peace and cooperation were the norm. After a few years the norm of peace began to disintegrate, but disintegration was not uniform. Hostility tended to be targeted at certain groups of settlers and not others, and be perpetrated against natives by certain settlers and not others.

The model presented here helps make sense of these outcomes by examining incentives determined by social network position. Rapid population growth, high turnover, and enclave settlement patterns all have consequences for a group’s communication network, often resulting in especially peripheral positions which strain cooperative arrangements. When cooperation breaks down, the most peripheral become victims of misbehavior by in-group members; their best response is to defect in return, which can usher in a less-cooperative equilibrium in which the peripheral players are effectively ostracized. Indeed, Chinese immigrants to boomtowns, who uniquely settled in enclaves with limited network reach, experienced a pattern of interactions consistent with this story: initial cooperation, then some breakdown, followed by wholesale hostility and ostracism.

This paper thus makes three contributions to the study of informal governance. First, it advances theory which makes the role of networks that spread information explicit and characterizes partially-cooperative equilibria in terms of heterogeneity in network position. Not only does the theory highlight sources of cooperation failure masked by non-network models, but it also identifies a source of persistent misbehavior that is not a result of accidents, errors, or irrationality. Second, the theory is unusual in its consideration of responses to shocks and transitions between equilibria. Groups engaged in informal governance, especially in weak state contexts, are particularly exposed to demographic and environmental changes like immigration flows and natural disasters. This paper characterizes when these changes should be expected to affect cooperative arrangements, who is likely to be most affected, and the equilibria that emerge as a result. Third, this paper explores an understudied case of informal governance. The theoretical claims advanced here are consistent with the history of 19th century boomtowns, and also offer an explanation for the otherwise puzzling phenomenon that the breakdown of cooperation appears to have systematically targeted some and not others.

2 Informal Governance in Weak States

There are many informal arrangements that can in principle enforce cooperative behavior. This paper joins the line of research focused on enforcement via peer sanction.[1]

[1] This type of enforcement scheme is prized for its realism. It is consistent with laboratory experiments finding that third parties punish (Fehr and Fischbacher, 2004); it is thought to be

Members of a community respond to behavior deemed inappropriate by issuing sanctions, and the threat of this response can, under the right conditions, dissuade everyone from misbehaving in the first place.

Theoretical work on social sanctions has demonstrated the existence and properties of fully cooperative equilibria in environments bounded by two extremes: one in which everyone learns about everyone else's behavior immediately (Kandori, 1992; Fearon and Laitin, 1996; Dal Bó, 2007), the other in which no one learns anything other than their own play (Kandori, 1992; Ellison, 1994; Harrington, 1995).

The information environment in real groups, especially those engaged in self-governance, is likely somewhere in between. Information about others' behavior tends to be newsworthy, and individuals who hear it tend to share it with others. This kind of social information, often labeled gossip, spreads from person to person through a social network, a fact used in many models that rely on social sanctioning by peers to enforce good behavior (Kandori, 1992; Greif, 1993; Fearon and Laitin, 1996; Lippert and Spagnolo, 2011; Larson, 2016). When someone misbehaves, others hear about it from their social contacts, who spread the news to their social contacts, and so on. Knowledge of misbehavior allows others to punish it, and the threat of this punishment can incentivize cooperation.

Much theory has been devoted to generalizing folk theorems and characterizing broad results for cooperation when actors are connected in networks (Renault and Tomala, 1998; Cho, 2011; Ali and Miller, 2013; Laclau, 2014; Nava and Piccione, 2014; Ali and Miller, 2016). This paper takes a narrower approach and considers a specific set of equilibria in order to generate hypotheses about an empirical case. Specifically, I consider a set of equilibria in which players use messages passed via word-of-mouth communication to implement an in-group policing strategy. In contrast to public goods

at play in settings that range from the Ottoman Empire (Fearon and Laitin, 1996) to present-day villages in Uganda (Habyarimana et al., 2009, p. 172); and evidence presented below suggests settlers in boomtowns used peer sanctioning schemes, making this the appropriate setup for deriving useful hypotheses.

games on networks (Pecorino, 1999; Haag and Lagunoff, 2007; Wolitzky, 2013; Balmaceda and Escobar, 2014), the action set here is binary (as in Ali and Miller, 2013; Nava and Piccione, 2014) so that to cooperate is to refrain from doing something bad (like jumping a claim or violating an informal land-use treaty). Players interact in a setting with word-of-mouth communication (as in Lippert and Spagnolo, 2011) and so use gossip about misbehavior to determine whether someone is in bad standing and worthy of punishment.[2]

The results I find are similar in character to a broad set of results finding that having too few links in networks can be problematic (see, e.g., Balmaceda and Escobar, 2014; Jackson, Rodriguez-Barraquer and Tan, 2012; Lippert and Spagnolo, 2011; Ali and Miller, 2013). The present paper characterizes a set of equilibria in which some, possibly all, play a network version of in-group policing (as in Larson, 2016) and some opt out and perpetually defect. I show that for a given set of parameter values, the maximum feasible size of the group of in-group policers (and hence cooperators in equilibrium) is a function of the most peripheral network positions. The presence of highly peripheral positions can preclude equilibria in which everyone cooperates, but still allow equilibria in which *some*, even *most* cooperate. Moreover, transitions to equilibria with fewer cooperators occur naturally in response to shocks, creating a ratchet effect in which after a shock, fewer cooperate and some engage in perpetual defection.

This setup generates a set of testable hypotheses which, I argue, are relevant to a uniquely well-documented instance of self-governance in a weak state setting: the historical record contains more than usual micro-level information on cooperation and conflict and some indirect evidence of network structure in the boomtowns of the "wild west." Settlers were tasked with policing behavior in their own communities and in

[2] This is in contrast to the standard approach of enforcing cooperation on networks via contagion strategies in which players "learn" information through the network by being defected on in the event that punishment is underway Kandori (1992); Ellison (1994); Wolitzky (2013); Acemoglu and Wolitzky (2015).

interactions between settlers and neighboring Native Americans. While these towns were remarkably peaceful and secure in the early years of the gold rush, cooperation deteriorated as the population surged and social structures changed. The model here helps make sense of why cooperation flagged, which community members were the perpetrators, and why some uncooperative behavior was persistent.

3 A Model of Settler- Native Interactions

3.1 Preview of the Boomtown Context

The model captures a setting in which individuals interact at random, and each interaction presents an opportunity to impose costs on someone else for one's own gain if one could get away with it. In the context of a boomtown to which this will be applied, this opportunity could take many forms: selling faulty products, using falsely-labeled weights when valuing gold ore, jumping a claim, committing petty theft, and so on. These opportunities would also be present in interactions with an out-group, in this case neighboring Native Americans, especially in the form of violating informal agreements about the use of land.

In the model, information about misbehavior spreads in the form of gossip through a fixed communication network. Since communications technology was rudimentary on the frontier, this process can be thought of as in-person, word-of-mouth sharing.[3] If someone is the victim of a jumped claim, that person tells his (and boomtown residents were overwhelmingly male) network neighbors, who tells his network neighbors, and so on. All those who hear can then punish the wrongdoer. If enough are expected to hear quickly, the disincentive to jump the claim in the first place can be mitigated. How well this works depends in part on the network.

[3]The other option was spreading news in print; however, even if the town developed a newspaper and even if the newspaper had a wide circulation, the process of manual typesetting, printing and delivering was quite slow (Dary, 1998), making word-of-mouth the primary option.

3.2 Model Setup

Begin with a standard community enforcement setup in which two groups A and B with sets of players $\{1, \ldots, n\}$ and $\{n+1, \ldots, 2n\}$, respectively, randomly encounter each other and play the prisoner's dilemma.[4] Specifically, define an infinitely repeated game $\mathcal{G}$ in which all players play one round of prisoner's dilemma with an opponent independently drawn from the out-group with probability p and from the in-group with probability $1-p$ each period.[5] Nature reveals to each player only his own pairing. Each round faces payoffs:

$$\begin{array}{c} \\ c \\ d \end{array} \begin{array}{c} \begin{array}{cc} c & d \end{array} \\ \begin{pmatrix} 1,1 & -\beta,\alpha \\ \alpha,-\beta & 0,0 \end{pmatrix} \end{array}$$

where $\alpha > 1, \beta > 0$ and $\frac{\alpha-\beta}{2} < 1$. Players discount future payoffs with common discount factor $\delta < 1$.

A group is a set of players who can all recognize each other: they can perfectly identify each other, describe each other, and would recognize each other if rematched. A group cannot recognize or describe individual out-group members. When matched with an out-group member, a player only knows he's playing 'someone' from the other group.[6]

Define a "communication network" for group A by the pair (g^A, A) with $n \times n$ adjacency matrix g^A where $g^A_{i,j} = g^A_{j,i} = 1$ indicates a link between $i \neq j \in A$, and

[4]This game generalizes Fearon and Laitin (1996) to include a communication network that spreads relevant information about play.

[5]The groups are assumed to be the same size to keep matching notation simple and avoid having to specify pairs of matching probabilities that are functions of the group size.

[6]This is the hard case for inter-group cooperation, and also describes well the relationship between groups of settlers (the in-group) and the neighboring Native Americans (the out-group) in the case discussed below.

likewise (g^B, B) for group B. I will refer to the networks as "g^A" and "g^B," or simply as g when the group identity is unimportant. Links in the networks are undirected and unweighted, and no links span the two groups. Networks are common knowledge within but not across groups, consistent with the assumption that individuals know little about the out-group.

Actions in in-group pairings are unobservable. Actions in out-group pairings are observable to a subset of others determined by the network.[7] The network serves two roles. One, it determines who observes whose out-group interactions– network neighbors observe each other in these encounters. Two, it determines who passes messages (spreads gossip) to whom.

Players learn about other in-group rounds via a gossip process by which the victims of misbehavior (determined by the strategies below) send a message containing the identity of the offender and the time of the offense to all network neighbors. These messages are spread through the network truthfully and deterministically at a rate $r = \frac{Degrees\ Spread}{Rounds\ Played}$.[8]

The order of play in the game $\mathcal{G}$ is as follows: in each round, nature pairs players at

[7]As will be described below, individuals learn information about others' rounds via messages sent by victims of misbehavior. By assumptions on the networks, no message sent by an out-group player reaches an in-group player. Consequently, to enforce out-group cooperation with in-group policing, out-group interactions must be observable to at least someone in the in-group; unobservable out-group interactions would all be uncooperative. Since the strategies below require players to unconditionally cooperate in out-group pairings, observing actions is sufficient to diagnose a defection: any d is misbehavior. This is not the case in in-group interactions, in which d's can be compliant with the strategy, as when issued in punishment. The cleanest way to model players dealing with this ambiguity is to assume they do not observe the actions at all but rely solely on the content of messages sent by victims. Players could play these same strategies while also observing in-group interactions, so the assumption of unobservable in-group rounds is not strictly necessary. Assuming observable out-group interactions and private in-group interactions is consistent with the context of the case below, in which encounters with Native Americans would be on open lands or occasionally in public marketplaces (observable) whereas encounters with fellow settlers could be in more private or intimate areas like homes, remote mines, etc.

[8]Gossip here is a mechanical process, not part of a strategy. While this is consistent with lab behavior (Sommerfeld et al., 2007) and the speculated evolutionary function of gossip (Enquist and Leimar, 1993), the opportunities for gain in this setup through strategic lying are not as prevalent as might be expected. See the online supplementary material for a discussion.

random respecting p; then players play one round of prisoner's dilemma; then observers of misbehavior in out-group pairings and victims of misbehavior in in-group pairings send messages, and all messages (both these new messages and previously received messages) spread through the network r degrees, which concludes the round and the next round begins.

3.3 Messages and Strategies

Without loss of generality, I will present strategies and messages from the perspective of group A, making A the in-group and B the out-group. I consider a set of strategy profiles which entail some subset of the in-group, $COOP \subset A$, playing a finite-punishment in-group policing strategy, and the complement of the group, $CHEAT \subset A$, cheating the out-group (playing d while they play c) and defecting against the rest of the in-group (playing d while they play d). In-group policing strategies like those considered here capture enforcement schemes used by real groups well.[9]

Strategies respond to messages sent through the network at the end of each round. Messages take the following form: when i deviates from strategy profile σ^{CHEAT} in a round with in-group member j, j sends a message $m_{j,i,t} = \{i, t\}$ which contains the identity of the offender and the time of the offense to himself and his neighbors. When i deviates from strategy profile σ^{CHEAT} in a round with an out-group member, i's network neighbors likewise send messages $m_{j,i,t} = \{i, t\}$ to themselves and their network neighbors. These messages establish who is in bad standing, and spread through the network at rate r, defined above. Call $M_{i,t}$ the set of individuals about whom i has

[9]Cooperation supported by the strategies played by $COOP$ has other desirable properties as well, which is perhaps why these strategies seem to be favored by real groups. Carrying out punishment is renegotiation-proof– punishers gain from punishing. Additionally, finite punishments are desirable in environments prone to errors or mistakes since they destroy minimal value off the equilibrium path and give groups the chance to return to the efficient outcome, which may have been particularly important in frontier life where drunken mishaps were common (McGrath, 1987, p. 75). Most importantly for the account here, they also resemble punishments that settlers opted to use to enforce communal norms. Accounts of misbehavior cite fines and other concessions that the offenders were pressured to pay for a finite period of time.

received messages by the start of time t about rounds that have occurred since $t - T$. This is the set of individuals that i knows to be in bad standing at that time.

Now consider the generic strategy profile in which the players participating in in-group policing condition punishment on these messages:

Definition 1 (**Network In-Group Policing with Cheaters** σ^{CHEAT})**.** *For all players $i \in COOP$:*

Play c when matched with an out-group player. When matched with an in-group player $j \in COOP$: play c in the first round. In round t, if $i \notin M_{j,t}$ (opponent j has received no message that i is in bad standing), play c if $j \notin M_{i,t}$ (i has not received a message that j is in bad standing) and d if $j \in M_{i,t}$ (i has received a message that j is in bad standing). In round t, if $i \in M_{j,t}$ (opponent j has received a message that i is in bad standing), play c if $j \notin M_{i,t}$ and d if $j \in M_{i,t}$.When matched with an in-group player $j \in CHEAT$, play d.

For all players $i \in CHEAT$: Always play d.

Strategies played by those in $COOP$ are responsive to deviations by others in $COOP$; punishment here takes the form of capitulation for a finite number of rounds T so that a defector concedes value to his punishers for the T rounds that follow his defection. Player i knows his set of messages $M_{i,t}$, and can infer his opponent j's messages about i– whether or not $i \in M_{j,t}$– because i knows when he i has deviated, and he knows the network structure and rate of transmission r.[10]

An important classification for the analysis that follows will be the extent to which a player is peripheral, which is a function of his network position. First, consider a generalized definition of network neighborhood which includes neighbors more than one degree away:

[10]It turns out players can play a variant of these strategies without knowing whether their opponent has received a message about themselves or not. Players know when they have themselves done something wrong, and so know when messages would be sent. Even if they cannot identify who has received them, so long as they play "always play c for the T rounds after I defect," cooperation can still be enforced.

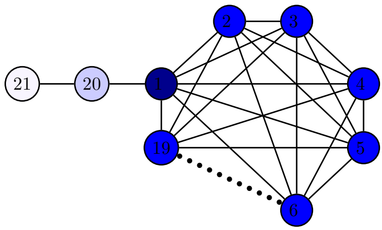

Figure 1: Extent to which players are peripheral in a simple example when $r = 1$, $T = 1$. Here $\#N_{21}^1 = 1$, $\#N_{20}^1 = 2$, $\#N_2^1 \ldots \#N_{19}^1 = 18$, and $\#N_1^1 = 19$.

Definition 2 **(k-neighborhood).** *Let $\ell(i,j)$ be the length of the shortest path from i to j. Player i's* ***k-neighborhood*** *in network g^A, $N_i^k(g^A)$ is the set of all j such that the shortest path from i to j is less than or equal to k. That is,*

$$N_i^k(g^A) = \{j \in A : \ell(i,j) \leq k, i \neq j\}.$$

Player i's k-neighborhood is the set of all other players reachable from i in paths of length k (geodesic distance k). When the network is clear, I will suppress dependence on g and simply write N_i^k. Now we can be precise in classifying players as more or less peripheral:

Definition 3 **(Peripheral Players).** *Player i is* ***more peripheral*** *than player j in network g^A if i's rT-neighborhood is smaller than j's; that is, if*

$$\#N_i^{rT}(g^A) < \#N_j^{rT}(g^A).$$

Figure 1 denotes the extent to which each player is peripheral in an example network for $r = 1$, $T = 1$. The lighter the shade, the more peripheral the node.

Now we can consider partial cooperation in equilibrium.

4 Enforcing Partial Cooperation

4.1 Cheating in Equilibrium

Ultimately, the goal is to characterize partial cooperation in equilibrium, identify when groups are only able to enforce less-than-full cooperation in equilibrium, and characterize transitions between equilibria and responses to shocks.

In strategy profile σ^{CHEAT}, a (possibly empty) subset of the in-group $CHEAT \subset A$ plays a strategy in which they always defect in in- and out-group pairings, and a (possibly empty) subset $COOP \subset A$ cooperates in out-group pairings, plays an in-group policing strategy with others in $COOP$, and always defects against those in $CHEAT$. First I establish the conditions under which in-group policing among $COOP$ is sufficient to keep all in $COOP$ cooperating in pairings with the out-group and with others in $COOP$. The equilibrium outcome entails everyone in $CHEAT$ playing d in out-group pairings, everyone in $COOP$ playing c in out-group pairings, pairings among $COOP$ resulting in mutual c and pairings among $CHEAT$ and between $CHEAT$ and $COOP$ resulting in mutual d.

For σ^{CHEAT} to be sequentially rational, it must be that for a division of A into $CHEAT$ and $COOP$, no individual has an incentive to deviate from her prescribed strategy in any history of play. This holds under the following conditions:

Lemma 1 (Partial Cooperation). *σ^{CHEAT} with partition of A $\{COOP, CHEAT\}$ is sequentially rational if and only if, given r, p, T, g_A, for all $i \in COOP$:*

$$\delta^T \geq \frac{(n-1)(\alpha-1)}{\#(N_i^{rT} \cap COOP)(1-p)(\beta+1)}$$

and

$$\delta^T \geq \frac{(n-1)\beta}{\#(N_i^{rT} \cap COOP)(1-p)(\beta+1)}.$$

The online supplementary material contains the proof, along with a discussion of beliefs that extend the behavior to sequential equilibrium.[11] The conditions ensure that those playing the in-group policing strategy can keep each other cooperating, even when accounting for the fact that those not in $COOP$ do not participate in punishment. Any equilibrium requires that those who are supposed to in-group police are not too peripheral among those who are also in-group policing.[12]

As with any repeated prisoner's dilemma, an equilibrium with $COOP = \emptyset$ and $CHEAT = A$ will always exist. In fact, there can exist many partitions of A into $COOP$ and $CHEAT$ that are sustainable in equilibrium since any subset playing all-d are always best-responding to each other. Since the present goal is to characterize successful self-governance, the interest will be in the most cooperative feasible equilibrium– the equilibrium with the most individuals comprising the set $COOP$ that is feasible– which equivalently is the most efficient feasible equilibrium. The most efficient equilibrium *possible* is one in which $COOP = A$ and $CHEAT = \emptyset$, but this is not always *feasible* for a given set of parameters. In fact, we can use the conditions in Lemma 1 to specify when full cooperation ($COOP = A$) is impossible:

Corollary 1 (When Full Cooperation is Impossible). *There exists no equilibrium with $COOP = A$, $CHEAT = \emptyset$ if, given r, p, T, and g_A,*

$$\delta^T < \min_{i \in A} \left\{ \frac{(n-1)(\alpha-1)}{\#N_i^{Tr}(1-p)(\beta+1)} \right\}$$

[11] As the proof makes clear, the conditions depend only on the final round of the punishment phase, T, because, although a player expects some amount of punishment in all rounds $1, \ldots, T$ following a defection, the condition in terms of only T is binding for those contemplating defecting a second time in a row. When the condition is satisfied for this hard case of defecting, it discourages all other cases of defection by those in $COOP$ as well.

[12] The statement $N_i^{rT} \cap COOP$ is equivalent to $N_i^{rT}(g|_{COOP})$, that is, the rT-neighborhood in the subnetwork induced by the set of cooperators $COOP$. To enforce cooperation among $COOP$, no one can be too peripheral in the network among only those in $COOP$.

or

$$\delta^T < \min_{i \in A} \left\{ \frac{(n-1)\beta}{\#N_i^{Tr}(1-p)(\beta+1)} \right\}.$$

Since supporting $COOP = A$ can be impossible, what is the most cooperative feasible equilibrium be for a given set of parameter values? In other words, what is the largest set of cooperators (or equivalently the smallest set of cheaters) that can be supported in equilibrium? The following result characterizes the maximally cooperative feasible equilibrium.

Proposition 1 (Maximally Cooperative Equilibrium). *An equilibrium with set of cooperators $COOP$ is the maximally cooperative partial cooperation equilibrium possible when, given r, p, T, g^A,*

$$\delta^T \geq \min_{i \in COOP} \left\{ \frac{(n-1)(\alpha-1)}{\#(N_i^{Tr} \cap COOP)(1-p)(\beta+1)} \right\} \tag{1}$$

and

$$\delta^T \geq \min_{i \in COOP} \left\{ \frac{(n-1)\beta}{\#(N_i^{Tr} \cap COOP)(1-p)(\beta+1)} \right\}, \tag{2}$$

and, for any other set of cooperators $COOP'$ such that $\#COOP' > \#COOP$, either

$$\delta^T < \min_{i \in COOP'} \left\{ \frac{(n-1)(\alpha-1)}{\#(N_i^{Tr} \cap COOP')(1-p)(\beta+1)} \right\} \tag{3}$$

or

$$\delta^T < \min_{i \in COOP'} \left\{ \frac{(n-1)\beta}{\#(N_i^{Tr} \cap COOP')(1-p)(\beta+1)} \right\}. \tag{4}$$

Conditions (1) and (2) ensure that the conditions from Lemma 1 hold for the most tempted individual playing in-group policing among $COOP$, and conditions (3) and (4) ensure that any candidate addition to the set of those playing in-group policing could not be incentivized to cooperate among that new set of $COOP'$. If all 4 conditions are satisfied, the equilibrium with partition $COOP$ and $CHEAT$ both entails everyone in $COOP$ cooperating and is the largest possible set of individuals who could be enticed to cooperate.

Note that if networks were assumed to be complete (as is often the case, at least implicitly, in non-networks models), the most cooperative feasible equilibrium would either entail no one cooperating or everyone cooperating. Intermediate ranges of cooperation would not be maximally cooperative since if anyone could be enticed to behave cooperatively, all could. Maximally cooperative equilibria with intermediate ranges of cooperation are possible here due to heterogeneity introduced by network position.

The network position determines the gains from potential defections from the in-group policing strategy: the most peripheral players are the most tempted. Individuals face punishment for misbehavior from those who receive messages from their victims of in-group wrongdoing or from witnesses of their out-group wrongdoing. Messages sent from more peripheral network positions have less reach; fewer others learn quickly. Intuitively, then, peripheral network positions generate incentives for individuals in $COOP$ to misbehave in two ways. First, the most peripheral have the greatest temptation to defect against the out-group. For them, the number of other in-group members who hear about the offense from observers is the smallest, yielding the smallest expected punishment. Second, the most peripheral *generate* the greatest temptation for in-group defections. Other in-group members who defect against people in these network positions in private interactions only need fear punishment from the few other in-group members who receive the message sent by the victims in these peripheral positions.

Proposition 1 reveals that in a maximally cooperative equilibrium, if any players cheat, the most peripheral players do:

Corollary 2 (The Cheating Periphery). *In a maximally cooperative equilibrium,* *there exists a threshold*

$$x^\star := \min_{j \in COOP} \{\#(N_j^{Tr} \cap COOP)\}$$

such that

$$\textit{if } \#N_i^{Tr} < x^\star, \textit{ then } i \in CHEAT.$$

In other words, there exists a cut below which all players who are at least that peripheral will be in $CHEAT$. Note that this cut is sufficient– peripheral players will be the cheaters– but not necessary – others can be too– for inclusion in $CHEAT$. $CHEAT$ can also include some players who are central; in fact, there can exist a maximally cooperative equilibrium in which $CHEAT$ contains a player i who is even more central in the whole network g than the most central player in $COOP$. This happens only when central player i is surrounded by too many others who are too peripheral to belong to $COOP$. In this case, though many of them could receive messages sent by i, since none of them could be enticed to act on the messages, the central position of i does not help to keep him cooperating. If i were added to the set of $COOP$, he would be highly peripheral among the set of cooperators: $\#(N_i^{Tr} \cap COOP)$ would be very small. In other words, highly peripheral players are not only contained in $CHEAT$ themselves, but can drag more central players into $CHEAT$ as well depending on their placement throughout the network. The online supplementary material contains an example of such a case.

One final bit of intuition follows straightforwardly from Proposition 1 and will be useful when analyzing responses to shocks in the next section. Maximally cooperative equilibria with a larger set of cooperative players ($COOP$) are more difficult to sustain.[13]

[13]Equilibrium 1 is more difficult to sustain than equilibrium 2 if, all else equal, equilibrium 2 can be satisfied for a smaller minimum value of discount factor δ than equilibrium 1.

Corollary 3 (The Difficulty of Enforcing High Cooperation). *All else equal, a maximally cooperative equilibrium with $\#CHEAT$ cheaters is more difficult to support than a maximally cooperative equilibrium with $\#CHEAT' > \#CHEAT$ cheaters.*

4.2 Shocks to the Gains from Defecting

The results of the last section established that the most efficient equilibria under σ^{CHEAT} are those with as many people as possible playing $COOP$, and these equilibria entail the most peripheral players perpetually defecting. These results also lend insight into the matters of selecting the equilibrium initially and transitioning out of equilibrium, perhaps to a new one, in response to shocks.

These conditions are informative for situations in which the conditions for full cooperation are not satisfied, whether due to natural constraints or to shocks to a strategic environment in which full cooperation *was* possible. The next-best equilibria entail persistent cheating by and against those in peripheral network positions. In-group policing only works to keep a (possibly large) subset of the in-group cooperating, and the others perpetually cheat.

In order to derive hypotheses about the consequences of shocks to the parameter space, a direct comparison of equilibria will be useful. The difference between two maximally cooperative equilibria, one with $\#CHEAT$ cheaters, and one with more, $\#CHEAT' > \#CHEAT$ cheaters is that the most peripheral among the cooperators in $COOP$ will be among the cheaters in $CHEAT'$.

Corollary 4 (Peripheral Become the Cheaters). *In an equilibrium with $CHEAT$ and $COOP$, if a new equilibrium with $CHEAT'$ and $COOP'$ is such that $\#CHEAT' > \#CHEAT$, the the most peripheral in the subnetwork induced by $COOP$ (have the smallest $N^{Tr} \cap COOP$) will be in $CHEAT'$.*

In the face of a shock that makes cooperation more difficult, the most peripheral among those cooperating will become cheaters. Just as with Corollary 2, while the most peripheral from $COOP$ will definitely become cheaters, some central players in $COOP$ could also become cheaters if their centrality among $COOP$ depended on connections to the most peripheral who switch to cheating. Once again, the placement of the peripheral throughout the network can result in some central players being dragged into cheating as well.

Because these results can inform responses to shocks, it is important to consider how equilibrium behavior would be expected to change given a shock, and how and if a new equilibrium could be coordinated.

In this case, a mechanism by which a group transitions from a more cooperative to a less cooperative equilibrium is straightforward. Suppose a group is participating in a fully cooperative equilibrium, when suddenly something about the environment changes to increase α (in the case presented below, an unusually harsh winter increased the gains from reneging on an agreement to not forage on lands shared with the out-group). While an increase to α raises everyone's temptation to defect, the first for whom this temptation binds are the most peripheral in the network. Recall that this temptation manifests itself in two ways. First, it gives the peripheral an extra incentive to defect on the out-group; expected in-group punishment is no longer sufficient to dissuade them. Second, it increases all other in-group members' incentive to defect on the peripheral; expected in-group punishment for doing so is also no longer a sufficient deterrent. Consequently, all in-group members have an incentive to defect against the most peripheral. Anticipating this new incentive, the peripheral player's best response is to always play d to mitigate the consequences. Since no one in the in-group has an incentive to play a responsive strategy, enticing the peripheral to return to playing c is impossible and the group becomes locked into mutual defect with the peripheral. The size of the shock to α determines the size of the peripheral group for whom this binds.[14]

[14]In fact, in resulting equilibrium, those in $CHEAT$ are effectively ostracized. They are forever denied gains from interactions with the rest of the group. This form of ostracism arises naturally

Groups can easily ratchet into less cooperative equilibria. Shocks that make cooperation more difficult bind first for the peripheral and generate a natural transition to a pocket of all-d. Interestingly, the same is not true for shocks that make cooperation easier. If a group is playing a partially cooperative equilibrium and then suddenly it becomes *less* profitable to defect (α decreases, say), moving to a more cooperative equilibrium is not as natural and requires an element of trust. Those previous cheaters who might now have an incentive to cooperate need some assurance that the rest of the in-group will transition to regarding them as cooperators with whom they play c by default. Because in-group cooperators would gain by playing d against a newly cooperative peripheral player who now plays c, transitioning to a more cooperative equilibrium poses greater difficulties.

The results thus far can be formulated into hypotheses pertaining to groups playing in-group policing in an environment subject to shocks. The first four are straightforward formulations of Proposition 1 and the related corollaries:

HYPOTHESIS 1: *When gains from defection increase, more cheating should obtain in equilibrium.*

HYPOTHESIS 2: *When gains from defection increase, the most peripheral should be among the first to begin cheating.*

HYPOTHESIS 3: *Transitioning from more to less cooperation should be easier than transitioning from less to more cooperation.*

when full cooperation under in-group policing is impossible, which suggests an endogenous means by which groups come to ostracize some. Those most tempted to defect cannot be prevented from doing so; anticipating their defection, in-group opponents steel themselves in these interactions by defecting as well. This results in a subset that is perpetually defected on by everyone else while the rest of the group carries on cooperating amongst themselves in the next-best equilibrium outcome. Ostracism reduces the total sum of payoffs and so is inefficient, and also reduces the number of players playing a responsive strategy, so makes enforcing cooperation among those not ostracized more difficult as well. Groups, then, should prefer to ostracize as few as possible if given the choice. This downside to ostracizing is the gossip network analog to (Ali and Miller, 2016) in which, when the network describes who *plays* whom, there can be a disincentive to implementing long-term ostracism in any bilateral relationship.

Hypothesis 4: *A reduction in cooperation should manifest itself in a set of in-group players who are subjected to perpetual mutual defect (they are effectively ostracized).*

4.3 Shocks Due to Population Change

While networks among a fixed group of individuals may themselves be reasonably fixed, groups engaged in self-governance may experience population changes that disrupt the size of the group as well as the network structure among its members. To generate expectations about the consequences of these changes, it is important to highlight that a change in population size– changing n– has ambiguous consequences on incentives for cooperation. A larger group size *can* dilute the efficacy of punishment if, for instance, in a group in which a person expects to be punished by x others for defecting against the out-group, an increase in group size occurs *without an increase in* x. Then the conditional probability of punishment changes from $\frac{x}{n-1}$ to a smaller value $\frac{x}{n'-1}$ for $n' > n$. However, a change in the size of the group necessarily means a change in the composition of the group, which likely has consequences for the network structure and possibly any individual's x.

The following corollary helps to make sense of the consequences of changes in n:

Corollary 5 (The Mixed Consequences of Changes in Group Size). *Changes in group size have ambiguous effects on the maximum extent of cooperation in equilibrium. The direction of change depends on how the network changes as a result of the change in group composition. For an original group A of size n with network g and $COOP$ cooperators in a maximally cooperative equilibrium, consider a change in group size resulting in new group A' of new size n' and attendant new network g'. The change in population strictly decreases (increases) the maximum extent of cooperation in equilibrium if, for*

$$P^{\star} := \frac{x^{\star}}{n-1} = \min_{j \in COOP} \left\{ \frac{\#(N_j^{Tr}(g) \cap COOP)}{n-1} \right\},$$

$$\frac{\#COOP}{n-1} > (<) \max_{NEW \in \mathcal{P}(A')} \left\{ \frac{\# \left\{ i \in A' | \#(N_i^{Tr}(g') \cap NEW)/(n'-1) \geq P^\star \right\}}{n'-1} \right\}$$

where $\mathcal{P}(A')$ is the power set of A'.

Intuitively, in the old maximally cooperative equilibrium, everyone in $COOP$ faced expected punishment (conditional on playing an in-group player) of at least $P^\star$. Those who would cooperate in a maximally cooperative equilibrium after the change in group composition would be those in the largest subset possible such that when all in the subset in-group police, they face conditional probability of punishment at least as large as $P^\star$. To remain exactly as cooperative after the change in group composition, this subset must comprise the same proportion of the new population as $COOP$ comprised of the old population. When such a subset comprises a larger proportion of the new population, more cooperation is possible in equilibrium after population change; when the set comprises a smaller proportion of the new population, less cooperation is possible in equilibrium.

The direction of change in cooperation following a change in population depends on how the network structure changes. To generate hypotheses about the consequences of population change, then, we need to make an additional assumption about how the network structure changes with changes to the population. With a minimal behavioral assumption about the formation of ties, we can make broad comparisons: assume that forging network ties takes time, so that the longer an individual has been part of a group, the more ties that individual has to other group members.[15] Then two hypotheses follow regarding certain instantiations of population change:

Hypothesis 5: *Population increases that are especially rapid are likely to reduce cooperation.*

[15]This follows from the notion that social ties are the product of time spent together, frequency of encounters, established trust, or shared experiences (Granovetter, 1973). We could make this assumption more realistic by adding "on average" and then making the ensuing hypotheses probabilistic, but the present statement is simpler.

Hypothesis 6: *Population change that is accompanied by high turnover– in which long-time residents leave while new residents enter- is likely to reduce cooperation.*

Given that social ties take time to forge, rapid population increases mean a large proportion of a group's network will occupy peripheral positions (at least for a while). Similarly, high turnover means those with the least peripheral network positions are those who leave the network and those with the most peripheral replace them. Both strain cooperation.[16]

Finally, we can consider different patterns of population change chosen to be informative for the case that follows. Specifically, consider two stylized types of settlement by individuals who immigrate into a group and comprise a small proportion of the resulting group. In the first, the immigrants settle in a closed community, forging links within the small, closed community but not with the existing members ("enclave"). In the second, the immigrants settle throughout the community, forging links in a dispersed manner with existing members ("integrated"). Then we can advance the following additional hypotheses about settlement:

Hypothesis 7: *Cooperation is more likely to break down in the presence of enclave settlement than in the presence of integrated settlement.*

Hypothesis 8: *When the reach of individuals in the enclave is small relative to the reach of individuals in the existing population, the existing population is likely to target those in the enclave, resulting in mutual defect between the existing population and members of the enclave.*

[16]Others have observed that a shock to population can disrupt cooperation. Freudenburg (1986) compares Colorado towns which have a relatively stable population to one which experiences a dramatic population boom. The rapidly growing town featured both a sparser density of acquaintances and more crime. The argument presented here is that a rapidly changing population poses dangers in two ways: first, new additions to a community may be relatively socially isolated and so may have incentives to misbehave, and second, the larger population means each person needs to sustain even more social contacts in order for the original members to continue cooperating. The latter makes sense of a puzzling finding in Freudenburg (1986) that the newcomers are not the only perpetrators of crime even though crime is more prevalent after they join the population.

The intuition for these hypotheses relies on the fact that enclave settlements relatively limit the reach of any immigrant in the network: at most he can reach others in the enclave. In integrated settlement, on the other hand, the reach of any immigrant is not limited to strictly the other immigrants and can be as large as the whole group. Whether this means the enclave positions are more peripheral than the integrated ones is not certain; however, if the original residents have lived together long enough, their network will be relatively dense (by assumption). If the extent to which these new positions are peripheral relative to the existing network is great, those in the existing community have an incentive to defect against those in the enclave, knowing news of these defections will not spread outside the enclave. The same incentive holds for all members of the existing community, generating an incentive for the enclave to play d in return in defense, and pushing the full group into a less-cooperative equilibrium.

Figures 2 and 3 depict a hypothetical original group with 187 members that faces a 10% population increase with enclave settlement. Suppose that $r = 2$, $T = 2$, and all members of the original group play as $COOP$. The original inhabitant on the far right, depicted with the largest circle, is the most peripheral– messages sent by him reach 62 others in $rT = 4$ steps. Due to the insularity of the enclave settlement and their small size relative to the original inhabitants, the reach of anyone in the enclave is constrained. In 4 steps, messages sent by anyone in the enclave reach everyone else in the enclave – 18 people– and no others. This means the temptation to defect against anyone in the enclave is much greater than the temptation to defect against a fellow original inhabitant. When this temptation is too great, groups can find themselves in a less cooperative equilibrium in which everyone defects against members of the enclave.

In the next section I present the case of boomtowns on the American western frontier and assess support for the above hypotheses.

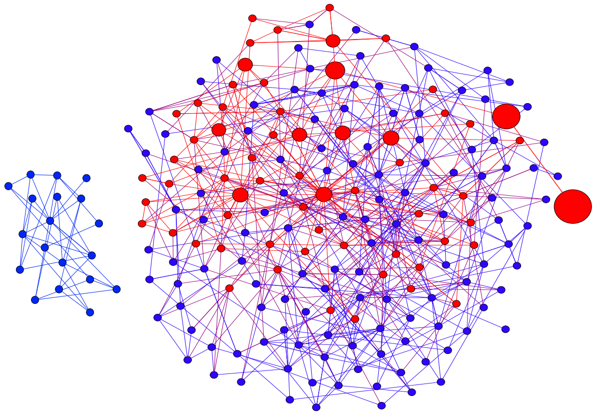

Figure 2: Example group with 187 original inhabitants (right) and 19 new members who settled in an enclave (left). News sent from the most peripheral original inhabitant (largest circle on far right) reaches 62 others when $r = 2, T = 2$.

5 Boomtowns

5.1 Peer Enforcement on the Frontier

In 1848, the discovery of gold at Sutter's Mill triggered a flood of migration to California fueled by hopes of striking it rich. Over 300,000 prospectors moved to the region over the two decades that followed. The rapid surge in population led to a phenomenon known as the "boomtown," in which a small, sparsely-populated mining camp became a dense makeshift town with thousands of residents over a very short period of time.

These rapidly growing boomtowns were emerging in an otherwise weakly-governed environment; the western American frontier in the mid 19th century is a textbook example of a weak state setting. Formal governing institutions were largely absent and weak when present. Federal and state law pertaining to mining and land rights was

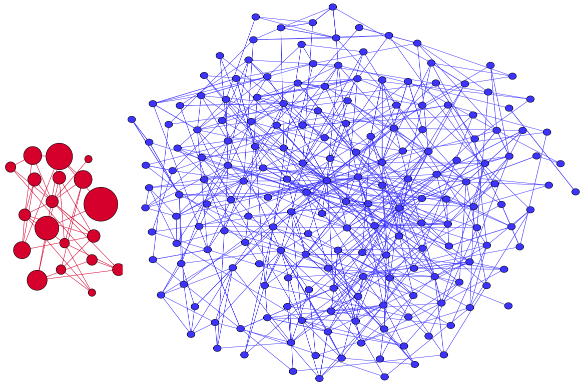

Figure 3: Example group with 187 original inhabitants (right) and 19 new members who settled in an enclave (left). News sent from the most peripheral member of the enclave (largest circle on left) reaches only 18 others when $r = 2, T = 2$. Enclave settlements limit the reach of messages and so generate incentives to defect against members of the enclave.

barely existent in the area (Umbeck, 1977, p. 203), and settlers were far outside the reach of the enforcement of laws related to personal safety, the security of personal property, and day-to-day wellbeing (Clay and Wright, 2005, p. 159). Boomtowns had especially weak governing institutions, in no small part because the growth of the towns outpaced formal governance (and sometimes the construction of a jail). The code of conduct and its enforcement was left to the residents of the boomtowns.

Despite the absence of formal governing institutions and the wealth of opportunities to misbehave, mining towns on the frontier appear to have been remarkably peaceful and secure. In his history of the mining communities and their governance composed at the end of the 19th century, Shinn writes: "Scattered over a large territory, the men of the various camps dwelt together in peace and good-fellowship, without any representatives of the United States Government in their midst. Legal forms and judiciary machinery were as nearly non-existent as it is possible to imagine in a civilized country" (Shinn, 1884, p. 117). More recent histories of the frontier tend to begin by noting that the so-called "wild west" was surprisingly cooperative and peaceful despite the poor formal governing institutions (see, e.g., Prassel, 1972; Anderson and Hill, 2004). Some even point to metrics on which the western frontier rates as "a far more civilized, more peaceful and safer place than American society is today" (Hollon and Crowe, 1974, p.x). Stories circulated in the decades that followed the gold rush about settlers leaving thousands of dollars' worth of gold-dust in unguarded, unlocked tents while they were away as evidence of how trusting and trustworthy the settlers were (Shinn, 1884, p.150).

The historical record is rife with examples that point to a community enforcement scheme at play: settlers in the boomtowns understood a set of actions to count as violations and took it upon themselves to enforce good behavior, even to punish on behalf of other settlers. Shinn notes: "Men had to settle their financial affairs and their petty quarrels among themselves: that was the mining-camp doctrine" (Shinn, 1884, p. 126). Actions qualifying as offenses ranged from encroaching on mines– sluice-robbing and claim-jumping– to personal violations like cheating in a business transaction and committing violence.

Settlers monitored each other for cheating, which could be easy in the close living spaces or increasingly crowded streams being mined (Umbeck, 1977, p. 214). For instance, once miners had reached an understanding about who was entitled to mine where, other miners would watch and protect someone's claim in the expectation that he would help do the same for theirs; when punishment was warranted, it was swift (Umbeck, 1977, p. 216, 219). As another example, informal mining partnerships became a salient part of working life and the whole community was involved in enforcing relevant norms: "The legal contract of partnership, common in settled communities, became, under these circumstances, the brother-like tie of "pard"-nership, sacred by camp-custom, protected by camp-law; and its few infringements were treated as crimes against every miner" (Shinn, 1884, p. 111).

In general, petty crimes and misbehavior were rare because the punishment, understood to be communal, served as an effective deterrent. Speaking optimistically about the short-lived highly lucrative period of mining, Shinn explains: "Certainly it was easier to earn money than to steal it, but it was infinitely safer also. In later days, for a man to be caught sluice-robbing was to sign his own death-warrant" (Shinn, 1884, p. 119). While homicide was a rare punishment, there are also accounts of fines, beatings and whippings doled out by the community in response to offenses (see, e.g. Umbeck, 1977). In the few places that quickly developed a periodical, sometimes it was used to nudge the community to respond to particularly glaring cases of misbehavior: "in those mining districts where legally constituted law enforcement agencies were either ineffective or nonexistent, editors [of newspapers] encouraged the law-abiding population to use extralegal means of quieting chronic lawbreakers and violators of the public peace" (Halaas, 1981, p.85).

Settlers had to worry not only about interactions with fellow settlers living in the fledgeling towns, but also with nearby Native Americans. What few interactions there were between settlers and Native Americans occurred mostly in the land surrounding the towns and, much more rarely, in the small commercial centers of the boomtowns (Umbeck, 1977).[17] There is no record of social relationships forging between the two groups– from the perspective of the settlers, the Native Americans were the difficult-to-individually-identify outgroup. There *is* record of agreements between the two groups carving out acceptable and unacceptable behavior, sometimes promising payment in

[17]Few interactions between settlers in mining camps and Native Americans appear to have been commercial; the bulk of interactions took place in the territory just outside of the mining camps or on trails connecting mining camps to other towns. A rare instance of market interactions is reported in Umbeck (1977, p. 211) in which Native Americans were hired to mine on Mormon Island. Apparently settlers engaged in a variety of cheating schemes in these interactions: Native Americans were offered trade for other goods at exploitative rates, or were offered a value of their gold determined by faulty extra-heavy weights.

exchange for rights to land and restricted hunting, grazing and burning (Umbeck, 1977, p. 209), and sometimes laying out appropriate joint use of land (McGrath, 1987, p. 20). Once an agreement was understood or formally agreed to, settlers worked to keep fellow settlers from violating the terms (McGrath, 1987, p. 49).

In short, settlers living in rapidly growing "boomtowns" during the gold rush of the mid 19th century lived far from the reach of formal governance but appear to have enforced good behavior via threats of community punishment. These threats pertained to interactions with fellow settlers, and also with the rarer interactions with neighboring Native Americans.

5.2 Out-group Cheating in the Mining Towns

Assuming that settlers in fact enforced good behavior via threats of community punishment by those who learned about offenses, if we knew the precise social structure we could use the above results about network structure to offer individual-level explanations across settlers and across whole towns. Unfortunately, although the American western frontier is a uniquely well-documented weak state, the documentation is still highly qualitative and imprecise. While there were more detailed records, these records were on paper, and the quickly-constructed boomtowns were highly flammable: approximately every mining town burned down at some point between its heyday and today, destroying everything including their records (Umbeck, 1977, p. 216).

However, although we cannot map precise networks of communication among settlers, we can infer rough network position from the accounts that remain and use this to make coarser comparisons.

According to Hypotheses 1 and 2, when a shock makes defecting more profitable, everyone's incentive to commit the defection increases, but this increased incentive may not be sufficient to make everyone defect. The first for whom the incentive will encourage defection are the most peripheral in the network. While a complete log of behavior, especially in day-to-day interactions, is unavailable, qualitative accounts of behavior between settlers and nearby Native Americans are suggestive of this relationship.

Boomtowns were constructed rapidly, and tended to feature a densely-populated commercial strip surrounded by homesteads (sometimes tents) that became more sparsely arranged with distance into the countryside (Mann, 1972, p. 502). The main opportunities for learning town gossip would have occurred along the commercial strip (in the saloons and stores), in the mines, and among roommates (Mann, 1972, p. 486).[18] Since people tended to mine where they lived and towns filled from the center outward, channels of communication among miners were likely denser among the central core than among those living in the outskirts.[19] In other words, a reasonable inference is that settlers living in the outskirts were more peripheral to the mining town's communication network.

This process of settling first in a dense core and then the sparser outskirts could be seen in Aurora, a classic boomtown located just across the modern-day Nevada border which grew from a few prospectors to thousands of residents in the span of a year (McGrath, 1987, p. 9). In the height of the boom, with 5,000 residents, "Aurora was bursting at the seams. Every hotel, lodging house, and miner's cabin was jam-packed, and hundreds of people went without accommodations" (p. 9). The miners quickly outstripped supplies, and nearby cattle ranchers capitalized on the new market by driving cattle in and setting up ranches in the hills around the town (p. 17). The settlers occupied a very dense town center which filled first; those arriving later occupied a sparser set of ranches in the hills.

Of course, none of the land was actually previously unused, as the native Paiute

[18] People shared housing primarily with others whom they knew before entering the mining towns (Mann, 1972, p. 487).

[19] While this is speculative and there could easily be exceptions, those in the geographic center of a bustling community growing from the dense center outward naturally have greater access to news of the day. If someone violated a norm of the mining town, they would have reasonably heard soonest, especially compared to those living in the outskirts. This difference would be even starker if those in the outskirts arrived later to the village, after the center core was established.

used the land for foraging and growing roots. To live a peaceful existence, settlers then needed to cooperate both with fellow settlers and with the neighboring Paiute. As the settler population grew larger, relations between Aurora settlers and the Paiute grew tense. After some initial conflict between the white settlers and the Paiute, both parties met and drew up an informal treaty to establish appropriate behavior and promote inter-group peace (McGrath, 1987, p. 20). Both sides appear to have tried to encourage fellow members of their groups to uphold their end of the agreement (p. 23, 40).

The winter following the treaty, of 1862-63, was especially severe and made the resources shared by the two groups and governed by the informal treaty scarcer (p. 20). This shock made foraging on local plants and extending cattle grazing in violation of the agreement more profitable to the settlers, and made hunting and gathering on all parts of the territory in violation of the agreement more profitable to the Paiute. According to the model presented above, we should expect greater incentives to violate the treaty, and the first to act on those incentives to be the most peripheral.

Indeed, the first documented instance of inter-group conflict in violation of the treaty was by a Paiute known as "Joaquin Jim." Joaquin Jim is one of the very few Paiute to enter the historical record by name specifically because he was known for being an outcast among his people (McGrath, 1987, p. 21), suggestive of a peripheral network position among the Paiute. Likewise, the first settlers to violate the inter-group treaty were the more isolated ranchers living outside of the main core of town instead of the more densely packed prospectors in town (p. 18).[20]

While this is only one account and the exact motives of any of the actors are unknowable, the responses to a shock that increases the benefits to defection, α, among

[20] All settlers, not merely ranchers living in the outskirts, would have had incentives to forage for plants and violate the agreement. Also of note is that violence persisted as a string of isolated incidents through the fall and winter of 1863. Small-scale conflict can be durable, even if not permanent. Joaquin Jim acquired a band of followers who "remained at large and continued to prey on the unsuspecting traveler or prospector" (p. 40). The rarity with which they experienced punishment allowed this partially-cooperative equilibrium to persist.

those engaged in community enforcement are consistent with the results of the model above.

5.3 The Strains of Population Change

Boomtowns followed a similar trajectory in the middle of the nineteenth century. As already discussed, their populations grew rapidly, especially in the first few years following 1848. Populations were on net rising despite the fact that many early prospectors left shortly after arriving, generating substantial turnover (Mann, 1972, p. 493). The first wave of population influx was predominantly from elsewhere in the United States (Mann, 1972, p. 490).

About a decade after the initial gold rush took off, two changes occurred throughout western mining towns. First, the number and proportion of foreign miners substantially increased. For instance, in 1850, Grass Valley and Nevada City had almost no foreign-born miners; by 1860, about 20% of the population was Irish, 22% was British, and there were also significant proportions of Chinese, German and French miners (Mann, 1972, p. 496). In 1850 there were under 1,000 Chinese people living in California; by 1860 there were almost 35,000 and by 1870, almost 50,000 (DuFault, 1959, p. 155). Second, the relative peace and harmonious living miners had enjoyed in the 1850s was noticeably unraveling (Mann, 1972, p. 497).

Hypotheses 5 and 6 suggest that rapid population change with high turnover pose problems for cooperation. Hypotheses 4, 7 and 8 establish expectations for the targets of misbehavior: shocks generate incentives for groups to target a few, the most peripheral, and never cooperate with them.

Initially, reception of all foreign miners was positive or neutral, but attitudes toward some turned strongly negative and hostile; this was particularly the case for attitudes toward the Chinese (DuFault, 1959, p. 155). Early historical accounts blame the character of the foreign miners (Shinn, 1884, p. 144); later accounts attribute increased conflict to the fear of lost jobs and an inability to understand the foreigners (DuFault, 1959, p. 157). However, records do not corroborate a jobs-taking explanation. In fact, the Cornish appear to have consistently taken the best jobs, and yet did not face anything like the level of hostility directed at the Chinese (Mann, 1972, p. 500).[21]

Examples of conflict between the Chinese and American settlers abound, especially offenses perpetrated by the Americans against the Chinese, ranging from ignored murders to repeated robbery to denied services (DuFault, 1959, p. 158). In stark contrast with the early neutral reception, many mining camps transformed into places with rampant anti-Chinese sentiment and activity, and many eventually sought to expel the Chinese miners. Putting the issue harshly, the *Daily Free Press* printed in February 1880: "We reflect the sentiment of a large majority of the citizens of this coast when we say that we have no desire to see the Chinese ill-used or badly-treated in any way, but they are a curse to the people of the coast, and we do not want them here. They do not and cannot assimilate with Americans..." (McGrath, 1987, p.137).

Why did conflict surge in mining towns in the 1860s, and why was the treatment of Chinese settlers substantially worse than the treatment of other non-American settlers?

One important difference existed between Chinese and other non-American settlers: the Chinese consistently carved out separate communities within mining towns while other foreign settlers dispersed throughout the towns (Shinn, 1884; DuFault, 1959; Mann, 1972; McGrath, 1987). The Chinese settlers did interact with the American settlers in the towns and in the mines, but did so without forging social relationships; they lived segregated from the rest of camp (DuFault, 1959, p. 158).

From all accounts, the Chinese settled in highly insular enclaves within mining towns. Carving out separate living areas and maintaining separate habits resulted in few American settlers forging relationships with them, a separation exacerbated by

[21]Mann (1972, p. 497) writes that "The arrival of other ethnic groups did not result in such an outcry [compared to the Chinese], in part because the largest group among them, the Cornish, possessed skills needed for the general prosperity of the mines and towns." It is hard to believe their skills are all that exempted the Cornish from the hostility faced by the Chinese.

the language barrier in the many instances where the Chinese settlers did not speak English (McGrath, 1987, p. 124, 140). However, despite the absence of relationships that would result in embeddedness in the town's social network, the two groups did interact in daily life regularly. Mining towns tended to have a single option for basic services like stores, hospitals, stage line offices, and banks (though many options for saloons) at which all would interact (McGrath, 1987, p. 109). Working the same streams and mines would also generate opportunities to interact, and the Chinese areas of more developed mining towns tended to host highly popular opium dens of which many settlers partook (McGrath, 1987, p. 126). In other words, the Chinese settlers interacted with the other settlers without forging relationships outside of the small enclave.

One interpretation is: existing settlers began in their quite cooperative equilibrium. However, the restricted reach of the Chinese settlers' network positions limited the extent to which they could report misbehavior committed by other settlers. Understanding this, the existing settlers had an incentive to mistreat the Chinese since they expected to face limited repercussions. Facing increasing mistreatment, the Chinese defected in response to mitigate the consequences, and the group found itself ratcheted into a less cooperative equilibrium in which all settlers effectively ostracized the Chinese settlers in accordance with Hypotheses 3, 7 and 8. Other waves of migration into the boomtowns saw integrated rather than enclave settlement, resulting in greater embeddedness in the existing settlers' networks, a wider potential reach of gossip, and the absence of these incentives to ostracize. In those cases, a more cooperative equilibrium could persist.

Of course this is simply an interpretation consistent with the hypotheses and not a causally identified inference. The historical record does not allow ruling out every possible alternative explanation of the trajectory of cooperation breakdown. What we can say is that enclave settlement with few social ties to existing settlers and high levels of interaction generates both incentives to defect against the enclave and pressure to transition to a less cooperative equilibrium with ostracism. Settlement patterns in boomtowns would have made this incentive present in the case of Chinese and not other immigrants. The limited historical record precludes concluding that this incentive dominated other factors and *caused* mistreatment of the Chinese, though does admit this as a possibility.

6 Conclusion

Informal governance can keep neighboring groups cooperating internally and with each other, even when news about behavior spreads from person to person through social networks. Sometimes, though, due either to natural constraints or shocks to a strategic environment, the best a group can do is enforce less-than-full cooperation, tolerating some persistent cheaters along the way.

The trajectory of self-governance in the boomtowns on the American western frontier demonstrate this point well. In the early days, despite the limited formal governing institutions, settlers were quite successful at enforcing cooperation among their peers, and even cooperation with an out-group of Native Americans, many of whom remained strangers. The gossip mill churned, people expected to face great penalties doled out painfully by their peers if peers were to learn about misbehavior, and so life proceeded relatively peacefully.

Environmental shocks, rapid population growth, high turnover, and variance in settlement patterns administered shocks that strained groups' ability to enforce cooperation. Strains tend to ratchet a group into a less cooperative equilibrium in which the most peripheral become uncooperative (and perhaps ostracized in perpetuity). The Chinese immigrants to mining camps fared especial poorly, perhaps due to a pattern of settlement that resisted integration into social networks; established settlers faced new incentives to defect, specifically against the Chinese, since the reach of gossip they could spread to trigger punishment was highly limited. Consequently, cooperation deteriorated, especially among the Chinese and existing settlers.

While the results of the model presented here are consistent with the recorded history of 19th century boomtowns, the insights are about self-governance more generally. The extent to which news can spread widely and quickly through a community has consequences for peer-enforced cooperation, with particularly high stakes in weak state contexts. While a new and growing research tradition aims to measure communication networks among real groups of people, there is much more to learn about the empirical spread of information and informal enforcement of behavior.

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