WHY THE WEST BECAME WILD
Informal Governance with Incomplete Networks

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I. Introduction

INFORMAL institutions—unofficial, socially shared rules—are ubiquitous. Although they play an important role in well-functioning states by enforcing extralegal norms and mediating the effects of formal institutions,[1] they are even more important 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.[2]

A large body of empirical work documents that informal rules can enforce good behavior in both weak and strong states with applications ranging from eleventh-century Maghrebi traders[3] to modern-day resource sharers[4] and ethnically homogeneous African villagers.[5] Likewise, a large body of theoretical work demonstrates that arrangements that threaten peer sanction for misbehavior can support cooperation under a range of circumstances.

Existing theory provides the conditions under which peer sanction enforces cooperation perfectly: in equilibrium, no one misbehaves.[6] But

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[1] Helmke and Levitsky 2004.

[2] Dixit 2004.

[3] Greif 1993.

[4] Ostrom 1990.

[5] Miguel and Gugerty 2005.

[6] An exception is Ghosh and Ray 1996, in which imperfect cooperation is a possibility. Players have types, can form relationships, and can test one another with limited cooperation before agreeing to cooperate more fully.

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in reality, successful groups are those in which cooperation is the norm, but also where misbehavior occurs now and then. There were very few, but not zero, cases of Maghrebi traders cheating;[7] contributions to public goods in ethnically homogeneous villages are high, but some people still under contribute.[8] In the case discussed below, relations among settlers in nineteenth-century American mining towns were *mostly* civil at the start, but the few aberrations eventually turned into many systematic exceptions. To explain persistent misbehavior, identify the perpetrators and targets of misbehavior, and understand the trajectory of cooperation breakdown, richer theory is needed.

This article establishes social network position as one source of persistent misbehavior in informal institutions. If gossip about behavior spreads through a social network, one's position within the network determines how many others quickly hear one's news about someone's misbehavior, which determines how many others could act on the news and punish the perpetrator. 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 some people perpetually cheating. Furthermore, a shock that makes cooperation more difficult, such as 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 down into a less cooperative equilibrium in which the most peripheral members cheat and are cheated against in perpetuity, effectively ostracizing a subset that includes the most peripheral members.

After introducing a theory that makes this logic precise and deriving testable hypotheses about cooperation breakdown and persistent cheating, I present an unusual empirical case in which the perpetrators and victims of some misbehavior in a weak-state context are known. 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 nineteenth-century gold rush that they were dubbed boomtowns. These towns had little formal governance, so miners were left to their own devices to coexist with each other. Arguably due to their ability to threaten peer sanctions for misbehavior, these settlers experienced a long period in which peace and cooperation were the norm. After this period, the norm of peace began to disintegrate, but disintegration was not uniform. Hostility tended to target certain groups of settlers—especially Chinese settlers—and not others.

[7] Greif 1993, 598.
[8] Miguel and Gugerty 2005, 2327.

The model presented here helps to make sense of these outcomes by examining incentives to behave cooperatively 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 new, relatively peripheral positions that strain existing cooperative arrangements. When cooperation breaks down, the most peripheral members become victims of misbehavior and their best response is to retaliate, which can usher in a less cooperative equilibrium in which the peripheral players are effectively ostracized. Indeed, in boomtowns, Chinese immigrants who uniquely settled in enclaves with limited social network reach experienced a pattern of interactions consistent with this story—initial cooperation, then some breakdown, followed by wholesale hostility and ostracism.

This article thus makes three contributions to the study of informal governance. First, it advances a theory that 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 nonnetwork models, but it also identifies a source of persistent misbehavior that is not a result of accidents, errors of judgment, or irrationality. Second, the theory generates comparative statics that are informative for real groups engaged in self-governance. These results provide a logic for why transitioning from more to less cooperation is easier than transitioning from less to more, which is helpful for understanding the consequences of changes in an environment that are especially relevant for groups in weak-state contexts. Third, the article explores an understudied case of informal governance. The theoretical claims advanced are consistent with the history of nineteenth-century boomtowns, and offer an explanation for the otherwise puzzling phenomenon of cooperation breakdown that appears to systematically target some but not others.

II. Informal Governance in Weak States

There are many informal arrangements that in principle can enforce cooperative behavior. This study joins other research focused on enforcement via peer sanction.[9] Members of a community respond to behavior deemed inappropriate by issuing sanctions, and under the right condi-

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

tions the threat of this response is enough to dissuade everyone from misbehaving in the first place.

Theoretical work on social sanctions demonstrates 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,[10] and one in which no one learns anything other than one's own play.[11] The information environment in real groups, especially those engaged in self-governance, is likely somewhere in between; people learn something about the actions of a subset of others.

This article is part of a tradition that examines this realistic, intermediate range of information.[12] Approaches across the studies vary. Some consider players who only interact with and know the actions of a subset of others,[13] while others look at players who can infer what others have done based on the actions of others.[14] My work is consistent with a third approach, which holds that private information known by a player can spread to others across links in a social network via word-of-mouth communication.[15] Information about others' behavior tends to be newsworthy, and individuals who hear it tend to share it. This kind of social information, which can be labeled as gossip, spreads from person to person through a social network. When someone misbehaves, others hear about it from their social contacts, and spread the news to their social contacts, who may spread the news to theirs, and so on. Knowledge of misbehavior allows others to punish it, and the threat of punishment by many can incentivize cooperation.

Much theory has been devoted to generalizing folk theorems and characterizing broad results for cooperation when actors are connected in networks.[16] This article takes a narrower approach and considers a specific set of equilibria 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 games on networks,[17] the action set here is binary: to cooperate is to refrain from doing something bad, such as jumping a claim or violating an informal land-use

[10] Kandori 1992; Fearon and Laitin 1996; Dal Bó 2007.

[11] Kandori 1992; Ellison 1994; Harrington 1995.

[12] For a recent overview, see Nava 2016.

[13] See, e.g., Lippert and Spagnolo 2011; Nava and Piccione 2014.

[14] See, e.g., Kandori 1992; Ellison 1994; Wolitzky 2013; Acemoglu and Wolitzky 2016.

[15] Kandori 1992; Greif 1993; Fearon and Laitin 1996; Dixit 2003; Lippert and Spagnolo 2011; Ali and Miller 2016; Larson 2017a.

[16] E.g., Renault and Tomala 1998; Cho 2011; Ali and Miller 2013; Laclau 2014; Nava and Piccione 2014. For a review of results of this form, see Nava 2016.

[17] Pecorino 1999; Haag and Lagunoff 2007; Wolitzky 2013; Balmaceda and Escobar 2014.

treaty.[18] Players interact in a setting with word-of-mouth communication and use gossip about misbehavior sent by victims of the misbehavior and transmitted through the network to determine whether someone is in bad standing and worthy of punishment.[19]

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[20] and that limits to the reach of information can restrict the size of self-governing groups.[21] The article characterizes a set of equilibria in which some, possibly all, play a network version of in-group policing[22] and some opt out and perpetually behave uncooperatively. 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 members cooperate and more engage in perpetual defection.

This setup generates testable hypotheses that pertain to weak states in general and help to explain events in the weak-state setting of boomtowns in the American Wild West in particular. Settlers were tasked with policing behavior in their own communities, and although these towns were remarkably peaceful and secure in the early years of the gold rush, cooperation deteriorated as populations surged and social structures changed. But the cooperation breakdown was not complete, and misbehavior was neither uniform nor random. The model I present makes sense of why cooperation flagged, which community members were the perpetrators, which members were the targets, and why the less-cooperative arrangement persisted.

III. A Model of Interactions in Weak States

In this section, I present a model that is designed to capture interactions in a weak-state setting like a boomtown on the western frontier.

[18] Similar to Ali and Miller 2013; Nava and Piccione 2014.

[19] This approach 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 when punishment is underway. Kandori 1992; Ellison 1994; Wolitzky 2013; Acemoglu and Wolitzky 2016.

[20] Balmaceda and Escobar 2017; Jackson, Rodriguez-Barraquer, and Tan 2012; Lippert and Spagnolo 2011; Ali and Miller 2013.

[21] Dixit 2003.

[22] Larson 2017a; Fearon and Laitin 1996.

In such settings, people would have opportunities to interact with others in the town (in the model, people encounter one another at random), and each interaction would present an opportunity to impose costs on someone else for one's own gain if one could get away with it. In a boomtown, this opportunity could take many forms, for example, selling faulty products, using falsely labeled weights when valuing gold ore, jumping a claim, committing petty theft, and so on.

People would also have opportunities to share news of the day with any of their social contacts. One relevant bit of news would be information about who behaved badly. In the model, when a person is wronged in an interaction, gossip about misbehavior spreads through a fixed social network. Since communications technology was rudimentary on the frontier, this process can be thought of as person-to-person, word-of-mouth sharing.[23] If someone is the victim of a jumped claim, that person tells his (boomtown residents were overwhelmingly male) network neighbors, who tell their network neighbors, and so on. All those who hear the story can then punish the wrongdoer. If a sufficient number of people are expected to hear about a wrongdoing quickly, punishment would likely be severe, and the incentive to commit the wrongdoing (jump the claim) in the first place could be mitigated. How well this works depends in part on the network structure—how the settlers are interconnected socially.

Informal Overview

In the model, individuals in a group encounter one another at random. In every time period, each person is matched uniformly at random with another person, and all pairs play one round of prisoner's dilemma.[24] A pair's interaction is private, so only the pair observes who took which action.

People are interconnected in an exogenous social network, fixed ex ante. The social network spreads gossip. A tie in the network indicates a channel through which gossip can flow, so that if one person knows gossip, that person shares it with his or her social contacts in the network. A rate parameter governs how quickly news spreads through the

[23] The other option was to spread news in print, but even if the town developed a newspaper and that newspaper had a wide circulation, the process of manual typesetting, printing, and delivering was quite slow (Dary 1998), making word of mouth the primary means.

[24] The prisoner's dilemma is a game in which two players each simultaneously choose one of two actions, a cooperative or an uncooperative one. The defining feature is that each player has an incentive to take the less cooperative action, even though both would be better off if they both chose the cooperative one. This game captures situations in which a person would prefer to misbehave if he or she could get away with it.

network, so that the higher the rate, the more links the gossip traverses. When the rate is at its minimum, gossip only spreads one degree—a person tells neighbors and the gossip spreads no further. For higher values of the rate, gossip can spread multiple degrees, passing from person to person to person. People are effectively gossip machines: gossip spreads truthfully and mechanically.

Gossip is about behavior in interactions. A person initiates gossip when behavior is negative. Specifically, when a person is mistreated in an interaction, that person initiates gossip about who misbehaved and when. Since interactions are private, people identify who is behaving badly via gossip about other people's interactions. People always have enough information to judge whether they themselves were mistreated or not. In their next random encounter, people punish those whom they heard misbehaved in the previous period. Punishment takes the form of capitulation: the punished person plays *c* (cooperate), while the punisher plays *d* (defect), akin to paying a fine or atoning. Failure to atone when playing with someone who has heard the gossip is gossip worthy, earning punishment anew. Punishment is finite. In the setup below it lasts only a single round, though in the supplementary material I generalize the game to consider longer, finite punishment periods.[25]

A person's network position determines how widely the gossip that person shares will spread. Where networks are incomplete, some people occupy network positions from which gossip will spread to very few. These peripheral network positions generate incentives in others to defect against the players occupying them. When these peripheral players blow the whistle, few will punish the wrongdoers in the next period, since few will have heard about the offense.

It turns out that there can be network positions that generate such a strong temptation to defect that the people occupying them cannot be part of a cooperative arrangement in equilibrium. I consider the division of a group into a set of people who participate in enforcing cooperation, called *coop*, and a set of people who opt out and always play *d*, called *cheat*. Those in *coop* police each other's behavior and incentivize each other to be cooperative in interactions. They give up on those in *cheat*, playing *d* against them, and those in *cheat* play *d* against everyone. How large the set *coop* can be and who opts out of the largest possible set of cooperators depends on the network's properties.

[25] Larson 2017b.

Model Setup

Society is comprised of a finite set of players $N = \{1, \ldots, n\}$, with n even. In every time period, $t = 1,\ldots,\infty$, every player is matched with one other player uniformly at random to play a stage game. Call $\mu(i,t)$ player i's assigned match in time t; then $Prob\{\mu(i,t) = j\} = \frac{1}{n-1}$ for all $i \neq j \in N$. Matching in one time period is independent from matching in another time period.

In the stage game, each matched pair of players plays one round of prisoner's dilemma. Players i and j taking actions a_i, a_j from action set $A = \{c,d\}$ earn payoffs

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

where $\alpha > 1$, $\beta > 0$ and $\frac{\alpha-\beta}{2} < 1$. Players discount future payoffs with common discount factor $\delta < 1$. Stage games are private; no one except the two parties to a match observes the two players' actions.

Player i's private history at time t, h_i^t, is the identity of all i's matches, the actions of both i and i's matches in every round, and the time of the round in all stage games strictly prior to t. The set of all possible private histories at t is $\mathcal{H}^t$.

Players are interconnected in an exogenously determined social network g defined by the pair (N,g) where g is an $n \times n$ adjacency matrix. Links in the network are unweighted and undirected. The network reveals some private information, specified below, to others according to transmission process τ. g and τ are common knowledge among the players.[26]

The information structure of the game is analogous to that in games with local information processing in which some mechanical process reveals some information to other players.[27] A typical approach in such games is for players to have a state that is determined and revealed to some players via a specified, exogenous process.[28] In this model, players have something like a state *in the eyes of another player*, so that i's state according to j may be different than i's state according to k, and information relevant to determining the state is mechanically transmitted through a social network. The analogue to a state captures a player's view of another player's reputation, as learned via gossip spread through

[26] Matching is, by assumption, independent of g. It can be shown that all results here continue to hold if players are more likely to play a neighbor in g, as long as the probability of playing a network neighbor is not precisely 1.

[27] E.g., Okuno-Fujiwara and Postelwaite 1995.

[28] E.g., Kandori 1992.

a social network. Two players, one who has heard gossip about *i* misbehaving and one who has not, may appraise *i*'s reputation differently.

As an analogue to local information processing, this game can be said to have *network information processing* in that it has the following information structure. Players form a *judgment* about their match's action in the stage game. A mechanical network transmission process reveals players' judgments to others based on their positions in the network. Players use all judgments revealed to them to form an *appraisal* about every other player. Strategies map from private histories and appraisals into action. Specifically:

1. All players have an *appraisal* of every other player: *i*'s appraisal of any $j \neq i$ before playing the stage game in time t is $z_{i,j,t}$. The set of *i*'s appraisals of all other players in N by t is $Z_{i,t}$. The set of all possible sets of appraisals in t is $\mathfrak{Z}^t$.
2. All players play the stage game and form a *judgment* about their match's action in t. i forms judgment $J_{i,j,t}$ about any match j's action in t as a function of *i*'s private history and *j*'s action in t, given the network transmission process and strategies σ: $J_{i,j,t} = f(h_i^t, a_{j,t} | \tau, \sigma)$.
3. After the stage game in t, the network transmission process (τ) reveals to each player a (possibly empty) subset of all judgments that have been made by any player up to and including t. The set of judgments that are revealed to i at the end of round t is $J_{\rightarrow i,t}$.
4. Players' appraisals in $t + 1$ are a function of their past appraisals and all judgments revealed to them in t: $Z_{i,t+1} = h(Z_{i,t}, J_{\rightarrow i,t})$.
5. Player *i*'s strategy σ_i is a mapping from *i*'s private history, *i*'s appraisals of others, and *i*'s match into an action, $\mathcal{H}^t \times \mathfrak{Z}^t \times N \rightarrow A$.

Specifying a game with network information processing requires specifying three exogenous features: f, the function that determines players' judgments of actions, h, the function that determines players' appraisals of other players, and τ, the process by which the network transmits information from some players to others.

For the present model, let an appraisal be binary, so that $z_{i,j,t} \in \{0,1\}$. For simplicity, an appraisal of 1 is *in good standing* and 0 is *in bad standing*. Let a judgment be an ordered 4-tuple, $J_{i,j,t} = (J^1_{i,j,t}, J^2_{i,j,t}, J^3_{i,j,t}, J^4_{i,j,t})$, where the first element is binary, $J^1_{i,j,t} \in \{0,1\}$; the second element is the identity of the person forming judgment, *i;* the third element is the identity of the person being judged, *j*; and the fourth is the time of the judgment, *t*. Call a judgment with $J^1 = 1$ a *positive judgment*, and a judgment with $J^1 = 0$ a *negative judgment*. Judgments are formed by referencing a strategy profile. A player judges the action of a match to be negative when that action is not in compliance with the strategy.

Consider the following strategy profile in which an exogenously determined subset of players, COOP, participate in in-group policing and condition punishment on their appraisals of others, while the subset containing the rest, CHEAT, perpetually play *d*.[29]

DEFINITION 1. Network in-group policing with cheaters σ^{CHEAT}. *For all players $i \in$ COOP: When matched with a player $j \in$ COOP, play c in the first round. In round t, play c if $z_{i,j,t} = 1$ and d if $z_{i,j,t} = 0$. When matched with a player $j \in$ CHEAT, always play d. For all players $i \in$ CHEAT: Always play d.*

Players in the set *COOP* play *c* with all others in *COOP* whom they appraise to be in good standing and play *d* to punish those in *COOP* whom they appraise to be in bad standing. This strategy profile implies that punishment takes the form of capitulation to those appraised to be in good standing; a player *i* appraised by match *j* to be in bad standing plays *c* while *j* plays *d* unless both appraise each other to be in bad standing, in which case they both play *d*. In other words, a player who defected in the previous period capitulates to the innocent in the current period. Players always play *d* with those in *CHEAT*, and all players in *CHEAT* play *d* with everyone.

Since this is a game of network information processing, appraisals are determined by the judgments that players form and that are then transmitted through the network according to τ. Players form judgments of the actions of their matches based on whether the action complies with σ^{CHEAT}. If *i*'s match *j* in *t* deviates from σ^{CHEAT} in *t*, *i* judges *j*'s action negatively: $J_{i,j,t} = \{0,i,j,t\}$. If *j* does not deviate, *i* judges *j*'s action positively: $J_{i,j,t} = \{1,i,j,t\}$. Players can always tell if their match deviated from σ^{CHEAT} in the round they play together.[30] A player can distinguish his match playing *d* out of punishment from playing *d* out of defection because he knows his private history h_i^t, and so knows if he deserved punishment. He also knows *g* and τ and thus knows if his match knows this.[31]

[29] Finite punishment schemes like this one 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, 75). Most important for this account, 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.

[30] Because not all players know about every round in the game, even if they could observe what actions other pairs take, they could not discern whether all play in the game is in compliance with σ^{CHEAT}; specifically, distinguishing *d* the defection from *d* the due punishment requires extensive knowledge of histories. However, a player can always tell if his or her match is deviating from σ^{CHEAT}.

[31] Player *i*'s match *j* can deviate when playing *i* in many ways (see the supplementary material, Larson 2017b, Section 3. The simplest statement of judgments is to say *i* judges all deviations to be

The network transmission process τ governs how judgments are revealed to others in the network g. Fix τ as the following mechanical process: when i forms a negative judgment about j in t, $J_{i,j,t}$ is revealed (that is, sent as gossip) to all network neighbors of i in radius r by $t + 1$.[32] Call all players within radius r of i on network g, including i, i's r-neighborhood, expressed as $N_i^r(g)$.[33] This network transmission process implies that the judgments revealed to i in t, $J_{\rightarrow i,t}$, are the negative judgments formed in t by anyone in i's r-neighborhood.

Players begin by presuming that everyone is in good standing: $z_{i,j,1} = 1$ for all $i,j \in N$. Let one negative judgment be sufficient to consider a player to be in bad standing. Specifically, for any t,

$$z_{i,j,t+1} = \begin{cases} 0, & \textit{if } \#J_{\rightarrow i,j,t} > 0 \\ 1, & \textit{otherwise} \end{cases}$$

where $\#J_{\rightarrow i,j,t}$ is the number of judgments i has received about j by the end of round t. This form implies that if i has heard nothing negative about j in the last period (from i or others), i will regard j to be in good standing in this period. This form builds in quick forgiveness. Section 1 of the supplementary material presents a generalization of this setup, which allows for negative judgments to stick longer, and hence allows for punishment that lasts longer.[34] The definition of τ implies that i's appraisal of j in $t + 1$ is a function of the judgments of j formed by everyone in i's r-neighborhood in t:

$$z_{i,j,t+1} = \min_{k \in N_i^r(g)} \{J^1_{k,j,t}\}.$$

$Z_{i,t}$ is a record of i's knowledge of negative judgments about others in the previous period. Note that when $z_{i,j,t} = 0$, j was judged negatively

negative. But for one type of deviation, j neglecting to punish i when j knows i is in bad standing, i would be unlikely to judge this deviation negatively. Since punishment is capitulation, punishers always prefer to punish, even if no one else would punish them for not punishing. Therefore, modifying the setup to say that i does not judge this one case of deviation negatively would not change the results.

[32] That only negative gossip spreads in this way is meant to realistically capture how information about one another spreads through groups. Changing τ to also transmit positive judgments would not change the results. Gossip here is a mechanical process, not part of a strategy. Although 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 Section 5 in the supplementary material for a discussion; Larson 2017b.

[33] Player i's r-neighborhood in network g is the set of all j such that the shortest path from i to j is less than or equal to r, including i himself. That is, $N_i^r(g) = \{j \in N \mid \ell(i,j) \leq r\} \cup i$.

[34] Larson 2017b.

in the previous period. When $z_{i,j,t} = 1$, i has not heard that j was judged negatively in the previous period. This could be because j was not judged negatively in the previous period or because j was judged negatively, but due to τ and g, gossip about it did not reach i.

Each time period proceeds as follows. At the beginning of t, nature randomly matches players. Each matched pair plays one round of prisoner's dilemma, after which each player forms a judgment about the other's action. Judgments that are negative are spread r degrees through the network. Players' appraisals of other players are updated based on the negative judgments received, ending t.

If everyone in *COOP* complies with σ^{CHEAT}, all interactions among *COOP* can be cooperative. A player's incentive to comply hinges on the extent of punishment that player expects for deviating. Since the player will be punished by anyone who hears the gossip that he or she deviated, the player's expected punishment is a function of the number of others who hear the gossip. Gossip is sent by the victim of the player's deviation, so deviations in rounds with players who have small r-neighborhoods are more profitable than deviations in rounds with players with larger r-neighborhoods.

Section IV makes this logic precise by considering cooperation in sequential equilibrium for arbitrary networks. Before presenting results in full, I illustrate the strategies and network transmission process for a small, tractable example network in the subsection below.

Example

Before moving to the full characterization of results, consider a simple group with six members, $N = \{1,2,3,4,5,6\}$, with their network g depicted in Figure 1. Here, one group member has no ties to any others, three have ties to two others, and two have ties to three others.

Suppose that all six players are in *COOP*, so that all plan to play σ^{CHEAT} as in-group policers. Suppose also that by the beginning of time t, everyone has perfectly complied with σ^{CHEAT}. This means that no one would have formed a negative judgment about anyone's action, so everyone must appraise everyone else in example group 1 to be in good standing ($z_{i,j,t} = 1 \; \forall \; i \neq j \in \{1,\ldots,6\}$), shown in Figure 2(a).

For illustration, set $r = 1$, so that gossip spreads one degree and no farther. Now suppose nature randomly matches players in t as shown in Figure 2(b), so that 1 plays 2, 3 plays 6, and 4 plays 5. Given everyone's appraisals and histories, σ^{CHEAT} instructs everyone to play c. Suppose everyone plays c except player 1, who deviates and plays d. Player 2 knows that player 1 playing d is a deviation; player 2 can tell he is the

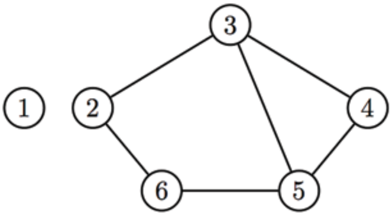
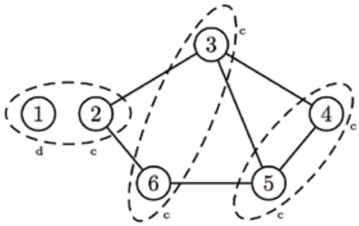


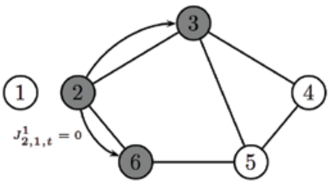
FIGURE 1
EXAMPLE GROUP 1

$$z_{i,j,t} \in \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & - & 1 & 1 & 1 & 1 & 1 \\ 2 & 1 & - & 1 & 1 & 1 & 1 \\ 3 & 1 & 1 & - & 1 & 1 & 1 \\ 4 & 1 & 1 & 1 & - & 1 & 1 \\ 5 & 1 & 1 & 1 & 1 & - & 1 \\ 6 & 1 & 1 & 1 & 1 & 1 & - \end{array}$$

Appraisals in t
(a)



Random Matches and Actions in t
(b)



Spread of Player 2's Negative Judgment
When $r = 1$
(c)

$$z_{i,j,t+1} \in \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & - & 1 & 1 & 1 & 1 & 1 \\ 2 & 0 & - & 1 & 1 & 1 & 1 \\ 3 & 0 & 1 & - & 1 & 1 & 1 \\ 4 & 0 & 1 & 1 & - & 1 & 1 \\ 5 & 1 & 1 & 1 & 1 & - & 1 \\ 6 & 1 & 1 & 1 & 1 & 1 & - \end{array}$$

Appraisals in $t + 1$
(d)

FIGURE 2
EXAMPLE GROUP 1 PLAYING IN TIME t [a]

[a] Everyone appraises everyone else to be in good standing before the stage game in t. Nature randomly assigns player 1 to play 2, 3 to play 6, and 4 to play 5. Suppose player 1 defects by playing d while everyone else complies by playing c. Player 2 forms a negative judgment of player 1's action, which spreads to players 3 and 6 (since $r = 1$), affecting their appraisal of 1 in $t + 1$.

victim of a defection. In this case, player 2 need only consult his private history—player 2 knows he complied with σ^{CHEAT} in all previous rounds, so 1 could not appraise 2 to be in bad standing. Hence, any *d* played against player 2 must be a defection and not punishment. Consequently, player 2 forms a negative judgment about player 1's action in t: $J_{2,1,t} = (0,2,1,t)$. All other players form positive judgments about the actions of their match in t.

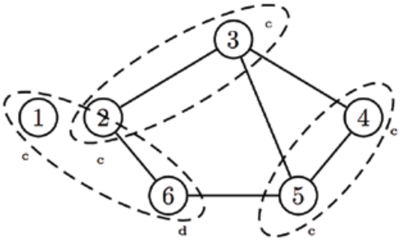
Since $r = 1$, τ mechanically transmits this negative judgment to 2's 1-neighborhood, so that the players who receive it by the end of t are {2,3,6} (shown in Figure 2(c)). All players update their appraisals at the end of t. Those who have heard a negative judgment of 1 appraise him to be in bad standing; players appraise everyone else, about whom they have heard nothing, to be in good standing (shown in Figure 2(d)).

Now continue the example in $t + 1$. Given the appraisals at the end of t, a total of three players would punish 1 if matched with that player in $t + 1$—the three who regard player 1 to be in bad standing. Suppose that nature matches the players in $t + 1$ according to Figure 3, so that player 1 plays 6, 2 plays 3, and 4 plays 5. σ^{CHEAT} instructs player 6 to punish 1, playing *d* while player 1 plays *c* and everyone else is to play *c*. If this is what all players do, no negative messages are sent, and all players appraise everyone else to be in good standing for $t + 2$.

Note that player 1's punishment hinged on being randomly matched to play someone who had heard player 2's gossip about player 1; player 1's probability of punishment in round $t + 1$ was $3/5$. If player 1 had been randomly matched to play 4 or 5, player 1 would have avoided punishment for his or her offense in t. Of course, if gossip spreads more rapidly through the network, the chances of being punished would be higher. If $r = 2$, so that gossip spreads to network neighbors who pass it to their network neighbors, then players {2,3,4,5,6} would all hear it before $t + 1$ (depicted in Figure 4). In this case, player 1's probability of punishment in $t + 1$ would be $5/5$.

Contrast the above response to a deviation by player 1 when matched with player 2 to a response to a deviation by another player against 1. Suppose players are again matched in t so that 1 plays 2, 3 plays 6, and 4 plays 5, and consider again the scenario in which all players have perfectly complied with σ^{CHEAT} up until t, so that everyone appraises everyone else to be in good standing. Now suppose that this time everyone complies except player 2, who defects against player 1, shown in Figure 5(a).

Player 1 judges 2's action negatively: $J_{1,2,t} = (0,1,2,t)$. τ spreads this to player 1's r-neighborhood but regardless of r, this is simply {1}. The



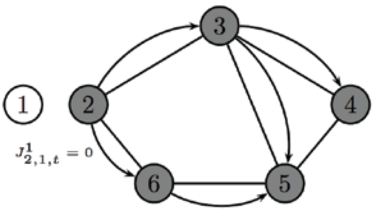
Random Matches in $t+1$; Player 6 Punishes Player 1
(a)

$$z_{i,j,t+2} \in \begin{array}{c} \\ 1\\2\\3\\4\\5\\6 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{bmatrix} - & 1 & 1 & 1 & 1 & 1 \\ 1 & - & 1 & 1 & 1 & 1 \\ 1 & 1 & - & 1 & 1 & 1 \\ 1 & 1 & 1 & - & 1 & 1 \\ 1 & 1 & 1 & 1 & - & 1 \\ 1 & 1 & 1 & 1 & 1 & - \end{bmatrix} \end{array}$$

Appraisals in $t+2$
(b)

FIGURE 3
CONTINUATION OF THE GAME FROM FIGURE 2[a]

[a] Player 6 received player 2's negative judgment of player 1 and so appraises 1 as in bad standing in $t + 1$. Suppose player 6 punishes 1, 1 capitulates, and all others who play someone whom they appraise to be in good standing play *c*. Everyone is complying with σ^{CHEAT}, so no negative judgments are sent; everyone appraises everyone else as being in good standing for $t + 2$.



Spread of Player 2's Negative Judgment When $r = 2$
(a)

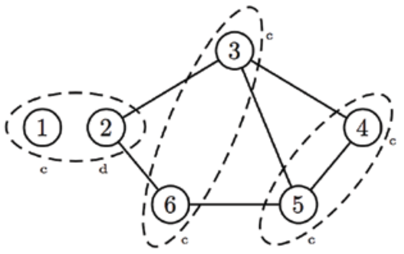
$$z_{i,j,t+1} \in \begin{array}{c} \\ 1\\2\\3\\4\\5\\6 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{bmatrix} - & 1 & 1 & 1 & 1 & 1 \\ 0 & - & 1 & 1 & 1 & 1 \\ 0 & 1 & - & 1 & 1 & 1 \\ 0 & 1 & 1 & - & 1 & 1 \\ 0 & 1 & 1 & 1 & - & 1 \\ 0 & 1 & 1 & 1 & 1 & - \end{bmatrix} \end{array}$$

Appraisals in $t+1$
(b)

FIGURE 4
THE SPREAD OF PLAYER 2'S NEGATIVE JUDGMENT IN THE EXAMPLE FROM FIGURE 2 , WHEN $r = 2$

only player whose appraisal of player 2 changes is player 1. Consequently, the probability that player 2 will be punished in round $t+1$ is $1/5$. Because of player 1's isolated network position, increasing r does not increase the chance that player 2 will be punished for defecting against 1.

In effect, player 2's network position protects 2 more than player 1's



Random Matches in t
(a)

$$z_{i,j,t+1} \in \begin{array}{c c} & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} & \begin{bmatrix} - & 0 & 1 & 1 & 1 & 1 \\ 1 & - & 1 & 1 & 1 & 1 \\ 1 & 1 & - & 1 & 1 & 1 \\ 1 & 1 & 1 & - & 1 & 1 \\ 1 & 1 & 1 & 1 & - & 1 \\ 1 & 1 & 1 & 1 & 1 & - \end{bmatrix} \end{array}$$

Appraisals in $t + 1$
(b)

FIGURE 5
REPEATING THE GAME IN FIGURE 2, ASSUMING THAT PLAYER 2 DEFECTS AGAINST PLAYER 1[a]

[a] Player 1 forms a negative judgment about player 2's action, but regardless of r, this information reaches no one but 1. Because of player 1's isolated network position, 1's gossip is ineffective at getting others to punish 2 in the next period. Unless player 2 happens to be randomly matched to play 1 again in $t + 1$, 2 will not be punished.

position protects 1 in example group 1 because player 2 has access to a larger share of the group than 1 (Figure 1). The gossip that player 2 spreads has the potential to reach many more people and increase the probability that someone defecting against him or her faces punishment in the next round, compared to gossip spread by player 1. If the network transmits gossip about negative judgments fast enough, positions with greater reach in the network can deter defections against people occupying these positions. Isolated network positions may be tempting targets of defection regardless of the rate of network transmission.

In fact, since anyone defecting against player 1 only expects to be punished with probability $1/5$ (because anyone's odds of being matched with someone who has heard player 1's negative judgment is one out of five), if defections are profitable enough or punishment is mild enough, it may be impossible to incentivize anyone to cooperate with 1. In such a case, player 1 would interact with the rest of the group as a member of *CHEAT* in equilibrium, perpetually defecting with the others. Whether the other five players can enforce cooperation among themselves depends on whether the player among them with the greatest temptation to cheat faces sufficiently likely punishment from the other four.

The next section makes this intuition precise, and formally characterizes prospects for as much cooperation as possible in arbitrary groups.

IV. Enforcing Partial Cooperation

This section uses the conditions for sequential equilibrium to characterize the prospects for cooperation in groups using the strategy profile σ^{CHEAT}. According to this strategy profile, some players, those in the set CHEAT, always play *d* while others, those in the set COOP, play reactive strategies that punish defections by others in COOP with a round of punishment. Under the right conditions, those in COOP always cooperate with one another.

In this setup, an equilibrium in which everyone plays as CHEAT ($COOP = \varnothing$ and $CHEAT = N$) will always exist since everyone always playing *d* is an equilibrium of a repeated prisoner's dilemma. The important question for understanding successful self-governance is: When can some be incentivized to behave cooperatively and how large can the group be that cooperates in equilibrium? In the language of the strategies above, the question becomes: What is the largest set of players who will play as COOP and comply with σ^{CHEAT}?

Of course, the largest set of players that could possibly play as COOP is *N*. But it turns out that an equilibrium in which all play as COOP is not always feasible. Some sets of parameter values and network structures will not support $COOP = N$, $CHEAT = \varnothing$ in sequential equilibrium. In such a case there can be smaller sets of players who can play as COOP while others play *d* as members of CHEAT, which can successfully enforce cooperation among those in COOP. The equilibrium with the largest set of COOP feasible for the parameter values and network structure is the most efficient feasible equilibrium.

For a set of parameter values, call the sequential equilibrium in which the largest possible set of players play as COOP the *maximally cooperative equilibrium*. The following main result characterizes these equilibria.

Proposition 1. *The maximally cooperative feasible sequential equilibrium entails the set of cooperators* COOP, *given* α, β, δ, *r, and g, when*

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

and

$$\min_{i \in COOP} \left\{ \frac{\#(N_i^r(g) \cap COOP)}{n-1} \right\} \geq \frac{\beta}{\delta(\beta + 1)}$$

and for any other candidate set of cooperators COOP' *such that* #COOP' > #COOP, *either*

$$\min_{i \in COOP'} \left\{ \frac{\#(N_i^r(g) \cap COOP')}{n-1} \right\} \geq \frac{\alpha - 1}{\delta(\beta + 1)}$$

or

$$\min_{i \in COOP'} \left\{ \frac{\#(N_i^r(g) \cap COOP')}{n-1} \right\} \geq \frac{\beta}{\delta(\beta + 1)}$$

This result uses the conditions for sequential rationality, which can be found in sections 2 and 3 of the supplementary material with proof.[35] These conditions establish when a set of players, all incentivized to cooperate with one another as members of *COOP*, is the largest possible such set.

The first and second conditions of Proposition 1 ensure that for everyone in *COOP*, the benefits of complying with σ^{CHEAT} outweigh the benefits of deviating, given the network positions of the others in *COOP*. The numerator of the term on the left hand side, $\#(N_i^r(g) \cap COOP)$, counts the number of group members in *i*'s *r*-neighborhood who are in *COOP*. Recall that given the network transmission process τ, negative judgments formed by *i* can reach everyone as gossip in *i*'s *r*-neighborhood, $N_i^r(g)$. If everyone were in *COOP*, a count of those in this neighborhood would be sufficient to determine a count of those who would respond to the negative judgments and punish. But when not everyone is in *COOP*, the count must adjust for those who would not respond to a negative judgment. Only players in *COOP* punish in response to a negative judgment, so the players in *i*'s *r*-neighborhood who are also in *COOP* matter for the count of future punishers. This count, as a fraction of total possible players with whom one could be matched, determines any player's expected probability of punishment for defecting against an $i \in COOP$. The higher the expected probability of punishment, the weaker the incentive to defect. In equilibrium, this condition must hold for defections against all members of *COOP*. The binding case is the player against whom defections would face the lowest expected punishment (hence,

[35] It turns out that the binding conditions are independent of beliefs, so any consistent beliefs trivially extend the sequentially rational behavior to sequential equilibrium. Larson 2017b.

the minimum). If players in *COOP* prefer to cooperate with this player, players in *COOP* prefer to cooperate with all players in *COOP*.

The key implication of the first two conditions of Proposition 1 is that given the prisoner's dilemma payoffs and players' patience, individuals in *COOP* must occupy network positions that are close (within r degrees) to a sufficiently large number of other individuals in *COOP*. These positions ensure that their negative judgments will reach enough other people willing to punish in response to them, which generates a high expected probability of punishment and keeps everyone in *COOP* cooperating with one another.

The third and fourth conditions of Proposition 1 ensure that the set of cooperators is maximal. These conditions say that there is no other, larger set of players who could play as *COOP* and successfully incentivize one another to cooperate. The expected probability of punishment for a defection against the most tempting member of a larger set of *COOP* would be too low to prevent others in this larger set from acting on this temptation. When all four conditions are satisfied, σ^{CHEAT} is sequentially rational for the largest possible set of *COOP* (and, as section 2 of the supplementary material shows, any consistent beliefs extend the behavior to sequential equilibrium).[36] The next subsection explores implications of this logic.

Who Cheats in Equilibrium

Proposition 1 implies a few important takeaways about the relationship between network structure and prospects for cooperation. First, it is possible that the maximally cooperative equilibrium entails fewer than n players cooperating.

Corollary 1. *There exists no equilibrium with* COOP *= N,* CHEAT *= ∅ if, given r and g,*

$$\min_{i \in N} \left\{ \frac{\#N_i^r(g)}{n-1} \right\} < \frac{\alpha - 1}{\delta(\beta + 1)}$$

or

$$\min_{i \in N} \left\{ \frac{\#N_i^r(g)}{n-1} \right\} < \frac{\beta}{\delta(\beta + 1)}.$$

If at least one network position is so isolated that the expected punishment for defecting against him or her is too low to offset the benefit

[36] Larson 2017b.

of doing so, even if everyone were willing to punish in response to gossip sent by that position that judges the perpetrator's action negatively, the group cannot enforce full cooperation.

Consider example group 1 in Figure 1 again. Set $r = 1$. In this example, $\min_{i \in N}\left\{\frac{\#N_i^r(g)}{n-1}\right\} = \frac{1}{5}$. This minimum value is due to player 1: $\left\{\frac{\#N_1^1(g)}{6-1}\right\} = \frac{1}{5}$. If α, β, and δ are such that either $\frac{\alpha-1}{\delta(\beta+1)} > \frac{1}{5}$ or $\frac{\beta}{\delta(\beta+1)} > \frac{1}{5}$, then there is no sequential equilibrium in which all six players cooperate as members of *COOP*. The sticking point is player 1. For 1 to be included in *COOP*, it would have to be the case that punishment by a single member of the group is sufficient to offset the gains from defecting. If this is not the case, player 1 cannot be included in *COOP* and full cooperation is impossible.

Note that if networks were assumed to be complete (as is often the case, at least implicitly, in nonnetwork models), the maximally 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 in this instance due to heterogeneity introduced by network position.[37]

The problem with player 1's network position is clear; 1 is completely isolated, so 1's negative judgments reach no other players. Positions like this are not the only barriers to cooperation. Even within a connected component of a network, certain network positions can be relatively more isolated than others and so make cooperation relatively more difficult. Proposition 1 implies a precise characterization of these problematic network positions, which I call peripheral.

DEFINITION 2. Peripheral players. *Player i is more peripheral than j in network g if i's r–neighborhood is smaller than j's; that is, if* $\#N_i^r(g) < \#N_j^r(g)$.

Player i's network position is more peripheral than j's when fewer players can be reached from i in paths of length r than can be reached

[37] In fact, in the example above, when α, β, and δ are such that expected punishment of $^2/_5$ by a member of *COOP* is sufficient to deter a defection but $^1/_5$ is not, the maximally cooperative equilibrium for example group 1 entails *COOP* = {2,3,4,5,6} and *CHEAT* = {1}. In this equilibrium, {2, ..., 6} will cooperate with one another, everyone will play d when matched with 1, and 1 will always play d. No one has an incentive to deviate, and no larger group of players could be incentivized to cooperate in equilibrium.

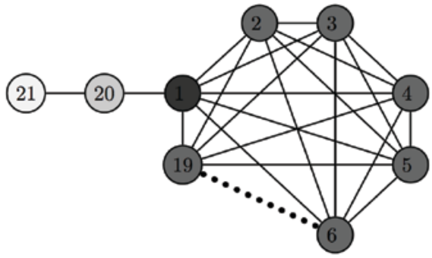


FIGURE 6
EXTENT TO WHICH PLAYERS ARE PERIPHERAL IN EXAMPLE GROUP 2 WHEN $r = 1$[a]

[a] $\#N^1_{21} = 1$, $\#N^1_{20} = 2$, $\#N^1_{2} \ldots \#N^1_{19} = 18$, and $\#N^1_{1} = 19$.

from *j*. Figure 6 shows example group 2, which has twenty-one players. In this example group, all members are connected. Nonetheless, some are more peripheral than others. Figure 6 depicts the extent to which each player in the example group is peripheral for $r = 1$ (the lighter the shade, the more peripheral the node).

Peripheral positions are relevant because Proposition 1 reveals that in a maximally cooperative equilibrium, if any players play as *CHEAT*, the most peripheral players will be included in *CHEAT*.

COROLLARY 2. *In a maximally cooperative equilibrium, there exists a threshold*

$$x^*: = \underset{j \in COOP}{\min_i} \{\#(N^r_j(g) \cap COOP)\}$$

such that

$$\text{if } \#(N^r_i(g) < x^*, \text{ then } i \in CHEAT.$$

In other words, there exists a cut below which all players who are at least that peripheral in the full network will be in *CHEAT*. Note that this cut is sufficient for inclusion in *CHEAT* but not necessary—peripheral players will be the ones who play all *d*, but others can be included too. *CHEAT* can also include some players who are central in network *g*.[38]

One final bit of intuition follows straightforwardly from Proposition 1 and is useful when analyzing responses to shocks in the next subsec-

[38] Section 4.2 in the supplementary material shows an example of a case in which a player central to the overall network is surrounded by players in *CHEAT*, which makes the player very peripheral *among those in COOP*. Highly peripheral players are not only contained in *CHEAT* themselves, but they can also drag more central players into *CHEAT*, depending on their placement throughout the network. Larson 2017b.

tion. Maximally cooperative equilibria with a larger set of cooperative players (*COOP*) are more difficult to sustain.[39]

Corollary 3. *All else equal, a maximally cooperative equilibrium with #CHEAT cheaters is more difficult to support than a maximally cooperative equilibrium with #CHEAT′ > #CHEAT cheaters.*

In general, enforcing cooperation among a larger subset of a group is more demanding than enforcing cooperation among a smaller subset. The next two subsections explore the consequences of this logic for responses to a changing environment.

Shocks to the Gains from Defecting

The results of the section above establish that the most efficient equilibria under σ^{CHEAT} are those with as many people as possible playing *COOP*. It can be that the largest possible set that plays as *COOP* is a strict subset of the group, in which case the most peripheral players in the network are among those who perpetually defect. These results also lend insight into the matters of initial equilibrium selection and transitions out of equilibrium, perhaps into a new one, in response to shocks.

Consider the case 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 subset (possibly large) of the group cooperating, and the others perpetually cheat.

To derive hypotheses about the consequences of shocks, a direct comparison of equilibria is 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 cheaters in *CHEAT*′.

Corollary 4. *In an equilibrium with CHEAT and COOP, if a new equilibrium with CHEAT′ and COOP′ is such that #CHEAT′ > #CHEAT, then the most peripheral in the subnetwork induced by COOP, those that have the smallest $N^r(g) \cap COOP$, will be in CHEAT′.*

When confronting 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

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

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.

Corollary 4 suggests a natural mechanism by which a group could transition from a more to a less cooperative equilibrium. Suppose a group is participating in a fully cooperative equilibrium when suddenly something about the environment changes to increase the gains to defecting (α increases). Although all defections are suddenly more tempting, the defections most tempting on net are those perpetrated against the most peripheral in the network.[40] If the increase in α is large enough, all group members would have an incentive to defect against the most peripheral in *COOP*. Anticipating this new incentive, the peripheral players' best response is to always play *d* to mitigate the consequences. Since no one in the 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 it binds.[41]

Groups can easily ratchet down into less cooperative equilibria. Shocks that make cooperation more difficult bind first for interactions with 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 suddenly it becomes *less* profitable to defect (α decreases), moving to a more cooperative equilibrium is not as natural as moving away from one and requires an element of trust. Previous cheaters, who might now have an incentive to cooperate, need some assurance that the rest of the group will transition to regarding them as cooperators with whom they play *c* by default. Because existing cooperators would gain by playing *d*

[40] Or if our thought experiment began with a group with a set of *COOP* and a nonempty set *CHEAT*, the most tempting defections would be those perpetrated against the most peripheral *among those in COOP*.

[41] In fact, in the 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 when full cooperation under in-group policing is impossible, which suggests an endogenous means by which groups come to ostracize some members. Those most tempted to defect cannot be prevented from doing so; anticipating those defections, in-group opponents steel themselves against the consequences of these interactions by defecting as well. This sequence of events results in a subset that is perpetually defected on by everyone else while the rest of the group continues to cooperate among themselves in the next-best equilibrium outcome. Ostracism reduces the total sum of payoffs and so is inefficient. It also reduces the number of players playing a responsive strategy and 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.

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 its corollaries:

—H1. When gains from defection increase, more cheating should occur in equilibrium.

—H2. When gains from defection increase, cheating should occur in interactions involving the most peripheral.

—H3. Transitioning from more to less cooperation should be easier than transitioning from less to more cooperation.

—H4. A reduction in cooperation should manifest in a set of group members who are subjected to perpetual mutual defect (they are effectively ostracized).

Shocks Due to Population Change

Although 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 note that a change in population size—changing n—has ambiguous consequences for incentives to cooperate. A larger group size can dilute the efficacy of punishment, for instance, if in a group in which a person expects to be punished by x others for a certain defection, an increase in group size occurs without an increase in x. Then the probability of punishment changes from $\frac{x}{n-1}$ to a smaller value $\frac{x}{n'-1}$ for $n' > n$. For instance, if two new members joined example group 1 in Figure 1 and forged links with some of the players 2, ..., 6, but not with 1, then the probability of punishment for a defection against 1 decreases from $1/5$ to $1/7$. If, instead, the new members forged enough new links and added them to player 1 and some of 2, ..., 6, their presence could result in a higher probability of punishment for any offense, making cooperation easier.

In short, a change in the size of the group can improve or hinder a group's ability to enforce cooperation. The direction of the effect depends on how the network changes as a result of the change in the number of group members.

Corollary 5. *For an original group N of size n with network g and* COOP *cooperators in a maximally cooperative equilibrium, consider a change in group size resulting in* *new group N′ 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*

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

$$\frac{\#COOP}{n-1} > (<) \max_{NEW \in \mathfrak{P}(A')} \left\{ \frac{\#\{i \in A' \mid \#(N_i^r(g') \cap NEW)/(n'-1) \geq P^*}{n'-1} \right\}$$

where $\mathfrak{P}(N')$ *is the power set of N′.*

Intuitively, in the former maximally cooperative equilibrium, everyone in *COOP* faced expected punishment of at least P^* for any defection. 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^*. 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 in boomtowns, we need to make an additional assumption about how the network structure changes as the population changes. 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.[42] Two hypotheses follow regarding certain instantiations of population change:

—H5. Population increases that are especially rapid are likely to reduce cooperation.

—H6. Population change that entails high turnover characterized by long-time residents leaving and new residents entering is likely to reduce cooperation.

[42] 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.

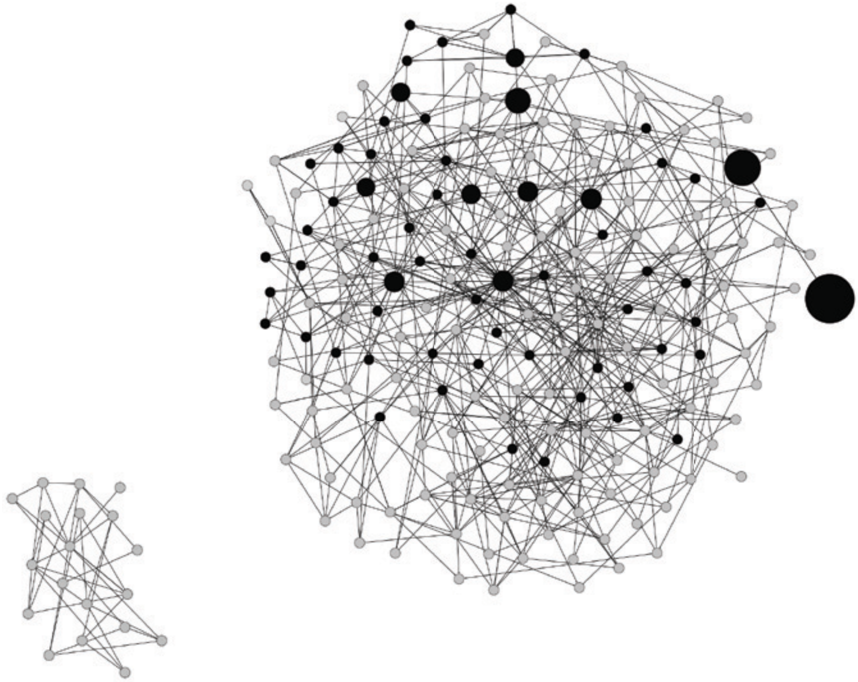
Given that social ties take time to forge, rapid population increases mean a large proportion of a group's network will occupy relatively peripheral positions, at least for a while. Similarly, high turnover means those occupying the least peripheral network positions are those who leave the network, and their replacements are most peripheral. Both strain cooperation.[43]

Next, compare two 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 with members in this small group, but not with existing members (enclave). In the second, the immigrants settle throughout the community, forging links in a dispersed manner with existing members (integrated). The following additional hypotheses about settlement can now be advanced:

> —H7. Cooperation is more likely to break down in the presence of enclave settlement than in the presence of integrated settlement.
>
> —H8. 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.

The intuition for the latter two hypotheses relies on the fact that enclave settlements relatively limit the reach of negative judgments formed by any immigrant in the network; at most, the immigrant's gossip reaches others in the enclave. But in integrated settlements, the reach of any immigrant's gossip is not strictly limited to the other immigrants and, if r is large enough, it can reach the whole group. If the enclave is small relative to the original group, or if the original residents have lived together for a long time, enclave members' positions will be peripheral compared to the original residents' positions. If the enclave positions are much more peripheral than the original residents' positions, those in the established community would have an incentive to defect against those in the enclave, knowing news of these defections

[43] Others have observed that a shock to population can disrupt cooperation. Freudenburg 1986 compares Colorado towns that have a relatively stable population to one that experiences a dramatic population boom. The rapidly growing town features 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 be tempting targets of misbehavior, and second, the larger population means each person needs to sustain even more social contacts 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.



19 New Members Who Settled in an Enclave
(a)

187 Original Inhabitants
(b)

Figure 7
Example Group 3 with 187 Original Inhabitants and 19 New Members[a]

[a] When $r = 4$, news sent from the most peripheral original inhabitant (largest circle on far right of [b]) reaches sixty-two others (shaded in black), whereas news sent from any member of the enclave reaches only the eighteen other members of the enclave. Enclave settlements limit the reach of messages and so generate incentives to defect against members of the enclave.

will not spread outside the enclave. All members of the existing community would profit from defecting against members of the enclave, generating an incentive for the enclave to play *d* in defense, and pushing the full group into a less cooperative equilibrium.

Figure 7 depicts a hypothetical group with 187 original members that faces a 10 percent population increase with enclave settlement. Suppose that $r = 4$, so that gossip about negative judgments spreads four degrees—from person to person to person to person to person—and that all members of the original group play as *coop*. The original inhabitant on the far right of example group 3, depicted with the largest circle, is the most peripheral of the original inhabitants—the size of this inhabitant's 4-neighborhood is sixty-three. Due to the insularity of the enclave settlement and its small size relative to the set of original inhabitants, the reach of anyone in the enclave is constrained. In four steps, messages sent by anyone in the enclave reach everyone else in the enclave—eighteen other people—and no others. Hence, the size of anyone in the enclave's 4-neighborhood is nineteen. This means the temptation to defect against anyone in the enclave is much greater than the temptation to defect against even the most peripheral 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 section below I present the case of boomtowns on the American western frontier and assess support for the above hypotheses.

V. Boomtowns

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. More than three hundred thousand prospectors moved to the region in 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 in a very short period of time.

These boomtowns emerged in an otherwise weakly governed environment. The western frontier in the mid-nineteenth 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 barely existed in the area,[44] 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 well-being.[45] Boomtowns had especially weak governing institutions in no small part because the growth of the towns outpaced formal governance and sometimes even the construction of a jail. The code of conduct and its enforcement were left to the residents of these towns.

Despite the absence of formal governing institutions and an abun-

[44] Umbeck 1977, 203.
[45] Clay and Wright 2005, 159.

dance of opportunities to misbehave, mining towns on the frontier appear to have been remarkably peaceful and secure. A history of the mining communities and their governance written at the end of the nineteenth century reports, "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."[46]

More recent histories of the frontier tend to begin by noting that the so-called Wild West was surprisingly cooperative and peaceful despite weak formal governing institutions.[47] Some historians 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."[48] In the decades following the gold rush, stories circulated of settlers leaving thousands of dollars' worth of gold dust in unguarded, unsecured tents while they were away, conveying how trusting and trustworthy they were.[49]

The historical record is rife with examples that point to a community-enforcement scheme at play. Settlers in 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. One account notes, "Men had to settle their financial affairs and their petty quarrels among themselves: that was the mining-camp doctrine."[50] 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 would have been easy to do in the close living spaces and along the increasingly crowded streams being mined.[51] For instance, once miners had reached an understanding about who was entitled to mine where, miners would watch and protect someone's claim in the expectation that he would do the same in exchange; when punishment was warranted, it was swift.[52] 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

[46] Shinn 1885,117.
[47] E.g., Prassel 1972; Anderson and Hill 2004.
[48] Hollon and Crowe 1974, x.
[49] Shinn 1885,150.
[50] Shinn 1885, 126.
[51] Umbeck 1977, 214.
[52] Umbeck 1977, 216–19.

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."[53]

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, one historian 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."[54] Although homicide as a punishment was rare, there are accounts of fines, beatings, and whippings doled out by the community in response to offenses.[55] In the few places that quickly developed periodicals, the newspapers were sometimes used to nudge the community to respond to particularly glaring cases of misbehavior: "[I]n 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."[56]

In short, settlers living in western boomtowns during the gold rush lived far from the reach of formal government, but appear to have enforced good behavior via threats of community punishment.

The Strains of Population Change

Boomtowns followed a common trajectory in the middle of the nineteenth century. As discussed above, the number of inhabitants 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.[57] The first wave of settlers were people predominantly from elsewhere in the United States.[58]

About a decade after the initial gold rush, two changes occurred throughout these mining towns. First, the number of foreign miners and their proportion to the domestic population substantially increased. For instance, in California in 1850, Grass Valley and Nevada City had almost no foreign-born miners. By 1860, the mining population was about 20 percent Irish and 22 percent British, and included a large

[53] Shinn 1885,111.
[54] Shinn 1885,119.
[55] See, e.g., Umbeck 1977.
[56] Halaas 1981, 85.
[57] Mann 1972, 493.
[58] Mann 1972, 490.

number of Chinese, French, and Germans.[59] In 1850 there were fewer than one thousand Chinese people living in the state. By 1860 there were almost thirty-five thousand, and by 1870 the number was nearly fifty thousand.[60] Second, the relative peace and harmonious living miners had enjoyed in the 1850s had noticeably unraveled.[61]

Hypotheses 5 and 6 suggest that rapid population change with high turnover poses 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 refrain from cooperating with them.

Initially, reception of all foreign-born miners was positive or neutral, but attitudes toward some eventually turned strongly negative and hostile. This was particularly true for attitudes toward Chinese miners.[62] Early historical accounts reflect this lingering hostility and blame it on the character of the foreign miners.[63] Later accounts attribute increased conflict to a fear of job loss and an inability to understand the foreigners,[64] but employment records do not corroborate a jobs-taking explanation. In fact, the Cornish appear consistently to have been given the best jobs and did not face the level of hostility directed at the Chinese.[65]

Examples of eventual conflict between Chinese and American settlers abound, especially offenses perpetrated by Americans against the Chinese, ranging from ignored murders to repeated robbery to denied services.[66] In stark contrast to the early neutral environment, many mining camps transitioned 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* in the mining town of Bodie editorialized 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 …."[67]

Why did conflict surge in mining towns in the 1860s, and why was

[59] Mann 1972, 496.
[60] DuFault 1959, 155.
[61] Mann 1972, 497.
[62] DuFault 1959, 155.
[63] Shinn 1885, 144.
[64] DuFault 1959, 157.
[65] Mann 1972, 500. Mann writes, "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," p. 497. It is hard to believe their skills are all that exempted the Cornish from the hostility faced by the Chinese.
[66] DuFault 1959, 158.
[67] McGrath 1987, 137.

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 them.[68] The Chinese settlers did interact with the American settlers in the towns and in the mines, but they did so without forging social relationships. They lived segregated from the rest[69] in highly insular enclaves.

By carving out separate living areas and maintaining separate habits, the Chinese settlers forged relationships with few American settlers—a separation exacerbated by a language barrier in the many instances where the Chinese did not speak English.[70] But despite the absence of relationships that would result in Chinese embeddedness in the town's social network, the two groups did interact regularly in daily life. Mining towns tended to have a single option for basic services. Typically, there was one doctor and one store, one stage coach office, and one bank (though many saloons) where everyone would interact.[71] Working the same streams and mines also generated opportunities for interaction, and the Chinese sections of the more developed mining towns tended to host opium dens that were highly popular with other settlers.[72] In other words, Chinese settlers interacted with other settlers but rarely forged relationships outside of their small enclave.

The combination of enclave settlements and mixed day-to-day interactions suggests one interpretation for the pattern of cooperation breakdown observed in mining towns. Existing settlers began their community in a quite cooperative equilibrium, but when foreign settlers began to arrive and Chinese settlers chose to live in enclaves, the restricted reach of their network positions limited the extent to which they could report misbehavior committed by other settlers and tap into large-scale communal punishment. Understanding this, the existing settlers had an incentive to mistreat the Chinese because the settlers expected to face limited repercussions for doing so. Confronted with increasing mistreatment, the Chinese defected in response to mitigate the consequences of it, and the entire group found itself ratcheted down into a less cooperative equilibrium in which all non-Chinese settlers effectively ostracized the Chinese settlers, in line with hypotheses 3, 7,

[68] Shinn 1885; DuFault 1959; Mann 1972; McGrath 1987.
[69] DuFault 1959, 158.
[70] McGrath 1987, 124–40.
[71] McGrath 1987, 109.
[72] McGrath 1987, 126.

and 8. Other waves of migrants chose to integrate rather than to settle in enclaves, and as a result experienced greater embeddedness in the existing settlers' networks, a wider potential reach of gossip, and the absence of incentives to be ostracized. In such 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 for the trajectory of cooperation breakdown. Enclave settlement with few social ties to existing settlers and high levels of interaction generates incentives to defect against the enclave, as well as pressure to transition to a less cooperative equilibrium with ostracism. Settlement patterns in boomtowns would have presented this incentive in the case of Chinese and no other immigrants. The limited historical record does not allow us to conclude that this incentive dominated other factors and caused mistreatment of the Chinese, though does admit this as a possibility.

VI. Conclusion

Informal governance can ensure that individuals coexist peacefully, even when news about behavior spreads from person to person through social networks. Sometimes, though, due either to natural constraints or to shocks to a strategic environment, such as especially rapid growth, population turnover, and enclave settlement of newcomers, the best a group can do is to 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 demonstrates this point well. In the early days, despite limited formal governing institutions, settlers were quite successful at enforcing cooperation among their peers. 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.

Rapid population growth, high turnover, and variance in settlement patterns served as shocks that strained settlers' abilities to enforce cooperation. Strains tend to move a group into a less cooperative equilibrium in which the most peripheral become uncooperative and perhaps even 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 behave uncooperatively, specifically against the Chinese, since the reach of the gossip the Chinese could spread to trigger punishment was highly limited. Consequently, cooperation deteriorated.

Although the results of the model presented here are consistent with the recorded history of nineteenth-century boomtowns, the insights are about self-governance more broadly. 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. Barriers to the wide reach of gossip, whatever their origin, can undermine a group's ability to enforce harmonious living among its members.

These results also highlight a poignant dilemma for groups that relocate, such as immigrant and refugee communities. A large research tradition points out the value of at least some in-group insularity for groups that are left to their own devices to provide services and enforce behavior. For example, groups who screen on in-group and out-group distinctions can successfully enforce contracts,[73] develop markets,[74] provide public goods,[75] extend credit[76]—the list goes on. According to those findings, groups that find themselves outside the reach of formal institutions, such as refugees or immigrants new to an area, do well to remain insular. But this article identifies a downside to insularity. Perfect insularity—no interactions between an immigrant community and the existing community—may be optimal for the immigrant community in dealings with one another, but at a cost. Insularity may generate incentives for the existing community to treat the new community poorly. Forging social contacts across groups can protect the new community from mistreatment by the established group, but may compromise the insularity that is helpful for the provision of services and enforcement of behavior within the new community.

Finding the right balance will be an important topic for future research. 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.

Supplementary Material

Supplementary material for this article can be found at https://doi.org/10.1017/S0043887117000181.

[73] Landa 1981.
[74] Greif 1993.
[75] Miguel and Gugerty 2005.
[76] Laszlo and Santor 2009.

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