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Optimal Parochialism: The Dynamics of Trust and Exclusion in Networks

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Abstract

Networks such as ethnic credit associations, close-knit residential neighborhoods, ‘old boy’ networks, and ethnically linked businesses play an important role in economic life but have been little studied by economists. These networks are often supported by cultural distinctions between insiders and outsiders and engage in exclusionary practices which we call *parochialism*. We provide an economic analysis of parochial networks in which the losses incurred by not trading with outsiders are offset by an enhanced ability to enforce informal contracts by fostering trust among insiders. We first model one-shot social interactions among self-regarding agents, demonstrating that trust (i.e., cooperating without using information about one’s trading partner) is a best response in a mixed-strategy Nash equilibrium if the quality of information about one’s partner is sufficiently high. We show that since larger networks have lower quality information about specific individuals and greater trading opportunities, there may be an optimal (payoff-maximizing) network size. We then model the growth and decline of networks, as well as their equilibrium size and number. We show that in the absence of parochialism, networks may not exist, and the appropriate level of parochialism may implement an optimal network size. Finally, we explore the welfare implications and reasons for the evolutionary success of exclusion on parochial and other grounds.

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1 Introduction

Formally structured nonmarket institutions, such as firms, clubs, partnerships, and families, have been the subject of extensive study by contemporary economists. More diffuse social affiliations, such as those arising from close-knit residential relationships, ‘old boy’ networks, and ethnic or religious identity, have received less attention. We will call these *networks*, defined as sets of agents engaged in relatively frequent, non-anonymous interactions structured by high entry and exit costs, but lacking centralized collective decision-making institutions.¹

Networks support interpersonal interactions that promote the informal enforcement of incomplete contracts. Well documented empirical examples include the management of common pool resources such as fisheries, irrigation, and pasturage (Ostrom, Gardner and Walker 1994, Wade 1987, Baland and Platteau 1997), the regulation of work effort in producer cooperatives (Whyte 1955, Homans 1961, Lawler 1973, Craig and Pencavel 1992, 1995), the enforcement of non-collateralized credit contracts (Hossain 1988, Udry 1993, Banerjee, Besley and Guinnane 1994) the promotion of neighborhood amenities in residential communities (Sampson, Raudenbush and Earls 1997), and the private enforcement of contracts among traders in securities (Baker 1984) and diamond (Bernstein 1992) markets.

As these examples suggest, we view networks as governance institutions that often provide solutions to otherwise intractable problems of contractual incompleteness. This view contrasts with the more common representation of ethnic, religious, and other groups as expressions of underlying shared values, often termed ‘particularistic,’ in contrast to the more ‘universalistic’ values underpinning market transactions and liberal polities (Parsons n.d.). According to this conventional view, the exclusionary values that often maintain group boundaries and restrict membership typically also restrict exchange, and thus impose allocative inefficiencies on their members. For this reason, networks and their frequently associated values of loyalty to insiders, close personal interaction, and xenophobia are often seen as vestigial remnants of ‘traditional’ society, whose importance will ebb under the competitive pressures of a market economy.

While ingroup values often inhibit trade with outsiders, members of exclusionary networks often do quite well economically, counter to the standard prediction. Moreover, far from being inertial remnants of the past, groups that have prospered for generations may disperse rapidly, while newly formed groups can be quite suc-

¹The theory of social exchange, initiated in sociology by Blau (1964) and Homans (1958), and in anthropology by Sahlins (1972) provide insights into the economics of networks. For contributions by economists, see Ben-Porath (1980), Hollander (1990), Iannaccone (1992), Kandori (1992), Wintrobe (1995), Greif (1994), Akerlof (1995), Pagano (1995), Bénabou (1996), Durlauf (1996), Kranton (1996), Taylor (1997), and Glaeser (1997).

cessful, as the flourishing informal ethnic business linkages among new immigrants to the United States and the United Kingdom attest.² For instance, Cambodians run more than 80 per cent of California's doughnut shops. They often raise startup funds by forming credit associations of friends and family to pool resources, the member offering to pay the highest interest rate receiving as a loan the sum of the individual contributions (Kaufman 1995). Similarly, Indians own more than a third of the motels in the United States, frequently raising initial capital through unsecured loans from extended family members (Woodyard 1995).

Among the problem-solving capacities of networks are the powerful contractual enforcement mechanisms made possible by small-scale interactions, notably effective retaliation facilitated by close social ties and the availability of low cost information concerning one's trading partners. This problem-solving capacity allows successful networks to overcome the disabilities imposed by the restricted gains from trade due to small size and exclusionary practices.³ Members, of course, do not normally express their identification with groups in terms of their economic advantages, typically invoking noninstrumental values, such as religious faith, ethnic purity, the natural order of things, or personal loyalty. These sentiments often support exclusion or shunning of outsiders. We model these practices, which we term *parochialism*, in Section 2.

The mechanism for the success of networks explored in this paper is their ability to promote *trust*.⁴ We consider a large population of identical agents who take three types of actions. First, they locate in one of a variable number of networks, or

²See Rauch (1996), Granovetter (1985) and Kotkin (1993). The current concern with a "decline of community" typically refers to socially approved aspects of networks thought to be less prevalent in the modern world. Perhaps Jack Hirschleifer (1994):3-4 exaggerates when he writes: "when people cooperate it is generally a conspiracy for aggression against others..." But his remark is a useful reminder that networks as we have defined them often engage in practices that others find offensive. See also Hardin (1995).

³The advantages of trade with outsiders is a common explanation of the permeability of group boundaries in small scale societies (Adams 1974) and of the extinction of very restrictive groups in favor of more inclusive entities (Gellner 1985, Weber 1976). A particularly well-documented example of this tension is Greif's (1994) account of how the competitive advantages stemming from the superior within-group contractual enforcement capabilities of the tight-knit 13th century community of Maghribi merchants was eventually offset by their lesser ability to engage in successful exchange with outsiders, resulting in their inability to compete with the more individualistic Genovese traders. Yoram Ben-Porath (1980) develops similar reasoning concerning the economic capabilities of families and other face to face groups:

The transactional advantages of the family cannot compensate for the fact that within its confines the returns from impersonal exchange and the division of labor are not fully realizable. (p. 14).

⁴Our model develops insights provided by a number of contributions to the sociology of groups. Granovetter (1985) writes:

remain outside any network in what we will call the ‘anonymous pool’ of traders. Second, they choose strategies that govern their behavior with trading partners. Third, they update these strategies in light of their relative payoff compared to other available trading strategies. Network size and the number of networks are governed by a gravity model in which individuals move both spontaneously and according to payoff differentials. We explore the evolution and equilibrium frequency of behaviors within networks, the distribution of population between networks and the anonymous pool, and the size and number of networks, under the influence of parochial practices.

In Section 3 we develop a model with incomplete contracts among self-regarding agents. We use this model to analyze the conditions under which trust may represent an equilibrium strategy. We formalize the effects of variations in network size on such an equilibrium in Section 4. We analyze optimal network size in Section 5.

The size and number of networks in equilibrium is then determined by the degree of openness of networks to new members, as well as the rate of creation and dissolution of networks. We show in Section 6 that parochial practices resulting in excluding people from networks may implement an optimal network size. We then investigate the conditions under which parochialism remains viable in a competitive economic system, and we conclude by considering the likely future economic importance of networks in light of our results.

2 Parochialism

The desire to associate with others who are similar to oneself in some salient respect is a robust behavioral regularity (Homans 1961, Thibaut and Kelly 1959). Homophily, the principle that likes attract, has been documented in a variety of experimental and natural settings (Lazarsfeld and Merton 1954). Among the salient characteristics on which homophily operates are race and ethnic identification, personality characteristics, political orientation, drug use and other forms of deviant behavior, religion and even experimentally induced trivial similarities (Berscheid and Walster 1969, Cohen 1977, Kandel 1978, Tajfel, Billig, Bundy and Flament 1971, Obot 1988). Conversely, people seek to avoid interactions with those who are different from themselves.

Individuals implement their desires to limit social distance in their interactions with friends, neighbors, co-workers, and business associates by means of what we

...social relations, rather than institutionalized arrangements or generalized morality are mainly responsible for the production of trust in economic life. (pp. 490-491)

For additional ways in which groups solve coordination problems stemming from incomplete contracts, see Bowles and Gintis (1998).

term *parochial practices*. These practices may take the form of shunning, refusal to trade or to extend friendship, verbal or physical assaults or other behaviors that preclude ongoing interaction. Members of networks often adopt parochial practices with the result that networks are more homogeneous and/or smaller than they would otherwise be.

The restrictions on matching for purposes of trade or production imposed by these exclusionary practices foster allocational distortions that, *ceteris paribus*, lower the returns to members of parochial networks. McMillan and Woodruff's study of trust among businesses in Vietnam suggests the salience of this tradeoff:

Trading relations in Vietnam's emerging private sector are shaped by two market frictions: the difficulty of locating trading partners and the absence of formal third party enforcement of contracts...firms able to resolve the difficulties of more specialized production and/or more distant trade grow more rapidly. By contrast, buying from suppliers managed by family members or friends involves fewer contracting problems. (p. 23)

Thus, in some cases, small size or homogeneity may offer advantages offsetting the gains from trade forgone by close-knit groups. Highly exclusive communities such as the Pennsylvania Amish and the Canadian Hutterites have expanded their numbers and thrived economically.⁵ Among the Amish, for example, distinctive dress, dialect, and technology construct a "cultural moat" around the group and, acting as "armaments of defense, they draw boundary lines between church and world [to] announce Amish identity to insider and outsider alike." (Kraybill 1989:50,68). Yet the boundaries erected around Amish culture have not prevented economic success and population growth. Further, the record of successful ethnic business affiliations suggests that parochialism may not only foreclose opportunities, but also contribute to the success of groups.

What might these gains be? Suppose, for instance, that individuals with differing ascriptive traits embody complementary productive inputs so that group heterogeneity is favored by the production function, but these positive effects of heterogeneity are partially offset by the increased cost of enforcing incomplete contracts among heterogeneous agents, perhaps due to the lack of a common normative framework, less accurate information transfer, or the reduced sanctioning power of social ostracism. By promoting group homogeneity, parochial exclusion might then enhance

⁵See Wilson and Sober (1994) and Kraybill (1989). Hechter (1990) found that two indicators of group homogeneity—common ethnic background and uniform style of dress—were among the few robust predictors of survival of utopian communes established in the late 18th and early 19th century in the United States. He interprets this finding as in part reflecting variable information costs. See also Longhofer (1996) for a model of the relationship between cultural affinity and monitoring costs.

the return to group members, despite the losses associated with forgone trade opportunities. Here the key variable would be heterogeneity rather than size, which will play the central role in the model we develop below.

We model parochialism as a filter on given ascriptive traits of those with whom one might interact, a particular form of parochialism excluding those with ‘objectionable’ traits.⁶ Individuals who do not exclude those with ‘objectionable’ traits are themselves objectionable, even if their traits *per se* are not objectionable.⁷ Thus any parochialism filter different from one’s own is assumed to be ‘objectionable’ so networks will be made up of individuals with the same type of parochialism; however different they are in other respects (for example, pursuing different strategies in economic interactions, or differing in a trait not covered by the parochialism filter) they will agree on the common traits for which their parochialism selects.

Suppose in pairwise strategic interactions, agents can condition their actions on whether the other player is an ‘insider’ or an ‘outsider.’ Each individual has a certain set of traits (ethnicity, language, physical attributes, cultural or demographic characteristics, and the like), which we take to be fixed. We label these ‘traits’ $j = 1, \dots, n$, each individual being characterized by a trait profile $a = a_1 \dots a_n$, where each $a_j = 1$ or $a_j = 0$ according as the individual does or does not possess trait j . Let A be the set of all possible trait profiles. An individual with traits $a \in A$ may have a ‘parochialism filter,’ defined as a vector $b \in A$ such that $b \leq a$; i.e., the individual has all the traits indicated by b . We say the individual with parochialism filter b is *b-parochial* if the individual treats another agent as an outsider if the other agent either (i) lacks one or more traits in the filter b , or (ii) trades with other agents who lack one or more of these traits. Otherwise the individual considers the other agent to be an insider. In effect, *b-parochial* agents choose a subset of the traits they possess (the unit-entries in b that are also unit-entries in a), and consider as insiders exactly those agents who have these traits and are ‘like-minded’ in the sense that they have the same criteria for distinguishing between insiders and outsiders. We assume throughout that the property of being *b-parochial* is common knowledge.

This formalization reflects our view that the immense variety of noticeable individual differences and similarities is the raw material on which parochialism works. A particular *b-parochialism* makes some subset of these differences behaviorally salient while ignoring others. For instance, suppose the array of traits

⁶Iannaccone (1992) analyzes a more active form of parochialism, in which membership in a network subject to participatory crowding is restricted to those who are willing to accept “stigma, self-sacrifice, and bizarre behavioral restrictions.”

⁷Lazarsfeld and Merton (1954:26ff) term this second order exclusiveness “value homophily” and present evidence for it with respect to racial attitudes: white ‘racial liberals’ prefer not to associate with white ‘racial illiberals’ and conversely.

are ('female', 'French speaking'). An agent with characteristics $a = 11$ is a female Francophone. Such an individual could be b -parochial for $b = 11$ (insiders are like-minded female Francophones), $b = 01$ (insiders are like-minded Francophones), $b = 10$ (insiders are like-minded females), or $b = 00$ (insiders are like-minded—i.e. they treat all others as insiders).

We use this representation to model the effects of parochialism on the central problem a group faces: how to solve coordination problems under conditions of contractual incompleteness. We turn now to this problem.

3 Trust in Networks

To model the population of traders, consider a game G where many agents are randomly paired to play a one-shot prisoner's dilemma in which each receives c if they both defect, each receives b if they both cooperate, and a defector receives a when playing against a cooperator, who receives d . The assumptions of the prisoner's dilemma then require $a > b > c > d$ and $2b > a + d$ (the latter inequality ensuring that mutual cooperation yields higher average payoffs than defect/cooperate pairs). The coordination failure underpinning the prisoner's dilemma structure of this interaction arises because some aspects of the goods or services being exchanged are not subject to costlessly enforceable contracts. The Defect strategy, for example could represent supplying shoddy goods where product quality is not subject to contract.

We assume each agent precommits to following one of three available 'norms.' The first, which we call *Defect*, is to defect unconditionally against all partners. The second, which we call *Trust*, is to cooperate unconditionally with all partners. The third, which we call *Inspect*, is to monitor an imperfect signal based on information provided by other members of the network indicating whether or not one's current partner defects against cooperators. We assume the signal correctly identifies a Defector with probability $p > 1/2$ and correctly identifies a non-Defector with the same probability p . The Inspector then refuses to trade with a partner who is signalled as a Defector, and otherwise plays the cooperate strategy. We assume that an agent who does not trade within the network has access to the anonymous market, with a payoff that we set arbitrarily to 0. Thus when either partner to a within-network exchange refuses to trade, each receives payoff 0, which is assumed better than the mutual defect payoff c ; i.e., we assume throughout that $c < 0$.⁸ We assume that the signal is costlessly observed. Assuming a (not excessively large)

⁸It is easy to show that other actions available to an Inspector who receives a signal indicating a defecting partner involve either mimicking the behavior of Trusters or Defectors, or else are strictly dominated by playing as indicated above. We thus lose nothing by ignoring such alternatives.

positive cost of inspecting changes our results in an intuitively expected way, so we abstract from such costs in the interests of simplicity. The payoff matrix for a pair of agents has the normal form shown in Figure 1. We write $G(p)$ for the game with signal accuracy p .

	Inspect	Trust	Defect
Inspect	bp^2, bp^2	bp, bp	$d(1-p), a(1-p)$
Trust	bp, bp	b, b	d, a
Defect	$a(1-p), d(1-p)$	a, d	c, c

Figure 1: The Inspect-Trust-Defect Game

Let α_t , β_t , and δ_t be the fraction of the population playing Inspect and Trust at time t , respectively. We assume these are continuous variables. Let π_I^t , π_T^t , and π_D^t be the payoffs to the strategies Inspect, Trust, and Defect at time t , respectively, against the mixed strategy given by $(\alpha_t, \beta_t, \delta_t)$. We find that

$$\pi_I^t = bp(p\alpha_t + \beta_t) + d(1-p)\delta_t \quad (1)$$

$$\pi_T^t = b(p\alpha_t + \beta_t) + d\delta_t \quad (2)$$

$$\pi_D^t = a(\alpha_t(1-p) + \beta_t) + c\delta_t \quad (3)$$

$$\bar{\pi}^t = \alpha_t\pi_I^t + \beta_t\pi_T^t + \delta_t\pi_D^t. \quad (4)$$

where $\bar{\pi}^t$ is the average payoff in the game. Equating the payoffs to the three pure strategies, we find that the Nash equilibrium frequencies $(\alpha^*, \beta^*, \delta^*)$ satisfy

$$\alpha^* = (-adp + b(d(2p-1) + c(1-p)))/D \quad (5)$$

$$\beta^* = p(ad(1-p) - b(d(2p-1) + c(1-p)))/D \quad (6)$$

$$\delta^* = ab(1-p)(2p-1)/D, \quad (7)$$

where

$$D = a(b(1-p)(2p-1) - dp^2) + b(1-p)(d(2p-1) + c(1-p)).$$

We have

Theorem 1. A Trust Equilibrium. *There is a $p_* < 1$ such that for $p_* < p < 1$, $G(p)$ has a unique Nash equilibrium $(\alpha^*, \beta^*, \delta^*)$. In this equilibrium all three types of players occur as strictly positive fractions of the population. The payoff $\pi^*(p)$ in this equilibrium is positive and an increasing function of p , and the fraction of Defectors $\delta^*(p)$ is a decreasing function of p .*

To prove the theorem, choose $p < 1$ such that

$$d(1 - p) > c \quad \text{and} \quad bp^2 > a(1 - p). \quad (8)$$

Since $d < c < 0$ and $a > b > 0$, clearly such a p exists. Moreover, if (8) holds for some p , it holds for all p' such that $p < p' < 1$. So let p_* be the greatest lower bound of the set of p for which (8) holds, and let p be any probability satisfying $p_* < p < 1$. A routine check then indicates that there are no Nash equilibria involving fewer than all three strategies. Hence by Nash's existence theorem, there is an equilibrium of $G(p)$ involving all three strategies. This proves that p_* has the asserted property. Equations (5)-(6) This imply

$$\pi^* = -abd(2p - 1)^2/D, \quad (9)$$

so $\pi^*/\delta^* = -d(2p - 1)/(1 - p) > 0$, showing that payoffs are positive. A tedious calculation verifies that

$$\frac{d\pi^*}{dp} = \delta^{*2}(-d) \frac{b(d(2p - 1) + 2c(1 - p)) + a(b(2p - 1) - 2dp)}{ab(1 - p)^2(2p - 1)}.$$

The denominator in the fraction is positive and the numerator can be written as

$$2(b(a - c) - d(a - b)) \left(p - \frac{1}{2} \right) + bc - da,$$

which is clearly positive. To prove the final assertion, we calculate

$$\frac{d\delta^*}{dp} = \frac{\delta^{*2}ab(2p - 1)^2(1 - p)^2}{bc(1 - p)^2 + adp(3p - 2)}.$$

The denominator in this expression is less than $bc(2p - 1)^2 < 0$, from which the assertion follows. ■

The intuition behind Theorem 1 is simple. Consider the simplex

$$T = \{(\alpha, \beta) | \alpha, \beta, \alpha + \beta \in [0, 1]\}.$$

By Nash's Existence Theorem there is an equilibrium within T . However Trust is strictly dominated by Defect, and Inspect is strictly dominated by Trust (since Inspectors refuse some profitable trades, while Trusters do not). When the two inequalities (8) hold, Defect is also strictly dominated by Inspect. Therefore all Nash equilibria must be confined to the interior of T . But it is easy to check that there is only one possible candidate, which thus exists and is unique. A phase diagram for the model is presented in Figure 2.⁹

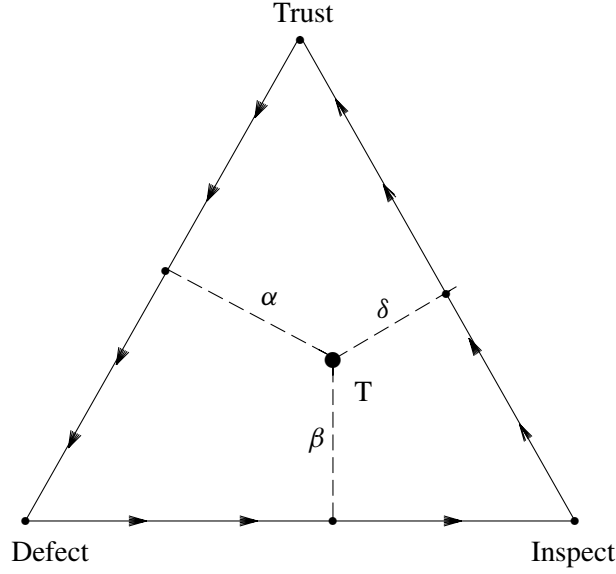


Figure 2: A Simplex Phase Diagram for $G(p)$ when $p_* < p < 1$. The frequency of Inspect, Trust, and Defect are α , β and δ respectively. The trust equilibrium is at T . Note that there are no equilibria along the two-dimensional boundary of the simplex, since each pure strategy can be invaded by another.

The replicator equations are then given by

$$\frac{d\alpha_t}{dt} = \alpha_t(\pi_I^t - \bar{\pi}^t) \quad (10)$$

$$\frac{d\beta_t}{dt} = \beta_t(\pi_T^t - \bar{\pi}^t), \quad (11)$$

reflecting our assumption that norms are implicated in the response to relative pay-offs.

We then have

Theorem 2. *Stability of the Trust Equilibrium For $p > p_*$, the unique equilibrium $P = (\alpha^*, \beta^*, \delta^*)$ of $G(p)$ is either stable or paths starting sufficiently near P converge to a periodic orbit of the replicator dynamic. In the latter case, the time*

⁹We must also check on the dynamic properties of the interior Nash equilibrium. There is no guarantee that this equilibrium is evolutionarily stable. Indeed, the reader can check that for $a = 2$, $b = 1$, $c = -1$ and $d = -2$ the equilibrium is not evolutionarily stable for $p \geq 0.78$, while if we change a to $a = 3$, it is evolutionarily stable. However, evolutionary stability is a sufficient, though by no means necessary, condition for dynamic stability (Gintis 2000):Ch. 10. Therefore we must inspect a plausible dynamic, which we take to be the replicator dynamic (Friedman 1991, Gintis 2000).

averages of the payoffs along the periodic orbit for the three strategy types are all equal to $\pi^(p)$. Thus in either the stable or limit cycle case, the long-run expected payoff to an agent is $\pi^*(p)$, which is an increasing function of the signal quality p .*

The first assertion follows directly from the Poincaré-Bendixson Theorem (Perko 1991):227, and the second from an ergodic theorem—Theorem 7.6.4 (p. 79) in Hofbauer and Sigmund (1998). By virtue of this theorem, we will therefore refer to either the stable or limit cycle case as a *stable equilibrium* of $G(p)$.

It is easy to check that when $p < p_*$, there are only All Defect, or Defect/Inspect equilibria, both of which yield negative expected payoff. The first is stable and the second unstable in the replicator dynamic. We assume the network disbands in such cases, so we take $\pi^*(p) = 0$ for $p < p_*$.

4 The Benefits and Costs of Networks

Theorem 2 illustrates an important attribute of the network as a structure of economic governance: the personal information available in networks may facilitate the informal enforcement of contracts. Yet the small-group interactions that permit agents to address problems of contractual incompleteness may limit access to gains from trade that are possible when exchanges are not confined within network boundaries. Members of parochial groups may fail to find trading partners with whom mutually beneficial exchange can occur. We model this tradeoff between the enforcement benefits and foregone gains from trade in this section, extending the results of Theorems 1 and 2 by exploring the effect of the size x on the equilibrium payoff structure.

To do this we consider one (of many) networks in a large population, some members of which belong to no network and trade in the anonymous pool. Agents trading in the anonymous pool have no means of informal enforcement and hence receive the market payoff, which we have arbitrarily set to 0. For agents trading within a network, however, the quality of the signal $p(x)$ is decreasing in network size x , and the probability $q(x)$ of meeting a partner for mutually beneficial trade is increasing in network size. Signal quality $p(x)$ is decreasing in x because larger networks possess less information concerning each individual, while $q(x)$ is increasing because a larger number of participants increases the probability of meeting a potentially mutually beneficial trading partner.

We define a *network information structure* $I(x, \kappa, p_o)$ with the following properties. Each member of a network of x individuals knows the type of κ other members. An Inspector who seeks the type of a specific member j of the network receives informant messages randomly from members of the network, until a message arrives from an informant who claims to know j 's type. An informant who

knows j 's type reports this fact and correctly identifies j 's type with probability one. An informant who does not know j 's type reports this fact correctly with probability p_0 , and when incorrectly claiming to know j 's type (with probability p_0), declares j to be a defector with probability one half.

Theorem 3. Network Size and Signal Quality. *Consider a network with x members and network information structure $I(x, \kappa, p_0)$, $p_0 < 1$, and let $p(x)$ be the quality of the resulting signal concerning a network member. Then $p(x)$ is a decreasing and convex function of x , asymptotic to $p = 1/2$ as $x \rightarrow \infty$.*

To prove the theorem, we note that $p(x)$ satisfies the recursion equation

$$p(x) = \frac{\kappa}{\kappa + x} + \frac{x}{\kappa + x} \left(\frac{1 - p_0}{2} + p_0 p(x) \right).$$

This has solution

$$p(x) = \frac{2\kappa + (1 - p_0)x}{2\kappa + 2(1 - p_0)x}, \quad (12)$$

which is easily seen to be decreasing and convex in x .¹⁰

To specify the shape of $q(x)$, suppose agents produce goods for trade in the morning, and take them to market for trade in the afternoon. Goods are perishable, and cannot be stored. Suppose there are x agents in the network, and there are goods $1, \dots, k$, corresponding to which there are 'marketplaces' that have exogenously given relative sizes f_1, \dots, f_k ($\sum_i f_i = 1$). Marketplace i thus has absolute size $x_i = f_i x$ for $i = 1, \dots, k$. The members who are to compose this x_i are assigned randomly at the start of the trading period. Each agent decides with equal probability to be a buyer or a seller that period. Buyers and sellers in the same marketplace are randomly paired, and if the number of buyers and sellers differ, a random selection of agents will make no trade at all, and as a result trades on the anonymous market, receiving a payoff of zero.

At the marketplace for good i , the number ξ_i of buyers and the number χ_i of sellers are independently distributed binomial random variables with mean $x_i/2$ and variance $x_i/8$. The expected number of agents not finding a trade is thus $E[|x_i - \chi_i|]$, where the expectation is with respect to the product distribution. We have

Theorem 4. Gains to Network Size. *Let $q(x)$ be the probability of making a trade when network size is x . Then $q(x)$ is increasing, concave, and approaches unity for large x .*

¹⁰It might be more reasonable to assume that i receives at most one message from any other member of the network. In this case the expression for $p(x)$ has no obvious closed form, but simulations show that this expression differs from (12) by less than one part in a thousand for all x and over plausible ranges of κ and p_0 .

The proof is in the Appendix.

Consider the game $G'(x)$, where x is the number of agents in the network, that differs from the game G in two ways. First, the payoff to the prisoner's dilemma stage game is the payoff in G multiplied by $q(x)$, which is a nonnegative, strictly concave, strictly increasing, bounded, differentiable function of network size x . We will assume, as per Theorem 4, that $q(\infty) = 1$, and there is a minimum network size, $x_{\min} > 0$, with $p(x_{\min}) > p_*$, below which $q(x) = 0$, while $q(x_{\min}) = q_{\min} > 0$. To avoid corner solutions in the analysis below, we assume also that $\pi'(x_{\min})x_{\min} > \pi(x_{\min})$. Second, we assume the quality of the signal $p(x)$ satisfies $p(x) > 1/2$ and is a nonnegative, convex, strictly decreasing, differentiable function of network size (see Theorem 3). We call the game $G'(x)$ the *variable size network game*.

The payoff in equilibrium in a network of size x is now simply

$$\bar{\pi}(x) = q(x)\pi^*(p(x)), \quad (13)$$

and the equilibrium frequencies of Inspectors and Trusters can be written as $\alpha^*(p(x))$ and $\beta^*(p(x))$, respectively. There must then exist an 'optimal' network size $x^* > x_{\min}$ that maximizes the per-agent payoff, supporting an equilibrium of $G'(x^*)$. This is because for $x = x_{\min}$, $p(x) > p_*$, so we have $\pi^*(p(x)) > 0$. But for sufficiently great x , we have $p(x) < p_*$, so $\pi^*(p(x)) = 0$.

5 The Demographics of Network Size and Market Size

To this point we have explained the effects of exogenous variations in network size. But as agents may 'migrate' in response to differential payoffs, we must now let variations in network size reflect the resulting migration flows.¹¹ To avoid unnecessary complications, we assume the same informational assumptions apply equally to old and new network members. In particular, immigrants know the types of others, and their types are known by others, with the same frequency as less recently arrived network members.

Suppose we have a number of networks, of sizes x_1, \dots, x_n (n may be variable over time), each in a locally stable trust equilibrium,¹² so the members of a network have payoffs given by (13). All agents not in a network fall into the anonymous

¹¹Here 'migration' refers to movement between networks and the pool of anonymous traders, and need not entail geographic relocation.

¹²There is a plausible alternative to the assumption that networks are locally stable at their equilibrium size, in which networks that become too large disintegrate into universal defection because the conditions for local stability of the trust equilibrium fail when the quality of the signal $p(x)$ becomes too low. We shall not deal with this case here. Modeling migration dynamics as we do below, we expect that this case will give rise to cycles of growth and dissolution of networks that may be of theoretical and practical interest.

pool of size z . We assume z is sufficiently large that traders in the pool secure transactions with certainty, so all anonymous traders receive the payoff zero in each period. However agents may migrate from the pool to the various networks according to a demographic dynamic in which the net movement is a function of the pre-migration size of the two populations and the difference between the payoffs to their members. Migration is proportional to the size of the anonymous pool. Thus net immigration into network i is given by¹³

$$m_i(x_i) = \gamma z \bar{\pi}(x_i). \quad (14)$$

The parameter $\gamma > 0$, which we call the *immigration coefficient*, reflects the sensitivity of immigration to the gains of network membership.¹⁴ We also assume that network members have a constant probability $\nu > 0$ of migrating spontaneously to the anonymous pool for reasons unconnected with the gains from network membership.¹⁵ For the remainder of this section, we analyze a single network, so we suppress the subscript i in (14) and related expressions.

The equation governing the expected size of a network is $dx/dt = m - \nu x$, or

$$\frac{dx}{dt} = \gamma z \bar{\pi}(x) - \nu x. \quad (15)$$

Equilibrium expected network size is that for which immigration and emigration are just offsetting, or $dx/dt = 0$, giving

$$\gamma z \bar{\pi}(x) = \nu x, \quad (16)$$

and the condition for stability of a network size equilibrium is that

$$\frac{\partial}{\partial x} \left(\frac{dx}{dt} \right) \Big|_{\frac{dx}{dt}=0} < 0, \quad (17)$$

which requires that

$$\nu > \bar{\pi}'(x) \gamma z. \quad (18)$$

The point \hat{x} in Figure 3 satisfies (16) and (18), and represents such a stable equilibrium. Over the interval $x \in (x', \hat{x})$ we have $dx/dt > 0$, with $dx/dt < 0$ for

¹³Our analysis remains valid, it can be shown, if migration varies with the size of the destination network; that is, if (14) is replaced by the more general equation $m(x) = \gamma x^\lambda z \bar{\pi}(x)$ for $0 \leq \lambda < 1$.

¹⁴We ignore the possibility that agents may migrate from one network to another. In equilibrium, all networks will have the same payoffs, so no such migration will take place. This is in contrast to flows between the anonymous pool and networks, which remain positive even in equilibrium.

¹⁵Spontaneous departures from a network may be occasioned by conflicts within the group, as is amply documented among the historically longest running type of network, the hunter-gather foraging band (Boehm 1993).

$x < x'$ or $x > \hat{x}$. Note that networks smaller than x' will lose population until they reach x_{\min} , and then will disappear (because of our assumption that $q(x) = 0$ for $x < x_{\min}$). Also x_{\min} is the point where $p(x) = p_*$, so the trust equilibrium is unstable for $x > x_{\max}$. We have assumed in the figure that the payoff to network membership at x_{\max} is strictly positive. To see that this is the case, note that the second inequality in (8), together with $a > b > 0$, imply $p_* > (\sqrt{5}-1)/2 \approx 0.618 > 1/2$, so (9) implies $\bar{\pi}(x_{\max}) > 0$. We have

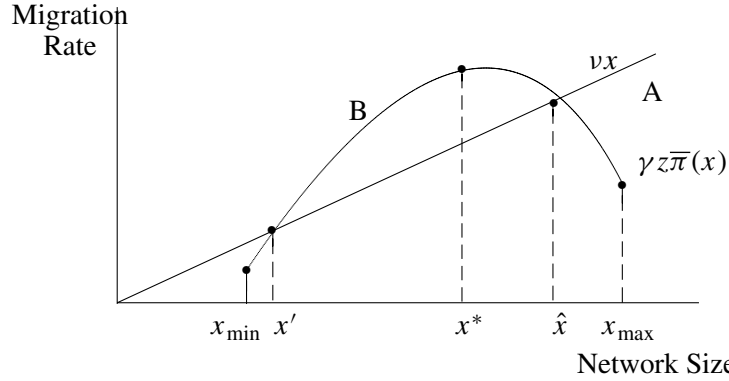


Figure 3: Optimal and Equilibrium Network Size. A is the right-hand side of (16), and B is the left-hand side. Equilibrium network size is \hat{x} , which is stable because A is steeper than B at \hat{x} . Also x' is endpoint of the basin of attraction of \hat{x} , and x_{\max} is the network size beyond which the trust equilibrium is unstable.

The next theorem says that for any anonymous pool size z , there is an interval of immigration coefficients within which the trust equilibrium is stable for high quality signals, the immigration coefficient that implements optimal network size lies in this interval, and the interval shifts to the left when the anonymous pool increases in size.

Theorem 5. Equilibrium Network Size. *For any anonymous pool size $z \in (0, 1)$, there is a minimum immigration coefficient $\underline{\gamma}(z)$, a maximum immigration coefficient $\overline{\gamma}(z)$, and an optimal immigration rate $\gamma^*(z)$ with the following properties:*

- a. *There is no trust equilibrium with $\gamma < \underline{\gamma}(z)$ or $\gamma > \overline{\gamma}(z)$.*
- b. *For any $\gamma \in (\underline{\gamma}(z), \overline{\gamma}(z))$, and for a sufficiently high quality signal $p(\cdot)$, there is a trust equilibrium that is stable in the replicator dynamic and in the migration dynamic for network size.*
- c. *For $\gamma = \gamma^* \in (\underline{\gamma}(z), \overline{\gamma}(z))$, equilibrium network size is optimal; i.e., we have $\gamma^* z \bar{\pi}(x^*) = \nu x^*$.*

d. There is are constant g_{\min} and g_{\max} such that $z\underline{\gamma}(z) = g_{\min}$ and $z\overline{\gamma}(z) = g_{\max}$ for all $z \in (0, 1)$.

To prove the theorem, choose x^+ to maximize $\overline{\pi}(x)/x$. Since by assumption we have $\pi'(x_{\min})x_{\min} > \pi(x_{\min})$, we know that $x^+ > x_{\min}$, and clearly $x^+ < x^*$, so the solution is interior. Now choose $g_{\min} = vx^+/\overline{\pi}(x^+)$, so the two curves in Figure 3 are tangent at x^+ when $\gamma z = g_{\min}$. Also, define $\underline{\gamma}(z) = g_{\min}/z$. By construction there is no network size equilibrium for $\gamma < \underline{\gamma}(z)$. If we define $g_{\max} = vx_{\max}/\overline{\pi}(x_{\max})$, then g_{\max} satisfies the conditions of (a), which proves (a). For $\gamma \in (\underline{\gamma}(z), \overline{\gamma}(z))$, there is at least one solution of (16), and this equilibrium is stable for a sufficiently high quality signal, by Theorem 2. To see that this is stable in network size if the equilibrium size \hat{x} satisfies $\hat{x} \geq x^*$, note that

$$\frac{\partial}{\partial x} (\gamma z \overline{\pi}(x) - vx)|_{x=\hat{x}}$$

is strictly negative. This proves (c). The rest of the theorem is straightforward. ■

Intuitively, $\underline{\gamma}(z)$ occurs in Figure 3 by shifting down curve B until it is tangent to curve A , and $\overline{\gamma}(z)$ occurs by shifting up B until its right endpoint hits A . For $\gamma < \underline{\gamma}(z)$ there is no intersection of A and B and hence emigration exceeds immigration for all network sizes, which precludes the existence of networks. Increasing γ from $\underline{\gamma}(z)$, curve B crosses curve A at x^* . At that point and for γ greater than this but less than $\overline{\gamma}(z)$, curve A has a greater slope than the curve B , which means that (17) holds, so the equilibrium is stable in the migration dynamic. For $\gamma > \overline{\gamma}(z)$ net immigration is positive for all $x > x'$, so the network will grow to size x_{\max} and then disband, since $p(x)$ then falls below p_* .

To model the dynamics and equilibrium conditions for the size of the anonymous pool, we now treat the number n of networks as a continuous variable. For a typical network, we assume there is a probability $\tilde{p}(x) > 0$ that an individual in the network will return to the pool because the network disbanded, perhaps because the network fell below size x' through a series of adverse random shocks.¹⁶ We assume $\tilde{p}(x)$ is u-shaped, with a minimum at x^* , reflecting the fact that a higher expected payoff makes the equilibrium more robust in the face of a given series of shocks. We assume also that random shocks within the anonymous pool lead to the flow of individuals into newly-formed of networks at the rate $p_z > 0$. Then the equation governing the expected size of the pool is

$$\frac{dz}{dt} = \sum_{k=1}^n [(v_k + \tilde{p}(x_k))x_k - \gamma z \overline{\pi}(x_k)] - p_z z,$$

¹⁶For models of this type, based on the theory of random perturbations of dynamical systems (Freidlin and Wentzell 1984), see Kandori, Mailath and Rob (1993) and Samuelson (1997).

where the first term in the summation represents the migration from networks to the anonymous pool (by individual emigration and network dissolution), the second term in the summation represents the immigration to networks, and the final term represents new network formation.¹⁷ In demographic equilibrium all networks are at equilibrium size, so from equation (16), this expression can be simplified to

$$\frac{dz}{dt} = \sum_{k=1}^n \tilde{p}(x_k)x_k - p_z z. \quad (19)$$

The equilibrium size of the anonymous pool, setting $dz/dt = 0$, is thus given by

$$z^* = \frac{1}{p_z} \sum_{k=1}^n \tilde{p}(x_k)x_k. \quad (20)$$

We then have

Theorem 6. Demographic Equilibrium. *There is a demographic equilibrium in which $z = z^*$ as defined in (20). For any $\gamma > \underline{\gamma}(z^*)$, there is a network trust equilibrium $x(\gamma)$ that is stable in the replicator dynamic and the migration dynamic for network size for a sufficiently high quality signal $p(x(\gamma))$.*

6 Optimal Parochialism

Theorems 5 and 6 show that there is a close relationship between the viability of networks and the payoff to network membership, on the one hand, and the rate of immigration γ into the network, on the other. In an economy with low transportation and communication costs, it is plausible to take γ to be so large that $\gamma > \bar{\gamma}(z^*)$, so stable networks cannot exist in equilibrium. This reasoning expresses the view that networks are vestigial remnants of traditional society doomed to long-run extinction.

Networks could form, however, if membership could be limited to a certain fraction ρ of potential immigrants. We formalize this by defining the *degree of exclusiveness* of a network as the fraction $\rho \in (0, 1)$ of potential immigrants who will be excluded. We first assume exclusion is random across character traits, taking up parochial exclusion later. Hence if γ_o is the immigration coefficient assuming no exclusiveness, and if the degree of exclusiveness is ρ , then the immigration coefficient in (14) is given by

$$\gamma = \gamma_o(1 - \rho), \quad (21)$$

¹⁷We have assumed that networks are sufficiently numerous that the number of networks that appear and disappear in each period can be replaced by their expected values.

and (14) becomes

$$m(x) = \gamma_o(1 - \rho)z\bar{\pi}(x). \quad (22)$$

We then have

Theorem 7. Optimal Exclusiveness. *There is a degree of exclusiveness ρ^* that maximizes the payoff to network members in a stable trust equilibrium. We call ρ^* the optimal degree of exclusiveness.*

To see this, we define ρ^* by

$$\rho^* = 1 - \frac{vx^*}{\gamma_o z^* \bar{\pi}(x^*)}. \quad (23)$$

then the network is in equilibrium at size $x = x^*$. Because $\bar{\pi}'(x) = 0$ at x^* , (18) shows that the optimally exclusive equilibrium is stable. ■

Figure 4 depicts network size equilibrium as the equality of the two schedules $(1 - \rho)\gamma_o z \bar{\pi}(x)$ and vx , the two terms in (16). An increase in exclusiveness shifts the first curve down proportionately, and the optimally exclusive solution occurs at x^* , so that net migration is negative to the right of x^* and positive to the left of x^* , and the condition for stability (17) is satisfied.

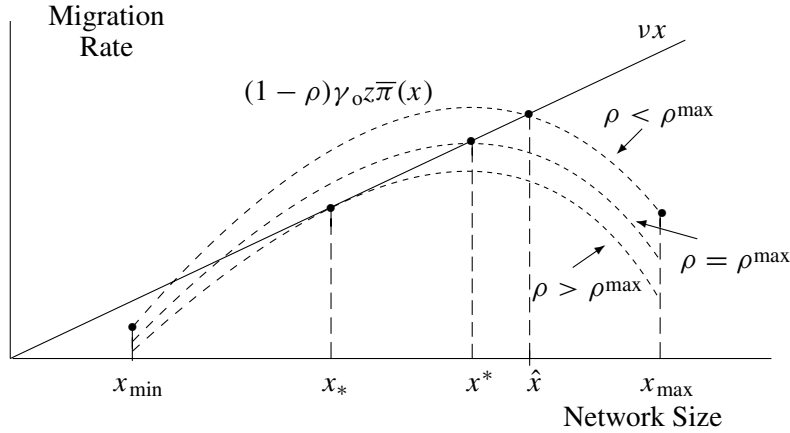


Figure 4: Exclusiveness and Optimal Network Size. As the degree of exclusiveness increases from ρ to ρ^* , equilibrium network size falls from \hat{x} to x^* . When the degree of exclusiveness reaches ρ^{\max} , the network is no longer of a sustainable size.

The welfare properties of a demographic equilibrium for the entire population are explored in:

Theorem 8. Welfare in Demographic Equilibrium. *Suppose networks are identical and they exhibit the same degree of exclusiveness ρ sufficient to sustain a stable trust equilibrium. Then in demographic equilibrium the following hold:*

- a. *The number z^* of agents in the anonymous pool is strictly positive.*
- b. *For $\rho < \rho^*$, an increase in exclusiveness increases the payoff to network members, decreases equilibrium network size, and increases the fraction of agents in the population who are in networks.*
- c. *The condition $\rho = \rho^*$ is Pareto efficient in the sense that it jointly maximizes the payoff to network membership and the fraction of the population receiving the trust equilibrium payoff.*

Proof: Part (a) follows directly from (19), given that $\tilde{p}(x_k) > 0$ for all k . For part (b), note first that by (16), equilibrium network size requires (dropping subscripts, since networks are identical),

$$(1 - \rho)\gamma_0 z \bar{\pi}(x) = vx.$$

Totally differentiating this equation with respect to ρ shows that $dx/d\rho < 0$ for $x > x^*$. This proves the first two assertions in (b). To prove the third assertion, notice that given exogenous variations in ρ and consequent changes in x , stationarity of z is achieved by the entry or exit of networks—that is, by varying n . Increased exclusiveness reduces network size and raise returns to members of networks, thus increasing the attractiveness of networks, while also rendering migration into networks more difficult. The net effect on the fraction of the population in networks is determined as follows.

To obtain an expression for n , we set $dz/dt = 0$ in (19), and we see that in equilibrium new entrants to the anonymous pool must be just offset by those exiting, or

$$n(\tilde{p}(x) + p_z)x = p_z z. \tag{24}$$

Totally differentiating this expression with respect to ρ , we find

$$\frac{dn}{d\rho}(\tilde{p}(x) + p_z)x + n[(\tilde{p}'(x) + p_z) + \tilde{p}'(x)x]\frac{dx}{d\rho} = 0.$$

Since $\tilde{p}'(x) > 0$ and $dx/d\rho < 0$, this equation shows that $dn/d\rho > 0$. Also, from (24) we know that the number of agents in networks is

$$nx = \frac{p_z z}{\tilde{p}(x) + p_z},$$

so

$$\frac{d(nx)}{d\rho} = -\frac{p_z z}{(\tilde{p}(x) + p_z)^2} \tilde{p}'(x) \frac{dx}{d\rho}$$

which is positive under the assumptions of the theorem. This proves part (b), from which part (c) is obvious. ■

It follows that barriers to entry may enhance welfare in the population as a whole, and that members of networks erecting barriers to entry may enjoy higher levels of well-being than those not in exclusive networks, thus supporting the persistence of exclusion even in highly competitive environments.¹⁸

These conclusions assume, of course, that exclusion is random rather than parochial. By contrast, let us suppose that the exclusiveness of a network derives from parochialism, so all newly created networks consist of b -parochial agents for some $b \in A$. The Trust and Inspect strategies analyzed in Section 3 now become “trust (resp. inspect) insiders (i.e., agents who are b -parochial) and defect on anyone else.” It is clear that the analysis of Section 3 applies to this new situation without change. Moreover only b -parochial agents can gain by migrating to a b -parochial network. Hence a b -parochial network will remain uniformly b -parochial throughout its existence.

Consider a b -type who is unselective, say the $b = 00$ of the “female/French-speaking” example above, who excludes nobody as long as they are similarly non-exclusive. Suppose that most members of the population were of this type; then the implied degree of parochialism ρ_b would be insufficient to implement the optimal network size, while a more restrictive filter, say $b' = 01$ (only like-minded Francophones welcome) might do so. The existence of some approximately optimally parochial b is assured if we expand the trait space sufficiently.¹⁹ To show this, we can write the immigration coefficient for a b -parochial network as

$$\gamma_b = (1 - \rho_b)\gamma_0, \quad (25)$$

where γ_0 is immigration coefficient that would obtain in the absence of exclusiveness, and the degree of parochialism ρ_b remains to be determined.

Because b -parochial networks exclude all who are not b -parochial, we have

$$\rho_b = 1 - z_b,$$

where z_b is the frequency of b -parochial agents in the anonymous pool. Let x_T be the size of the population, so $\mu_z = z/x_T$ is the fraction of the population in the

¹⁸Where $\hat{x} < x^*$, of course, inducements to entry will have the same effect, though we think this case less likely and have not explored it here.

¹⁹If there are multiple parochialisms which are mutually exclusive in the sense that members of one group are always excluded from the others, this analysis can be readily extended. We have not explored more complicated cases.

anonymous pool. Also let μ_b be the fraction of the population consisting of agents in b -parochial networks, and the f_b be the fraction of b -parochial agents in the population. We then have $\mu_b x_T = f_b x_T - z_b z = (f_b - z_b \mu_z) x_T$, so $\mu_b = f_b - z_b \mu_z$. This gives $z_b = (f_b - \mu_b) / \mu_z$, so we have

$$\rho_b = 1 - z_b = 1 - \frac{f_b - \mu_b}{\mu_z}. \quad (26)$$

Since the degree of b -parochialism depends not only on the exogenously given fraction f_b of b -parochial agents in the population, but also the distribution of agents between b -parochial networks (μ_b) and the anonymous pool (μ_z), which are endogenously determined, we must now analyze the population level equilibrium of the system.

We have

Theorem 9. Optimal Parochialism. *Suppose that there is but a single type of parochialism, b . Then Theorem 8 holds, where $\rho = \rho_b$ is given by (26). Moreover, if the frequency of b -types in the population satisfies*

$$f_b = \frac{p_z}{\tilde{p}(x) + p_z} + \frac{v x^*}{x_T \gamma_o \bar{\pi}(x^*)} \quad (27)$$

then b -parochialism supports optimal network size. We say that b is optimally parochial in this case.

Proof: The condition for equilibrium network size (16) can be rewritten

$$\frac{(1 - \rho_b) \gamma_o z}{v} = \frac{x}{\bar{\pi}(x)},$$

which, using the definition of ρ_b , now becomes

$$\frac{z_b \gamma_o z}{v} = \frac{x}{\bar{\pi}(x)}.$$

But $z_b z = (f_b - \mu_b) x_T$, so this becomes

$$\frac{(f_b - \mu_b) x_T \gamma_o}{v} = \frac{x}{\bar{\pi}(x)}. \quad (28)$$

Now in equilibrium, from (24) we have

$$\frac{n x}{x_T} = \frac{p_z}{\tilde{p}(x) + p_z}, \quad (29)$$

where n is the number of b -parochial networks.

Equations (28) and (29) yield the equilibrium condition

$$\frac{x_T \gamma_o}{v} \left[f_b - \frac{p_z}{\tilde{p}(x) + p_z} \right] = \frac{x}{\bar{\pi}(x)}. \quad (30)$$

The conclusion follows directly from this equation. ■

7 Conclusion

The fact that the exclusionary practices we have called ‘parochial’ may implement a group size or, by extension, a degree of group homogeneity, that maximizes network members’ benefits does not imply that these practices—often motivated by racial and ethnic hatred and religious intolerance—are socially desirable, of course. But it may help explain why groups and group identity remains such salient features even of societies whose competitive economies and liberal polities are widely thought to be hostile to parochial sentiment.

We have argued that networks have properties that allow them to persist in a market economy despite their relative inability to exploit economies of scale and the other efficiency-enhancing properties of markets. Among these properties, and the one explored in this paper, is the capacity of networks to support enforcement of prosocial behavior among network members. Networks have this capacity by virtue of their ability to reduce information costs, thus permitting the emergence of ‘trusting’ Nash equilibria that do not exist, or are unstable, when information costs are high. Our particular model of these relationships could readily be extended to capture other salient aspects of the determinants of network formation, parochial exclusion, and network extinction. For example, because parochialism makes networks not only smaller, but more homogeneous as well, corresponding efficiency enhancing effects of similarity or social affinity with parochial networks may be important.

The value of the informal contractual enforcement capacities of networks, the viability of networks, the optimal network size, and the optimal degree of parochialism all depend importantly on the nature of the goods and services that make up economic exchanges. Kollock (1994:341) investigated “the structural origins of trust in a system of exchange” using an experimental design based on the exchange of goods of variable quality. He found that trust in and commitment to trading partners as well as a concern for ones own and others’ reputations emerges when product quality is variable and non-contractible but not when it is contractible. These experimental results appear to capture some of the structure of actual exchanges. Siamwalla’s (1978) study of marketing structures in Thailand contrasts the impersonal structure of the wholesale rice market, where the quality of the product is readily assayed by the buyer, with the personalized exchange based on trust in the raw rubber market, where quality is impossible to determine at the point of purchase. Thus, were technologies to evolve such that quality and quantity of the goods being transacted are readily subject to complete contracting, preferential trading within networks would be of little benefit and would likely be extinguished due to the implied foregone gains from trade. Conversely, were the economy to evolve in ways that heighten the problem of incomplete contracting we would expect to

see growing economic importance of networks.

Applying this reasoning to our model, we consider the latter more likely. As production shifts from goods to services, and within services to information-related services (Quah 1996), and as team-based production methods increase in importance, the gains from cooperation will increase as well, because such activities involve relatively high monitoring costs and are subject to costly forms of opportunism. If this is the case the benefits associated with the mutual defect payoff relative to the mutual cooperate outcome will decline over time and a wider range of exchanges will be available.²⁰ This in turn will support more extensive use of network based trust equilibria as a means of addressing contractual incompleteness.

Further, advances in communications technology arguably increase the number (κ) of acquaintances from whom we can gather information at limited cost, thus by Theorem 3, increasing the quality of the signal $p(x)$. The following are consequences: (i) the range of payoff structures for which trust a equilibrium exists is expanded, (ii) the basin of attraction of a trust equilibrium is expanded, and (iii) the average payoffs to members of a network of given size in a trust equilibrium increase compared with the payoffs obtained by traders in the anonymous pool, and (iv) there is an increase in equilibrium network size (cf. Figure 3).

On the other hand the kinds of social exclusion motivating network-based parochialism often violate strongly held universalistic norms and may motivate either legal prohibition or other evolutionary disabilities not considered in this model.

A study of the evolution of parochial sentiments, which could be accomplished by endogenizing the parochialism filter, might yield useful insights, but is beyond the scope of this paper.

²⁰An increase in the cooperative payoff b does not make the standard prisoner's dilemma interaction any 'easier to solve' of course, but it may enhance evolutionary pressures for the emergence of new rules of interaction that effectively mitigate the dilemma. Wade (1987:774-5) describes such a process:

...a significant number of the villages (in one small part of Upland South India) have institutions for the provision of public goods and services, which are autonomous of outside agencies in origin and operation. ...Only a few miles may separate a village with a substantial amount of corporate organization from others with none...Why the differences between villages? It is not because of differences in norms or values, for the villages are located within a small enough area for the culture to be uniform. It is rather because of differences in net collective benefit.

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8 Appendix: Proofs (Not for Publication)

Proof in Theorem 3 that $r_n = 1 + n/(\kappa + 1)$. If there are $\kappa + n$ members of the network, the first queried will know the type of a particular individual with probability $\kappa/(\kappa + n)$, and if not, members of a network of size $\kappa + n - 1$, of whom κ know the individual in question, must be queried. Notice that the relationship $r_n = 1 + n/(\kappa + 1)$ is trivially true for $n = 0$. Suppose it is true for some value $n - 1 \geq 0$. Then

$$\begin{aligned} r_n &= 1 + \frac{n}{\kappa + n} r_{n-1} \\ &= 1 + \frac{n}{\kappa + n} \left(1 + \frac{n-1}{\kappa + 1} \right) \\ &= 1 + \frac{n}{\kappa + 1}. \end{aligned}$$

The assertion follows by induction on n . ■

Proof of Theorem 4: We assume x large enough relative to k that the normal approximation to the binomial is sufficiently accurate ($x > 10k$ is enough to ensure this). The difference between the number of buyers and sellers in a marketplace is a random variable ψ_i that is normally distributed with mean zero and variance $\sigma_i^2 = x_i/4$. Then $E[|\psi_i|] = E[\psi_i | \psi_i \geq 0]$ is then given by

$$\begin{aligned} \frac{1}{\sqrt{2\pi}} \int_0^\infty \psi_i e^{-\frac{\psi_i^2}{2\sigma_i}} d\psi_i &= \frac{1}{\sqrt{2\pi}} (-\sigma_i) e^{-\frac{\psi_i^2}{2\sigma_i}} d\psi_i \Big|_0^\infty \\ &= \frac{\sigma_i}{\sqrt{2\pi}} = \frac{\sqrt{x_i}}{2\sqrt{2\pi}} \end{aligned}$$

Thus the probability p_i of finding a trading partner in marketplace i is $p_i = 1 - E[|\psi_i|]/x_i = 1 - 1/2\sqrt{2\pi f_i x}$. Hence

$$q(x) = \sum_{i=1}^k f_i p_i = 1 - \left(\sum_{i=1}^k \frac{\sqrt{f_i}}{2\sqrt{2\pi}} \right) x^{-\frac{1}{2}}.$$

Clearly $q(x)$ has the asserted properties. ■