

Schumacher, Heiner; Hadnes, Myriam

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# Contract Enforcement by the Gods\*

Heiner Schumacher<sup>†</sup>      Myriam Hadnes<sup>‡</sup>

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## Abstract

We propose a theory that explains why rational agents start to believe in a causal relationship between unrelated events. Agents send and collect messages through a communication network. If they are convinced of a relationship between two events, they send messages confirming their belief with higher probability than messages contradicting it. The network aggregates this "communication bias" over individuals. Therefore, agents may find a strong relationship between unrelated events even if the communication bias is very small. We apply this model to an informal economy where the fear of punishment by supernatural forces prevents agents from cheating others.

**Keywords:** Informal Contract Enforcement, Communication, Learning, Networks

**JEL classification codes:** C72, D03, L14

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<sup>†</sup>Corresponding Author: Goethe-University Frankfurt, Grueneburgplatz 1, Rechts- und Wirtschaftswissenschaften, DE-60323 Frankfurt am Main, Germany, (0049) 69 798 34818, heiner.schumacher@econ.uni-frankfurt.de.

<sup>‡</sup>Goethe-University Frankfurt, (0049) 69 798 34794, mhadnes@wiwi.uni-frankfurt.de.

# 1 Introduction

*“To reason against African belief in witchcraft is useless because intellectually it is perfectly coherent.” (Evans-Pritchard 1935: 421)*

We develop a model of communication in which agents start to believe in a causal relationship between unrelated events. Agents send and receive messages through a communication network. As soon as an individual is convinced that a certain relationship between two events exists, she communicates messages that confirm this relationship (“positive messages”) with higher probability than messages contradicting it (“negative messages”). We call this bias “communication bias”. It operates unconsciously, therefore agents do not account for the communication bias when analyzing their set of collected messages. In a network where each agent has only few neighbors, positive messages reach on average much more agents than negative messages. Thus, the network aggregates individual biases. Consequently, agents may detect a strong relationship between unrelated events even if the communication bias is very small.

Our main motivation is to rationalize the spread and persistence of beliefs in supernatural forces (SNF).<sup>1</sup> Beliefs in SNF advocate the presence of entities and abilities that operate in the world, but do not dependent upon any natural laws. They play an important role in many societies, in particular in sub-Saharan Africa. Anthropologists refer to contemporary forms of occultism as a post-modern phenomenon (Moore and Sanders 2001). Occult beliefs are evoked by the process of globalization and increasing economic uncertainty.<sup>2</sup> Their occurrence is mostly independent of social indicators such as education, religion, or social status.<sup>3</sup> Each of the roughly three thousand existing African ethnic groups has its own religious system containing different beliefs in SNF. These beliefs are modified frequently to stay suitable to individual or societal experiences, reflections and needs (Mbiti 1975, 2008).

A unifying feature of beliefs in SNF is that they affirm a causal relationship between unrelated events. Misfortunes are often perceived as direct consequence to previous behavior.<sup>4</sup> Many occult beliefs proclaim punishment for bad behavior to come in present life (and not in the afterlife). There exists evidence that in many African societies people fear supernatural punishment. They might refrain from certain offences because they expect their neighbors’ and kins’ revenge through the use of SNF.<sup>5</sup>

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<sup>1</sup>In the following, we will use the terms “beliefs in supernatural forces” and “occult beliefs” synonymously.

<sup>2</sup>See Kohnert (1996, 2007).

<sup>3</sup>See Ashforth (1998), Behringer (1998), Geschiere (2000), Mbiti (2008).

<sup>4</sup>See Ashforth (2004), Harnischfeger (2006), Kohnert (2007).

<sup>5</sup>See Mbiti (1975, 2008) and Platteau (2009).

*“There is one form of justice administered through the use of the curse. The basic principle here is that if a person is guilty, evil will befall him according to the words used in cursing him. By the use of good magic, it is believed, a person can curse an unknown thief or other offender.” (Mbiti 2008: 206)*

The idea that beliefs in SNF serves as a mechanism for contract enforcement is widely accepted among anthropologists. We show that only minor deviations from full rationality are needed to explain occult beliefs on a large scale. Our theory is developed in the context of an informal economy. Agents repeatedly meet in a marketplace to exchange goods. Sometimes they have the chance to cheat their contractual partner. Also, they are exposed to the risks of misfortunes such as accidents or illness. Agents exchange messages about their observations in a communication network. Messages are either positive (“I was cheated and the cheater suffered a loss”) or negative (“I was cheated and the cheater is still well off”). Each agent collects all messages she receives and communicates them with positive probability to her neighbors. The probability of suffering a loss is common knowledge. Thus, agents can test the hypothesis that cheaters are exposed to an elevated risk of misfortunes. An agent believes in SNF (does not believe in SNF) if this hypothesis cannot be rejected (can be rejected) at a pre-specified level of significance. This agent will refrain from cheating if the estimated impact of SNF exceeds the gains from cheating.

Our central assumption is that an agent’s conviction influences her conversational behavior: if she believes in SNF, she sends positive messages with higher probability than negative ones. We interpret this bias as a consequence of well-known cognitive biases such as the confirmatory bias or the belief bias.<sup>6</sup> The confirmatory bias says that individuals tend to interpret information in a way that confirms their prior beliefs. This is particularly true for judgments about matters of great personal importance. The belief bias causes individuals to ignore opposed arguments in order to cherish their beliefs, or, seek actively for assertions that support their beliefs. Individuals who are subject to the belief bias remember events confirming their beliefs better than events contradicting it. Religious persons, for instance, rather remember situations in which prayers became true and suppress thoughts of prayers that did not (see Jennings et al. 1982). These biases are independent of cognitive ability. Furthermore, they proceed mostly unconsciously. Therefore, we assume that agents do not take into account the communication bias when analyzing their collection of messages.

The main result goes as follows: if there is a small group of agents who always believe in SNF, all agents will do so after finite time. However, if all agents communicate with

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<sup>6</sup>See Rabin and Schrag (2002) and Yariv (2005) for applications of the confirmatory bias in economics. Rabin and Schrag (2002) also provide a summary of psychological studies on the confirmatory bias. The belief bias is due to Luria (1982).

one another (i.e. if the communication network fully connected), a small communication bias leads to an equally small estimated impact of SNF. Consequently, agents will cheat whenever possible if the communication bias is sufficiently small. This changes if (i) the number of paths between any two agents is small and (ii) there are many agents in the population. Then, positive messages will reach on average much more agents than negative ones and agents will estimate a high impact of SNF. We call this implication of the network structure “network-effect”. If the network-effect is sufficiently strong, agents refrain from cheating even if this implies to forgo substantial payoffs.

In Section 4, we further illustrate how occult beliefs can lead to more trusting behavior. Agents do not only start to fear punishment by SNF (and therefore refrain from cheating), but they also learn that less cheating occurs in the market. This can change the nature of transactions. As long as all agents cheat whenever possible, it is rational for them to carry out “secure” transactions (such as cash-and-carry) where parties have few opportunities to cheat. However, if agents trust their contractual partner not to cheat even if she has the opportunity, it becomes optimal for them to carry out “insecure” transactions, which are mutual more beneficial than “secure” ones and where there are plenty of opportunities to cheat. Thus, if the network-effect is sufficiently strong, the fear of punishment by SNF can increase the efficiency of market outcomes. We show that this result remains valid even if agents reason anecdotally rather than probabilistically and take a single message as fully informative of the impact of SNF. It also remains valid if there are some agents in the market who never believe in SNF and therefore cheat whenever possible. However, if the fraction of these agents is too large, then agents learn that it is optimal for them to carry out secure transactions only. In this case, we get that many agents fear punishment by SNF, but this does not have a positive economic impact.

Our results contribute to the literature on informal contract enforcement and learning. In Section 5, we discuss why it is important to know that occult beliefs can serve as an alternative enforcement mechanism. Informal economies typically rely on some form of enforcement without the use of law. However, enforcement mechanisms that are based on repeated interaction or community enforcement require agents to be patient and that there are either stable relationships between trading parties or incentives for agents to share information about the behavior of others. These requirements are often not met in an informal economy of a low-income country. In contrast, the efficacy of occult beliefs in our model depends on completely different premises, in particular on the shape and size of the communication network.

Finally, we discuss in Section 6 the links between our model and the literature on learning in games and learning via communication in networks. A novel feature of our

model is that we combine a repeated game that is played between randomly matched agents with a communication network where agents exchange messages about their observations. We are therefore able to analyze the relations between agents' actions in the market and their conversational behavior.

## 2 The spread of occult beliefs via communication

*“Misfortune is not simply part of an isolated, random sequence of events. It must correspond to and have a causal base within something unusual in the client’s environment.” (Jules-Rosette 1978: 557)*

### 2.1 Framework

Time is discrete and indexed by  $t \in \{0, 1, \dots\}$ . Let  $I = \{1, \dots, N\}$  be a large, but finite set of risk neutral and myopic agents with typical element  $i$  and even number  $N$ . In each period, agents (i) trade with each other in a market, (ii) face the risk of a misfortune and (iii) exchange messages through a communication network.

**The market.** In a given period, each agent either takes on the role of a buyer or a seller, both with equal probability.<sup>7</sup> Sellers and buyers meet in the market and are paired up randomly. Transactions take place in an anonymous setting: sellers and buyers do not know each other’s identity. Each seller offers a contract  $(v, \pi)$ , where  $v > 0$  denotes the value of a good to the buyer and  $\pi$  denotes “social risk”.<sup>8</sup> Gains from trade are split equally such that  $\frac{v}{2}$  is the price the buyer has to pay. After the good is handed over, then with probability  $\pi > 0$  the buyer gets an opportunity to cheat. If she cheats, payoffs are  $v$  for the buyer and 0 for the seller. If not, payoffs are  $\frac{v}{2}$  for both parties. With probability  $1 - \pi$  this option does not exist and payoffs are again  $\frac{v}{2}$  for both parties. With small probability  $\varepsilon > 0$  the buyer chooses her action randomly. Thus, cheating always occurs with positive probability.

**Random misfortunes.** After transactions have been completed, each agent faces the risk  $\alpha \in (0, 1)$  of suffering a loss of  $D > 0$ . Both  $\alpha$  and  $D$  are common knowledge. A seller observes whether the buyer suffers a loss or not. If in period  $t$  the buyer cheated and suffers a loss, then a message  $(i, 1, t)$  is generated and received by  $i$ , where  $i$  is the identity of the seller. If the buyer cheated and did not suffer a loss, then message  $(i, 0, t)$

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<sup>7</sup>In an informal economy one observes quite often that individuals operate on both transaction sides.

<sup>8</sup>The cost of production of the good are normalized to 0.

is generated and received by  $i$ .<sup>9</sup> We will call a message  $(i, 1, t)$  positive and a message  $(i, 0, t)$  negative. All agents send and receive messages through a communication network as explained below.

**The communication network.** The agents in  $I$  are the vertices of a communication network  $G$ , whose graph is defined as the pair  $(I, E)$ .<sup>10</sup>  $E \subseteq I \times I$  is the set of links between agents. Let  $(i, j)$  denote the link between agents  $i$  and  $j$ . The graph is undirected, therefore we have  $(i, j) = (j, i)$  for  $i, j \in I$ . A path  $w_{i,j}$  between two agents  $i$  and  $j$  is a sequence of pairwise different agents  $i_1, \dots, i_n$  such that  $i_1 = i$ ,  $i_n = j$  and  $(i_q, i_{q+1}) \in E$  for each  $q \in \{1, \dots, n-1\}$ . The path's length is  $n-1$ . We assume that the network  $G$  is connected, i.e. for each pair  $i, j \in I$  there exists a path  $w_{i,j}$ . The length of the shortest path between  $i$  and  $j$  is called the distance between those agents and denoted by  $d_{i,j}$ . The set of agent  $i$ 's direct neighbors is given by  $i(1) = \{j \in I \mid d_{i,j} = 1\}$ . Her  $y$ -neighborhood is given by  $i(y) = \{j \in I \mid d_{i,j} = y\}$ , where  $y \geq 2$ . Let  $\mathbf{G}(N^*, L^*, K^*)$  be the set of connected graphs with equal or more than  $N^*$  vertices, where  $|i(1)| \leq L^*$  for each  $i$ , and where for each pair of vertices  $i, j$  there are equal or less than  $K^*$  different paths between  $i$  and  $j$ .

All messages that are generated in period  $t$ , are communicated in period  $t$  only: if agent  $j$  receives a message  $(i, l, t)$ , she sends this message to her direct neighbors with probability  $b$  (that will be specified below). The recipient agents in turn send the message to their direct neighbors with probability  $b$  and so forth.

**Testing for occult punishment.** There is a commonly known theory saying that those who cheat are likely to be punished by SNF. To find out whether this theory is true or not, an agent analyzes in each period the set of messages she received through the network. Denote by  $M_{i,t}$  the set of messages agent  $i$  has received until the beginning of period  $t$ , where  $M_{i,0} = \emptyset$  for all  $i$ . Let  $m_{i,t}^1$  ( $m_{i,t}^0$ ) be the number of positive (negative) messages in  $M_{i,t}$ . The relative share of positive messages is

$$\bar{m}_{i,t} = \frac{m_{i,t}^1}{|M_{i,t}|}. \quad (1)$$

In each period  $t$ , agent  $i$  uses her dataset  $M_{i,t}$  to test whether the theory is true or not. The null hypothesis states that the probability of a loss after cheating,  $m^1$ , is not different from the probability of a loss without cheating. Thus, she tests  $H_0 : m^1 = \alpha$

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<sup>9</sup>Other observations will not be communicated. This assumption is made for simplicity and does not affect our results. In particular, cheaters may include their own experiences to their collection of messages.

<sup>10</sup>Whether the network structure is common knowledge or not is not important for our results.

against  $H_1 : m^1 > \alpha$  by using a binomial test. The corresponding z-score is

$$z_{i,t} = (\bar{m}_{i,t} - \alpha) \sqrt{\frac{|M_{i,t}|}{\alpha(1-\alpha)}}. \quad (2)$$

If  $z_{i,t}$  exceeds a critical threshold  $\bar{z} > 0$ , agent  $i$  rejects  $H_0$  and believes in SNF. She then assumes that  $m^1 = \bar{m}_{i,t}$ . If she cannot reject  $H_0$ , she does not believe in SNF and assumes  $m^1 = \alpha$ .<sup>11</sup>

The following two assumptions are crucial for the spread of occult beliefs. First, there is at least one agent  $i^* \in I$  who always believes in SNF. Second, depending on whether an agent believes in SNF or not, she is subject to the communication bias: if an agent does not believe in SNF in period  $t$ , she sends all messages  $(j, l, t)$ ,  $j \in I$ ,  $l \in \{0, 1\}$ , with probability  $b_H > 0$ . If an agent believes in SNF in period  $t$ , she sends a positive message with probability  $b_H$  and a negative message with probability  $b_L$ , where  $b_H > b_L > 0$ . The sequence of events in each period is as follows:

1. Agents are randomly assigned to the roles of buyers and sellers. Buyers and sellers then are matched randomly. Sellers offer the contract  $(v, \pi)$ .
2. Each buyer randomly gets an opportunity to cheat or not.
3. Buyers who have the opportunity decide whether to cheat or not. Payoffs are realized.
4. Each agent suffers a loss with probability  $\alpha$ . Sellers observe their buyer's loss.
5. Messages are communicated in the network.

## 2.2 Main Result

We start by analyzing the trade-off for buyers. If a buyer does not believe in SNF in period  $t$ , then she cheats whenever possible. However, if she does believe, then her decision depends on the estimated impact of SNF,  $\bar{m}_{i,t} - \alpha$ . It appears rational to her not to cheat in period  $t$  if

$$(\bar{m}_{i,t} - \alpha) D \geq \frac{v}{2}. \quad (3)$$

As cheating always occurs in the market with positive probability, messages are generated and sent through the network in infinitely many periods. At least agent  $i^*$  believes in SNF and is subject to the communication bias. This triggers the spread of occult beliefs:

**Lemma 1** *We have  $\lim_{t \rightarrow \infty} z_{i,t} = \infty$  a.s. for each  $i \in I$ .*

<sup>11</sup>The value of  $\bar{z}$  will not influence our results and neither does the fact that  $\bar{z}$  is uniform for all agents.



It follows that there is almost surely a finite period  $t^*$  such that in all periods after  $t^*$  all agents believe in SNF. This fact alone does not imply a relevant impact on agents' behavior. If the communication bias, i.e. ratio between  $b_L$  and  $b_H$ , is close to unity, then the estimated impact of SNF may also be small such that (3) is violated for most agents in most periods. For example, assume that  $G$  is fully connected, i.e. for each two agents  $i$  and  $j$  we have  $(i, j) \in E$ . It is straightforward to see that in this case we have for all  $i \in I$

$$\lim_{t \rightarrow \infty} \bar{m}_{i,t} = \frac{\alpha}{\alpha + (1 - \alpha) \left( \frac{b_L}{b_H} \right)} \quad a.s. \quad (4)$$

which is close to  $\alpha$  if  $\frac{b_L}{b_H}$  is close to 1. We now show that if each agent has only a limited number of neighbors and the number of paths between any two agents is bounded,  $\bar{m}_{i,t}$  can grow arbitrarily close to unity for all  $i$  even if the communication bias is small.<sup>12</sup> Define  $P^n(b_L, b_H)$  as the probability that a message about some agent  $j \in I$ , which is received by another agent  $i$ , is positive, given that all agents in the population believe in SNF and  $d(i, j) = n$ . We can show:

**Lemma 2** *If  $G \in \mathbf{G}(N^*, L^*, K^*)$ , then we have*

$$P^n(b_L, b_H) \geq \max \left\{ \frac{\alpha}{\alpha + (1 - \alpha) \left( \frac{b_L}{b_H} \right)}, \frac{\alpha}{\alpha + (1 - \alpha) \left( \frac{b_L}{b_H} \right)^n K^*} \right\}. \quad (5)$$

Note that  $P^n(b_L, b_H)$  approaches unity if  $n$  grows large. Now consider a communication network with many agents and few paths between any two of them. In this network, positive messages reach on average more agents than negative messages, given that all agents believe in SNF. Whenever an agent receives a message about someone from her distant neighborhood, it is most likely a positive message. We call this the “network-effect”. If there are many agents and  $b_H$  is sufficiently close to unity, then most messages an agent receives are positive messages from her distant neighborhood. We therefore get:

**Proposition 1** *For given  $m' < 1$ ,  $b_L$  and  $L^*, K^* \in \mathbb{N}$  there exist  $N^* \in \mathbb{N}$  and  $\bar{b}_H < 1$ , such that  $\lim_{t \rightarrow \infty} \inf \bar{m}_{i,t} > m'$  a.s. for each  $i \in I$  whenever  $G \in \mathbf{G}(N^*, L^*, K^*)$  and  $b_H > \bar{b}_H$ .*

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<sup>12</sup>There is some evidence that this assumption is partly satisfied for the case of developing countries. In a rural setting, people generally maintain only few strong tie relationships to close friends, neighbors and family members (Dasgupta 2002, Lin 2000). Mistrust among strangers is very common (Nunn and Wantchekon 2009). Rapoport and Horvarth (1961) show that a network based on best and second best friends the size of the  $y$ -neighborhood increases relatively slowly in  $y$ .

The communication bias may be small, however, the network aggregates it over many individuals such that each agent receives a strongly biased set of messages. As individuals are not aware of the communication bias, they do not recognize this flaw in their data.<sup>13</sup> If  $\alpha$  is small enough and  $D$  sufficiently high, we can find a  $m' < 1$  such that  $m' - \alpha \geq \frac{v}{2D}$ . In this case, Proposition 1 tells us that there are networks where after finitely many periods all agents refrain from cheating. Thus, an “effective punishment” via SNF is severe (like death or a bad accident) and occurs with relatively low probability.

If we consider circles or lines as communication networks, then the claim of Proposition 1 follows directly from the shape of the network: if the network is a line, then between any two agents there is only one path, i.e.  $K^* = 1$ ; if the network is a circle, then between any two agents there are exactly two different paths, i.e.  $K^* = 2$ . Thus, we obtain:

**Corollary 1** *For given  $m' < 1$  and  $b_L$  there exist  $N^* \in \mathbb{N}$  and  $\bar{b}_H < 1$ , such that  $\lim_{t \rightarrow \infty} \inf \bar{m}_{i,t} > m'$  a.s. for each  $i \in I$  whenever  $G \in \mathbf{G}(N^*, 2, \infty)$  and  $b_H > \bar{b}_H$ .*

The results of Proposition 1 and Corollary 1 rely on the fact that messages are communicated frequently:  $b_H$  must be high such that positive messages reach on average many agents. If  $b_H$  is small, then only few messages about distant agents are received. In this case, the influence of own experiences (and the experiences of close neighbors) on an agents’ beliefs are substantial. These experiences are unbiased (or, in the case of experiences of close neighbors, only slightly biased). Therefore it depends on the frequency of communication whether or not occult beliefs change agents’ behavior. For some graphs we can quantify this limitation:

**Example** *Let the communication network be given by a circle of  $N \geq 4$  agents. From Corollary 2 it follows that there is a finite period  $t^*$  such that in all periods  $t \geq t^*$  all agents belief in supernatural powers and we have  $2D(\bar{m}_{i,t} - \alpha) > v$  for all  $i \in I$ , given that  $b_H$  and  $N$  are sufficiently high. In this case, we get (see the Appendix for details)*

$$\lim_{t \rightarrow \infty} \bar{m}_{i,t} < \frac{\alpha}{\alpha + (1 - \alpha) \frac{(1+b_L)(1-b_H)}{(1+b_H)(1-b_L)}} \quad \text{a.s.} \quad (6)$$

for each agent  $i \in I$ , regardless of  $N$ . This is because cheating always occurs in the market such that messages are generated and send through the network. Thus, if

$$2D \left( \frac{\alpha}{\alpha + (1 - \alpha) \frac{(1+b_L)(1-b_H)}{(1+b_H)(1-b_L)}} - \alpha \right) \leq v, \quad (7)$$

then a.s. in infinitely many periods cheating will appear beneficial to some agents.

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<sup>13</sup>The only way to make an unbiased estimation for an agent  $i$  would be to ignore all messages  $(j, l, t)$  with  $j \neq i$ .

### 3 Contracts and occult beliefs

#### 3.1 Extended Framework

We now analyze the economic impact of occult beliefs if sellers can choose among several contract offers, which differ in their value  $v$  and social risk  $\pi$ . All other parts of the model remain constant. Let there be two contracts  $(v_1, \pi_1)$  and  $(v_2, \pi_2)$ , where  $v_2 > v_1 > 0$  and  $\pi_2 > \pi_1 \geq 0$ . In each period, a seller  $i$  offers the contract  $(v_q, \pi_q)$  that maximizes

$$\left(1 - \pi_q + \mu_{i,t}^q \pi_q\right) \frac{v_q}{2}, \quad (8)$$

where  $\mu_{i,t}^q$  is the probability the seller assigns to the event that, in period  $t$ , the buyer does not cheat under contract  $(v_q, \pi_q)$  even if the opportunity exists. This value will be determined below. With small probability  $\varepsilon$  sellers tremble and offer each contract with equal probability. We assume that

$$\left(1 - \pi_2 + \frac{\varepsilon}{2} \pi_2\right) \frac{v_2}{2} < \left(1 - \pi_1 + \frac{\varepsilon}{2} \pi_1\right) \frac{v_1}{2}, \quad (9)$$

$$\left(1 - \frac{\varepsilon}{2} \pi_2\right) \frac{v_2}{2} > \left(1 - \frac{\varepsilon}{2} \pi_1\right) \frac{v_1}{2}. \quad (10)$$

Thus,  $(v_2, \pi_2)$  is the pareto-optimal contract. In the following, we call  $(v_1, \pi_1)$  the “secure contract” and  $(v_2, \pi_2)$  the “insecure contract”. Given that agents (do not) cheat whenever they have the opportunity, it is rational for sellers to offer the secure (insecure) contract. Let  $\theta_{i,t}^q$  be the number of times up to period  $t$  agent  $i$  offered contract  $(v_q, \pi_q)$  and the buyer did not cheat agent  $i$  although she had the opportunity.<sup>14</sup> Accordingly, let  $\bar{\theta}_{i,t}^q$  be the number of times up to period  $t$  agent  $i$  offered contract  $(v_q, \pi_q)$  and the buyer had the opportunity to cheat. We then define

$$\mu_{i,t}^q = \max \left\{ \frac{\varepsilon}{2}, \min \left\{ 1 - \frac{\varepsilon}{2}, \frac{\theta_{i,t}^q}{\bar{\theta}_{i,t}^q} \right\} \right\}. \quad (11)$$

This ensures that sellers react to changes in buyers’ behavior and account for the fact that buyers choose their action randomly with probability  $\varepsilon$ .

#### 3.2 Results

We again start by analyzing the trade-off for buyers. If a buyer  $i$  does not believe in SNF in period  $t$ , then she cheats the seller whenever possible. If she does believe, then she does not cheat the seller who offered contract  $(v_q, \pi_q)$  to her in period  $t$  if

$$(\bar{m}_{i,t} - \alpha) D \geq \frac{v_q}{2}. \quad (12)$$

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<sup>14</sup>Here we implicitly assume that the seller observes whether the buyer had the opportunity to cheat or not. This assumption is made in order to avoid further notation and can easily be dropped.

Note that for intermediate values of  $\bar{m}_{i,t}$  it appears rational to her to cheat if the contract is  $(v_2, \pi_2)$  and not to cheat if the contract is  $(v_1, \pi_1)$ . Cheating always occurs in the market with positive probability, therefore messages are generated and sent through the network in infinitely many periods. At least agent  $i^*$  believes in SNF and is subject to the communication bias. This again triggers the spread of occult beliefs. If the network-effect is sufficiently large, then after finite time agents fear the punishment by SNF and refrain from cheating even if the insecure contract is offered. After some time, sellers realize that cheating occurs infrequently and offer the insecure contract in most periods. We therefore get:

**Corollary 2** *If  $2D(1 - \alpha) > v_2$ , then for given  $L^*, K^* \in \mathbb{N}$  and  $b_L < 1$  there exist  $N^* \in \mathbb{N}$  and  $\bar{b}_H < 1$ , such that a.s. after finitely many periods each seller offers the insecure contract with probability  $1 - \frac{\varepsilon}{2}$  whenever  $G \in \mathbf{G}(N^*, L^*, K^*)$  and  $b_H > \bar{b}_H$ .*

Thus, the fear of punishment by SNF can increase welfare in this informal economy. For any mutual beneficial contract  $(v_2, \pi_2)$  with the property that  $2D(1 - \alpha) > v_2$ , we can find communication networks that support the spread of occult beliefs such that sellers will offer this contract in most periods.

### 3.3 $S(1)$ -players and strangers

We extend our framework by introducing two new types of agents, “ $S(1)$ -players” and “strangers”. Up to now we assumed that all agents are part of the communication network and process information by running a statistical test. Our goal in this Section is to show that the positive economic effect of occult beliefs (i) persists if we vary the degree of agents’ sophistication and (ii) may vanish if there are too many agents in the market who are not part of the communication network. From now on we call the agents of the previous Section “normal agents”.

**$S(1)$ -players.** This type of agent is the same one as in Spiegler’s (2006) “market for quacks”.  $S(1)$ -players reason anecdotally rather than probabilistically.<sup>15</sup> They belong to the set of agents  $I$  and are part of the communication network. The only difference to normal agents is that  $S(1)$ -players do not run a binomial test in order to find out whether SNF have an impact or not. Instead, a  $S(1)$ -player  $i$  picks in each period  $t$  one message out

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<sup>15</sup>The concept of the  $S(1)$ -routine was introduced by Osborne and Rubinstein (1998). A  $S(1)$ -player  $i$  samples her dataset  $M_{i,t}$  once and a sample point (i.e. a message) is interpreted as a random anecdote. The extension to  $S(\xi)$ -players with  $\xi > 1$  is relatively straightforward in our framework and therefore omitted.

of her set  $M_{i,t}$ . If this message is positive, she believes in SNF, if it is negative, she does not. If  $M_{i,t}$  does not contain any elements, she does not believe in SNF neither. Thus, the probability that this agent believes in SNF in period  $t$  is given by  $\bar{m}_{i,t}$ . Whenever she believes in SNF, she assumes that a loss occurs to her with probability 1 if she cheats and therefore refrains from cheating.

**Strangers.** These agents are not part of the communication network. The only data they receive are own experiences. We assume that they never believe in SNF. Let  $\tilde{I}$  be the set of strangers where  $I \cap \tilde{I} = \emptyset$ . Again, we assume that this set contains a finite and even number of elements.

The rest of the model remains unchanged. When a  $S(1)$ -player or a stranger takes on the role of a seller, she follows the same reasoning as a normal agent. In both roles,  $S(1)$ -players and strangers choose their action randomly with probability  $\varepsilon$ . Define the share of strangers in the population by

$$\lambda = \frac{|\tilde{I}|}{|\tilde{I}| + N}. \quad (13)$$

We first show that our results remain valid if there are no strangers and some (or all) agents are  $S(1)$ -players. Recall that the probability that a  $S(1)$ -player  $i$  believes in SNF and refrains from cheating in period  $t$  equals  $\bar{m}_{i,t}$ . If positive messages reach on average much more agents than negative ones, then a  $S(1)$ -player will behave like a normal agent in most periods. Our main result therefore does not depend on the agents' sophistication as long as all agents are part of a large communication network where messages can reach everyone:

**Proposition 2** *Let each agent  $i \in I$  be either a normal or a  $S(1)$ -player and assume  $\lambda = 0$ . If  $2D(1 - \alpha) > v_2$ , then for given  $L^*, K^* \in \mathbb{N}$  and  $b_L < 1$  we can find  $N^* \in \mathbb{N}$  and a  $\bar{b}_H < 1$ , such that a.s. after finitely many periods each seller offers the insecure contract with probability  $1 - \frac{\varepsilon}{2}$  whenever  $G \in \mathbf{G}(N^*, L^*, K^*)$  and  $b_H > \bar{b}_H$ .*

This can change if there are strangers in the market who cheat sellers whenever possible. As strangers do not influence communication within the network, occult beliefs spread in the population of normal and  $S(1)$ -players. However, the sellers' experience is affected by the presence of strangers in the market: if there are too many of them, it remains on average more beneficial to offer the secure contract, even when normal and

$S(1)$ -players cheat very rarely. If there are only few strangers, then the sellers' experience is hardly affected. This can be derived formally: fix  $\bar{\lambda} \in (0, 1)$  such that the expression

$$\left( (1 - \pi_q) + \pi_q \bar{\lambda} \frac{\varepsilon}{2} + \pi_q (1 - \bar{\lambda}) \left( 1 - \frac{\varepsilon}{2} \right) \right) \frac{v_q}{2} \quad (14)$$

takes on the same value for  $q \in \{1, 2\}$ . (14) represents the expected payoff of contract  $(v_q, \pi_q)$  for a seller if  $\lambda = \bar{\lambda}$  and cheating does not appear rational to all normal and  $S(1)$ -players. If  $\lambda \geq \bar{\lambda}$ , then, on average, sellers earn less with the insecure contract than with the secure contract. Therefore, the probability that a seller offers the secure contract approaches  $\frac{\varepsilon}{2}$ . Assume now that  $\lambda < \bar{\lambda}$ . As in the proof of Proposition 3, we can show that (almost surely) after finite time (i) cheating does not appear rational to normal agents and (ii)  $S(1)$ -players will cheat with a probability little above  $\frac{\varepsilon}{2}$ , given that  $b_H$  is sufficiently close to unity and the communication network is sufficiently large. Sellers again learn that, on average, the insecure contract is more beneficial to them and offer it with probability  $1 - \frac{\varepsilon}{2}$  in later periods. We thus can state:

**Corollary 3** *Let each agent  $i \in I$  be either a normal or a  $S(1)$ -player. (i) If  $\lambda \geq \bar{\lambda}$ , then a.s. after finitely many periods each seller offers the secure contract with probability  $1 - \frac{\varepsilon}{2}$ . (ii) If  $2D(1 - \alpha) > v_2$  and  $\lambda < \bar{\lambda}$ , then for given  $L^*, K^* \in \mathbb{N}$  and  $b_L < 1$  we can find  $N^* \in \mathbb{N}$  and a  $\bar{b}_H < 1$ , such that a.s. after finitely many periods each seller offers the insecure contract with probability  $1 - \frac{\varepsilon}{2}$  whenever  $G \in \mathbf{G}(N^*, L^*, K^*)$  and  $b_H > \bar{b}_H$ .*

Therefore, our results are robust against the presence of some strangers in the market. Note that the spread of occult beliefs has a positive externality on strangers who also take on the role as sellers and learn in the same way as normal and  $S(1)$ -players. However, if there are too many strangers, beliefs in SNF still will spread in some part of the population, but this does not have a positive effect on market outcomes.

## 4 Discussion

*“Another positive aspect of the [African] belief is that once people fear that their neighbor or relative may apply magic [...] against them, they are likely to refrain from certain offences [...]” (Mbiti 1975: 168)*

We developed our theory in the context of an informal economy. Agents in the informal sector usually have only limited access to legal enforcement. They do not pay taxes and therefore receive only little, if any, government support (Ray 1998). Most transactions among the poor take place within the informal sector. For Africa, the (nonagricultural)

employment share of the informal workforce is about almost 80 percent. Individuals are generally relying on oral agreements.

For an informal economy enforcement mechanisms without the use of law play an important role. We showed under what circumstances occult beliefs can serve as such a mechanism. However, we also observed that its efficacy was limited by (i) the size and structure of the communication network, (ii) the frequency of communication, in particular  $b_H$ , (iii) the probability of misfortune  $\alpha$  and the loss  $D$ , and (iv) whether or not there are too many strangers in the market who do not fear punishment by SNF. The game-theoretic literature knows many ways how to encourage cooperative behavior via repeated interaction and community enforcement. We therefore might ask what advantage(s) the fear of supernatural punishment has against these traditional forms of enforcement.

Repeated interaction can support efficient outcomes if the gains from cheating are lower than the long-term payoff from cooperation. A precondition for these mechanisms to work is that individuals are sufficiently patient. However, it is argued that the poor are less patient as present needs seem more important than future savings (Poulos and Whittington 2000). Furthermore, the concept of time is different from the western model in many parts of the world. Mbiti (2008) finds that in African societies “time is a two-dimensional phenomenon, with a long past, a present and virtually no future. [...] People set their minds not on future things, but chiefly in what has taken place.” Therefore, the ability to play strategies for building up long-term relationship is probably low in African informal economies.

Another mechanism that can ensure cooperative behavior is community enforcement. There exists an extensive theoretical and empirical literature on this topic.<sup>16</sup> Under community enforcement a deviating agent is punished not by the victim, but by a third party that has received information about her past behavior. Additionally to the agents’ patience, community enforcement requires that (i) information about cheating is transmitted to sufficiently many members of the community and (ii) it is in the best interest of agents to punish a deviator (even if they have to forgo a profitable trading-opportunity).<sup>17</sup> Both requirements are highly critical in our context. Dixit (2003, 2004) shows that community enforcement loses its efficacy if the population grows too large such that informa-

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<sup>16</sup>The theoretical literature was initiated by Ellison (1992) and Kandori (1992). Dixit (2004) contains a nice summary with many empirical examples. For empirical studies, see Greif (1993), Gambetta (1993), Anderson et al. (2009), Schaeffer (2008). A number of papers documents the workings of community enforcement in experimental settings, see Fehr and Gächter (2000), Fehr and Fischbacher (2004) and Bernhard et al. (2006).

<sup>17</sup>Fafchamps (2006) introduces the meta-punishment problem but still relies on the need of a signal revealing the actor’s type that must be transmitted or reported.

tion about cheating does not reach sufficiently many agents. Empirically, there exists only little evidence, neither about third-party punishment among African traders, nor about the fact that information sharing improves cooperative behavior (Fafchamps 2004, 2006; Mullainathan 2004). Another reason for information sharing to be ineffective is the fear of giving up valuable informational edges by diffusing insights of contract breaches (Fafchamps 2004). Furthermore, many informal traders think that other’s dishonest behavior is simply not of their business (Fafchamps 2006).

In contrast to repeated interaction and community enforcement, the fear of supernatural punishment as enforcement mechanism has completely different requirements. Specifically, interaction of individuals can be of one-shot nature, individuals are not required to be patient, as the “punishment by supernatural forces” is supposed to be exercised in the near future, no particular strategy is needed to “exercise” this punishment, and the size of the population can be (and should be) very large. The contents of messages are rather gloomy stories than competition-relevant information. Communication is costless or even beneficial for the sender and future business is not affected adversely by a competitive advantage of the recipient. We therefore conclude that occult beliefs may alleviate social dilemma situations whenever traditional forms of contract enforcement fail.

## 5 Related Literature

Our model relates to several strands of the literature on learning and communication. The literature on learning in games describes under what circumstances agents’ behavior converges to Nash play.<sup>18</sup> Several papers analyze to what extent false beliefs (or “superstitions”) about play off the equilibrium path can persist even if agents learn rationally. Fudenberg and Levine (2006) show for a class of games that superstitions can survive even if agents are very patient and can experiment infinitely often. The intuition behind this result is that some information nodes of the game are reached only rarely, therefore it does not pay off for agents to learn what happens if they deviate at this information nodes from the action that appears rational to them given their (wrong) beliefs. In our model, superstitions would not survive if agents would use only own observations to identify the true state of nature. However, they also include the experiences of others into their data set (which would be perfectly rational in the absence of the communication bias). A small communication bias then leads to wrong beliefs despite receiving infinitely many messages.

A substantial literature analyzes learning via communication and informational cas-

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<sup>18</sup>See Fudenberg and Levine (1998, 2008) for a summary of these theories.



cares.<sup>19</sup> Recently, networks have been used to add more structure to this process. In DeMarzo et al. (2003) individuals exchange their beliefs about an unknown parameter in a social network. It is assumed that they fail to adjust properly for repetitions of information and therefore suffer from a “persuasion bias”. As a result, an agent’s impact on the belief formation process of others does not only depend on the accuracy of her information, but also on how well connected she is. Golup and Jackson (2009) show how boundedly rational agents converge to fully rational beliefs when information is decentralized. There, agents use an updating rule introduced by DeGroot (1974): the new belief of two agents who exchange information equals the average of their pre-meeting beliefs. Acemoglu et al. (2009) provide a model where agents may converge to wrong beliefs when there are “forceful” agents who influence other agents by more than other agents influence them.

In contrast to this literature, we consider a setting where agents collect information and draw statistical inference from this data set. In particular, agents account for repetitions of information. We connect the process of belief formation to a game, which is played simultaneously in the population and where the outcomes of this game again influence the belief-formation process. Our goal is not to show how irrational agents succeed in learning the true underlying state of nature, but to demonstrate how rational agents get to a wrong conclusion about their environment and persistently choose actions that are strictly dominated.

## 6 Conclusion

We propose a theory that explains why almost perfectly rational agents, who are able to apply statistical methods, start to believe in a causal relationship between unrelated events. The trigger of this result is a small bias in the agents’ conversational behavior: an agent, who is convinced that a causal relationship between two events exists, communicates messages that confirm her belief with higher probability than messages contradicting it. If messages are sent through a network with few paths between any two agents, then this network aggregates individual biases: messages that confirm a common belief reach on average more agents than messages that contradict it. Therefore, each agent may find a strong relationship between unrelated events even if the communication bias is small.

We applied this model to rationalize the spread and persistence of beliefs in supernatural forces, which play an important role in many low-income countries. In an informal

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<sup>19</sup>See, for example, Bikhchandani et al. (1992), Banerjee (1993), Bala and Goyal (1998), Banerjee and Fudenberg (2004).

economy, where agents do not have access to legal enforcement, the spread of occult beliefs may enable efficient trade if agents fear punishment by supernatural forces. We therefore provide an alternative model of informal contract enforcement, which does not rely on the agents' patience or willingness to share information (as in models of repeated interaction and community enforcement). This result also holds if agents reason anecdotally (instead of applying statistical methods). However, it relies on the fact that there are not too many agents in the market who are immune against occult beliefs and cheat whenever possible.

One has to note that any connection between two classes of random events can be used to construct an occult belief that spreads in the population. Therefore, occult beliefs are very flexible and their welfare effects highly ambiguous. On the one hand, they can contribute to the solution of a social dilemma as discussed in this paper. On the other hand, the evil side of occultism must not be neglected. The fear of occult punishment also can lead to increased distrust among agents and promote anti-social behavior such as violence against elderly women (Sanders 2003, Miguel 2005). Ashforth (2004) specifies this problem as "spiritual insecurity". A welfare loss can occur if individuals spend substantial resources on worthless treatments by "healers" or "quacks" who promise to apply supernatural forces in order to cure patients. Future theoretical and empirical research might address the question to what extent occult beliefs help people to substitute weak institutions and under what circumstances they harm social welfare.

Our results may illuminate many situations where rational agents hold strange beliefs. Take for example a stock market. Let there be a considerable population of agents who believe that future stock prices can be derived from past stock prices by using some statistical technique. Now assume that these agents exchange messages about their techniques, successes and failures. It is quite intuitive that they might be exposed to the communication bias. Messages about successes are more likely to be communicated than messages about failures. Consequently, agents will find that the use of some techniques is highly correlated with financial success even if their own experiences are mostly characterized by failure.

## 7 Appendix

### 7.1 Proof of Lemma 1

Consider an agent  $i \in I \setminus \{i^*\}$ . We derive a lower boundary on the expected share of positive messages in the set  $M_{i,t+1} \setminus M_{i,t}$ . Define  $p_{i,j}^{l,t}(b_L, b_H)$  as the probability that a message  $(j, l, t)$ ,  $j \in I \setminus \{i\}$ , is received by agent  $i$  given that agent  $j$  sends the message

to her neighbors. This probability depends on which agents believe in SNF and which do not in period  $t$ . However, we can estimate

$$0 < p_{i,j}^{0,t}(b_L, b_H) \leq p_{i,j}^{1,t}(b_L, b_H) \leq 1 \quad (15)$$

for all  $t$  and all  $j \in I \setminus \{i\}$ . The probability that an agent  $j \in I \setminus \{i\}$  gets cheated in period  $t$  is in the interval  $[\frac{1}{4}\pi\varepsilon, \frac{1}{2}\pi(1 - \frac{\varepsilon}{2})]$ . As  $G$  is connected, a lower boundary on the expected share of positive messages in the set  $M_{i,t+1} \setminus M_{i,t}$  is given by

$$\frac{\#m_{i,t}^1}{\#m_{i,t}} > \alpha, \quad (16)$$

where

$$\#m_{i,t}^1 = \frac{1}{2}\pi \left(1 - \frac{\varepsilon}{2}\right) \left(\alpha + \sum_{j \in I \setminus \{i, i^*\}} \alpha b_H p_{i,j}^{1,t}(b_L, b_H)\right) + \frac{1}{4}\pi\varepsilon \alpha b_H p_{i,i^*}^{1,t}(b_L, b_H), \quad (17)$$

$$\begin{aligned} \#m_{i,t} &= \frac{1}{2}\pi \left(1 - \frac{\varepsilon}{2}\right) \left(1 + \sum_{j \in I \setminus \{i, i^*\}} (\alpha b_H p_{i,j}^{1,t}(b_L, b_H) + (1 - \alpha) b_H p_{i,j}^{0,t}(b_L, b_H))\right) \\ &\quad + \frac{1}{4}\pi\varepsilon (\alpha b_H p_{i,i^*}^{1,t}(b_L, b_H) + (1 - \alpha) b_L p_{i,i^*}^{0,t}(b_L, b_H)). \end{aligned} \quad (18)$$

As  $N$  is finite, it follows from (15) and the strong law of large numbers (SLLN) that

$$\liminf_{t \rightarrow \infty} \bar{m}_{i,t} > \alpha + o \quad a.s. \quad (19)$$

for some small  $o > 0$ . As cheating never stops, we have

$$\lim_{t \rightarrow \infty} |M_{i,t}| = \infty \quad a.s. \quad (20)$$

and therefore

$$\lim_{t \rightarrow \infty} z_{i,t} = \infty \quad a.s. \quad (21)$$

for each agent  $i \in I \setminus \{i^*\}$ .

## 7.2 Proof of Lemma 2

Let  $W_{ij}$  be the set of paths between agent  $i$  and agent  $j$ , where  $d(i, j) = n$ . Let  $K \in \mathbb{N}$  be the number of elements in  $W_{i,j}$ . By assumption we have that  $K \leq K^*$ . Now order all elements in  $W_{i,j}$  with respect to their length  $d(w_{i,j})$ , i.e.

$$d(w_{i,j}^1) \leq d(w_{i,j}^2) \leq \dots \leq d(w_{i,j}^K). \quad (22)$$

We now compute the probability  $p_{i,j}^l$  that a message  $(j, l, t)$  is received by agent  $i$ , given that all agents believe in SNF in period  $t$ . Let  $\gamma(x, y)$ ,  $x, y \leq K$ , be the number of agents

which are both in  $w_{i,j}^x \setminus \{i\}$  and  $w_{i,j}^y \setminus \{i\}$ . Note that  $\gamma(x, y) \geq 1$ . The probability that  $(j, l, t)$  is communicated by all agents in  $w_{i,j}^1 \setminus \{i\}$  is given by

$$b_l^{d(w_{i,j}^1)}. \quad (23)$$

The probability that  $(j, l, t)$  is communicated by all agents in  $w_{i,j}^2 \setminus \{i\}$ , but not by all agents in  $w_{i,j}^1 \setminus \{i\}$  is given by

$$b_l^{d(w_{i,j}^2)} \left(1 - b_l^{d(w_{i,j}^1) - \gamma(1,2)}\right). \quad (24)$$

Proceeding in this fashion we derive that the probability that  $(j, l, t)$  is communicated by all agents in  $w_{i,j}^y \setminus \{i\}$ ,  $y \leq K$ , but not by all agents in  $w_{i,j}^x \setminus \{i\}$ ,  $x \in \{1, \dots, y-1\}$ , is given by

$$b_l^{d(w_{i,j}^y)} \prod_{x=1}^{y-1} \left(1 - b_l^{d(w_{i,j}^x) - \gamma(x,y)}\right). \quad (25)$$

We therefore obtain

$$p_{ij}^l = b_l^{d(w_{i,j}^1)} + \sum_{y=2}^K \left( b_l^{d(w_{i,j}^y)} \prod_{x=1}^{y-1} \left(1 - b_l^{d(w_{i,j}^x) - \gamma(x,y)}\right) \right). \quad (26)$$

Rewrite this term as

$$p_{ij}^l = b_l^{d(w_{i,j}^1)} \left[ 1 + \sum_{y=2}^K \left( b_l^{d(w_{i,j}^y) - d(w_{i,j}^1)} \prod_{x=1}^{y-1} \left(1 - b_l^{d(w_{i,j}^x) - \gamma(x,y)}\right) \right) \right]. \quad (27)$$

As  $d(w_{i,j}^1) = n$ , we have

$$\frac{p_{i,j}^0}{p_{i,j}^1} \leq \left( \frac{b_L}{b_H} \right)^n K. \quad (28)$$

With this it follows from Bayes' rule that

$$P^n(b_L, b_H) \geq \max \left\{ \frac{\alpha}{\alpha + (1 - \alpha) \left( \frac{b_L}{b_H} \right)}, \frac{\alpha}{\alpha + (1 - \alpha) \left( \frac{b_L}{b_H} \right)^n K^*} \right\}. \quad (29)$$

### 7.3 Proof of Proposition 1

From Lemma 1 it follows that is almost surely a finite period  $t^*$  such that in all periods after  $t^*$  all agents believe in SNF. In the following, we analyze what happens in periods  $t \geq t^*$ . Choose  $m'' \in (m', 1)$  and a  $\bar{M} < 1$  such that

$$\bar{M}m'' + (1 - \bar{M})\alpha > m'. \quad (30)$$

From Lemma 2 it follows that we can choose a  $\bar{n}$  such that for any  $n \geq \bar{n}$  it holds that  $P^n(b_L, b_H) > m''$ . Consider an agent  $i \in I \setminus \{i^*\}$  and define the sets

$$N_{i,c}(y) = \bigcup_{\tilde{y}=1}^{y-1} i(\tilde{y}), \quad (31)$$

$$N_{i,d}(y) = \bigcup_{\tilde{y}=y}^{\infty} i(\tilde{y}). \quad (32)$$

If for each agent the number of direct neighbors is limited to  $L^*$ , we have for each  $y \in \mathbb{N}$  that  $|N_{i,d}(y)| \rightarrow \infty$  for  $N \rightarrow \infty$ , while  $|N_{i,c}(y)|$  is limited. In all periods the probability that an agent gets cheated is in the interval  $[\frac{1}{4}\pi\varepsilon, \frac{1}{2}\pi(1 - \frac{\varepsilon}{2})]$ . Therefore, a lower boundary on the expected share of messages about agents  $j \in N_{i,d}(\bar{n})$  in the set  $M_{i,t+1} \setminus M_{i,t}$  for  $t \geq t^*$  is given by

$$\frac{\frac{1}{4}\pi\varepsilon \sum_{n \geq \bar{n}} |i(n)| \alpha b_H^n}{\frac{1}{4}\pi\varepsilon \sum_{n \geq \bar{n}} |i(n)| \alpha b_H^n + \frac{1}{2}\pi(1 - \frac{\varepsilon}{2}) |N_{i,c}(\bar{n})|}. \quad (33)$$

For  $b_H \rightarrow 1$  this expression becomes

$$\frac{\frac{1}{4}\pi\varepsilon |N_{i,d}(\bar{n})|}{\frac{1}{4}\pi\varepsilon |N_{i,d}(\bar{n})| + \frac{1}{2}\pi(1 - \frac{\varepsilon}{2}) |N_{i,c}(\bar{n})|}. \quad (34)$$

Thus, if  $N$  and  $b_H$  are sufficiently large, then in each period  $t \geq t^*$  the expected share of messages about agents  $j \in N_{i,d}(\bar{n})$  in the set  $M_{i,t+1} \setminus M_{i,t}$  exceeds  $\bar{M}$ . Consequently, we get from the SLLN that

$$\liminf_{t \rightarrow \infty} \bar{m}_{i,t} > \bar{M}m'' + (1 - \bar{M})\alpha \quad a.s.$$

## 7.4 Derivation of (6)

Assume that there is a finite period  $t^*$  such that in all periods  $t \geq t^*$  all agents believe in supernatural powers and we have  $2D(\bar{m}_{i,t} - \alpha) > v$  for all  $i \in I$ . Then each agent gets cheated with probability  $\frac{1}{4}\pi\varepsilon > 0$  in a period  $t \geq t^*$ . As the communication network is a circle and  $N$  is an even number, we have

$$|i(1)| = |i(2)| = \dots = \left| i \left( \frac{N-2}{2} \right) \right| = 2 \text{ and } \left| i \left( \frac{N}{2} \right) \right| = 1 \quad (35)$$

for each agent  $i \in I$ . We use (27) from the proof of Lemma 2 to calculate the probability that agent  $i$  receives a positive message (given that this message has been created) about agent  $j \in i(n)$ ,  $1 \leq n \leq \frac{N}{2}$ . It is  $b_H^n + (1 - b_H^{n-1})b_H^{N-n}$ . Observe that

$$\sum_{n=1}^{\frac{N-2}{2}} b_H^n + (1 - b_H^{n-1})b_H^{N-n} = \frac{b_H - b_H^N}{1 - b_H} - b_H^{\frac{N}{2}} - \frac{N-2}{2} b_H^{N-1}. \quad (36)$$

The expected number of positive messages agent  $i$  receives in some period is therefore

$$\frac{1}{4}\pi\varepsilon\alpha\left(1+\frac{2(b_H-b_H^N)}{1-b_H}-(N-3)b_H^{N-1}\right), \quad (37)$$

while the expected number of negative messages agent  $i$  receives in some period is

$$\frac{1}{4}\pi\varepsilon(1-\alpha)\left(1+\frac{2(b_L-b_L^N)}{1-b_L}-(N-3)b_L^{N-1}\right). \quad (38)$$

As the ratio between (37) and (38) strictly increases in  $N$ , we get by using L'Hospitals rule and the SLLN

$$\lim_{t\rightarrow\infty}\bar{m}_{i,t}\leq\frac{\alpha}{\alpha+(1-\alpha)\frac{(1+b_L)(1-b_H)}{(1+b_H)(1-b_L)}} \quad a.s. \quad (39)$$

for all agents  $i\in I$ .

## 7.5 Proof of Corollary 2

Define

$$\pi'_1=\min\left\{\max\left\{\pi_1,\frac{\varepsilon}{2}\pi_2\right\},\frac{\varepsilon}{2}\pi_2\right\}. \quad (40)$$

Clearly, we have that  $\pi'_1>0$ . In all periods the probability that an agent gets cheated is in the interval  $[\frac{1}{4}\pi'_1\varepsilon,\frac{1}{2}\pi_2(1-\frac{\varepsilon}{2})]$ . Using this fact, one can go through the same steps as in the proof of Lemma 1 to show that  $\lim_{t\rightarrow\infty}z_{i,t}=\infty$  a.s. for all  $i\in I$ . If  $2D(1-\alpha)>v_2$ , we can choose a  $m'<1$  such that  $D(m'-\alpha)>\frac{v_2}{2}$ . One then can go through the same steps as in the proof of Proposition 1 to show that for given  $L^*,K^*\in\mathbb{N}$  and  $b_L<1$  we have  $\lim_{t\rightarrow\infty}\inf\bar{m}_{i,t}>m'$  a.s. for each  $i\in I$  whenever  $N$  and  $b_H$  are sufficiently large. In this case, there is almost surely a finite period  $t^*$  such that in all periods  $t\geq t^*$  it appears rational to all agents not to cheat, regardless of what contract is offered to them. As each agent offers in each period each contract with positive probability, we get from the SLLN

$$\lim_{t\rightarrow\infty}\mu_{i,t}^q=1-\frac{\varepsilon}{2} \quad a.s. \quad (41)$$

for all  $i\in I$  and  $q\in\{1,2\}$ . The result then follows directly from (10).

## 7.6 Proof of Proposition 2

Note that for any normal agent  $i\in I$  it holds that

$$\lim_{t\rightarrow\infty}z_{i,t}=\infty \quad a.s. \quad (42)$$

and that for any  $S(1)$ -player  $j\in I$  it holds that

$$\lim_{t\rightarrow\infty}\inf\bar{m}_{j,t}>\alpha \quad a.s. \quad (43)$$

which follows by going through similar steps as in the proofs of Lemma 1 and Proposition 2. Thus, there is almost surely (i) a finite period  $t^*$  such that in all periods  $t \geq t^*$  all normal agents believe in SNF, and (ii) a finite period  $t^{**}$  such that in all periods  $t \geq t^{**}$  the probability with which a  $S(1)$ -player believes in SNF is at least  $\alpha$ . We now consider adjustments after period  $\max\{t^*, t^{**}\}$ . Consider a group of  $n$  agents. The probability that  $y \leq n$  of these agents believe in SNF in a period  $t \geq \max\{t^*, t^{**}\}$  is at least

$$\binom{n}{y} \alpha^y (1 - \alpha)^{n-y}. \quad (44)$$

Define  $\tilde{P}^n(b_L, b_H)$  as the probability that a message about some agent  $j \in I$ , which is received by another agent  $i$ , is positive, given that  $d(i, j) = n$  and  $t \geq \max\{t^*, t^{**}\}$ . By going through the same steps as in Lemma 2, we see that

$$\tilde{P}^n(b_L, b_H) \geq \max \left\{ \alpha, \sum_{y=0}^n \binom{n}{y} \alpha^y (1 - \alpha)^{n-y} \frac{\alpha}{\alpha + (1 - \alpha) \left(\frac{b_L}{b_H}\right)^y K^*} \right\}. \quad (45)$$

Observe that  $\tilde{P}^n(b_L, b_H)$  approaches unity as  $n$  grows large. The result then follows by going through the same steps as in the proof of Proposition 1.

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