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The value of reputation

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Reputation plays a central role in human societies. Empirical and theoretical work indicates that a good reputation is valuable in that it increases one's expected payoff in the future. Here, we explore a game that couples a repeated Prisoner's Dilemma (PD), in which participants can earn and can benefit from a good reputation, with a market in which reputation can be bought and sold. This game allows us to investigate how the trading of reputation affects cooperation in the PD, and how participants assess the value of having a good reputation. We find that depending on how the game is set up, trading can have a positive or a negative effect on the overall frequency of cooperation. Moreover, we show that the more valuable a good reputation is in the PD, the higher the price at which it is traded in the market. Our findings have important implications for the use of reputation systems in practice.

Keywords: evolution of cooperation; reciprocal altruism; indirect reciprocity; reputation

1. INTRODUCTION

Reputation is a piece of public information that summarizes how a person behaves towards others. Individuals often invest substantial resources to maintain a good reputation. These costs are incurred because having a good reputation is valuable: empirical and theoretical studies from evolutionary game theory and economics indicate that having a good reputation increases one's expected payoff in future interactions with others [1–6]. Therefore, reputation can incentivize cooperative behaviour, i.e. behaviour that is individually costly, but socially beneficial. This function of reputation has been formalized in the framework of indirect reciprocal altruism [4,7–12]. Within this framework, one can quantify the theoretical value of having a good reputation [4]. Here, we examine a game where reputation can be earned in a repeated Prisoner's Dilemma (PD), but can also be bought and sold on a market. This game allows us to investigate how the trading of reputation affects the level of cooperation in the PD, and how people assess the material value of reputation.

In our experiments, players engage in a series of two-player PD games with different partners. In each round, players are randomly paired, and simultaneously choose between cooperation (C) and defection (D). Cooperation decreases one's payoff by a cost c, but increases the other player's payoff by a benefit b ($b > c$; we use $b = 30$ and $c = 10$). Defection has no effect on either payoff. Previous experiments exploring reputation in repeated PDs and related games [6,13–17] have established that giving information about a co-player's decision history promotes cooperation; and giving more information can lead to higher frequencies of cooperation [16]. In these experiments, it is typically left to the participants to assess a partner's reputation based on past history of play, and to then choose an action accordingly. With such a set-up, it is ambiguous how subjects are using the reputational information, and it is therefore impossible to calculate a well-defined theoretical value of a good reputation.

We resolve this ambiguity by assigning each player an explicit reputation that is either 'good' or 'bad'. The assignment depends on the player's behaviour in the previous round and is based on an assignment rule that is known to all players. Our choice of assignment rule is based on the seminal theoretical work of Ohtsuki & Iwasa [4,18,19]. To establish and maintain cooperation, assignment rules must take into account a player's action within the context of both the player's own reputation and the partner's reputation. We use two specific assignment rules that are derived from the social norm 'standing' (figure 1). 'Standing' assigns a good reputation to players that cooperate, except when a player in good reputation meets a player in bad reputation [8]. Here, the good player must defect to maintain good reputation. This social norm prescribes withholding cooperation from bad players, and thereby creates an incentive to maintain a good reputation.

To introduce trading, players are given the opportunity to change their reputation in trading rounds before and after each PD. Players in bad reputation can buy a good reputation and players in good reputation can sell their reputation, at a price set by the market.

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	reputation system 1		reputation system 2	
own/other's reputation	reputation after C	reputation after D	reputation after C	reputation after D
G/G	G	B	G	B
G/B	B	G	B	G
B/G	G	B	G	B
B/B	G	B	B	G

When in bad reputation and interacting with someone else in bad reputation, system 1 requires cooperation for obtaining a good reputation. System 2 prescribes defection in this situation.

Figure 1. Assessment rules for the reputation systems used in our experiments. C and D stand for cooperation and defection, G and B for a good and bad reputation. Assessment rules determine the reputation based on the last action of a player, her own reputation and the opponents' reputation. Eight of such third-order assessment rules, named the 'leading eight', have been demonstrated in theory to sustain a high level of cooperation [4]. The leading eight share a number of properties: When playing with a player in good reputation, cooperation results in a good reputation, while defection results in a bad reputation; and a player in good reputation can defect against a player in bad reputation without losing the good reputation. They differ in the way how an interaction between two bad players is evaluated, and how cooperation of a good player towards a bad player is evaluated. In our experiment, we use a reputation system referred to as 'standing' (reputation system 1). This system assigns a good reputation to players that cooperate, except when a player in good reputation meets a player in bad reputation. In this case, the good player must defect to stay in good reputation. We also use an alternative system (reputation system 2) that differs from the first system in how interactions between two bad players are evaluated. The maxim of this system could be expressed as 'Cooperate with those in good reputation, and refuse to cooperate with those in bad reputation. Then, and only then, your reputation will be good.'

Trading is facilitated by a market maker that always allows players to buy or sell reputation and converges towards stable prices when the supply of reputation meets the demand. The game is investigated in experiments with stochastic end and in finite-length games. We particularly focus on the impact of trading on the levels of cooperation, and on the relation between the price and the theoretical value of having a good reputation. Theoretical properties of the game are described in the electronic supplementary material.

2. RESULTS

2.1. Experiments with stochastic end

We first perform an experiment to demonstrate the effectiveness of a reputation system without trading. Participants repeatedly play PD games with different players. When choosing their action in the PD, the only information they have about their partner is the partner's reputation. After each interaction, the reputation of all players is updated according to the 'standing' assessment rule (see reputation system 1 in figure 1). We use a game with stochastic end to eliminate 'end-game effects' that arise in finite-length games [20,21] and can prevent cooperative strategies from being successful: subjects are informed that after each round, another PD with a new partner will be played with a probability of 95 per cent; otherwise the experiment ends. For such a rule, the expected number of additional PD games that will be played before the experiment ends does not depend on how many round have already been played. Further details on our experimental setting are given in §4 and the electronic supplementary material.

We observe that cooperation emerges and is maintained at a high frequency of roughly 80 per cent over the course of the experiment (figure 2*a*). Thus, most participants are in good reputation (figure 2*b*). The frequency of cooperation is below 100 per cent both because players occasionally make a move that is probably erroneous (players in good reputation, for instance, occasionally cooperate with players in bad reputation), and because there is a small fraction of players that unconditionally opt for defection. The strategies used by the participants largely follow theoretical expectations (see the electronic supplementary material). In a control experiment, where no reputation information of the co-player is provided, cooperation starts at intermediate levels, but quickly drops to an average frequency below 20 per cent (figure 2*a*). These findings are in line with previous experiments on reputation and indirect reciprocity [6,13–17] and show that information regarding the opponent's reputation as given in our experiments can maintain high levels of cooperation.

We next perform a set of experiments in which participants can trade reputation in trading rounds that occur between each PD round. In the trading rounds, participants have the opportunity to buy or sell their good reputation in a market. To provide sufficient liquidity, we use a simple market maker that allows participants to buy or sell at any point in time during the trading round without having an immediate counterparty among the other participants: players in bad reputation are offered to pay a price X to change their reputation to 'good'; while players in good reputation can receive $X - \Delta$ for changing their reputation from 'good' to 'bad'. Whenever a participate sells her good reputation to the market maker, the price decreases from X to $X - \Delta$; and when reputation is bought, the price increases from X to $X + \Delta$. We use a step size of $\Delta = 2$, and an initial price of $X = 40$. Such a high initial price allows us to investigate whether prices move towards an equilibrium. (If we instead used a starting price close to equilibrium, convergence could not be demonstrated as easily.) The market maker, therefore, requires a number of trades to converge towards stable prices, and thus a high trading activity is important for the markets to accurately reflecting the value of a good reputation in the PD.

We observe frequent trading in this setting. Participants traded their reputation on average 7.5 times over the course of an experiment; and thus, per group of eight players there were on average 90 trades (median 69; range from 42 to 195). Average prices

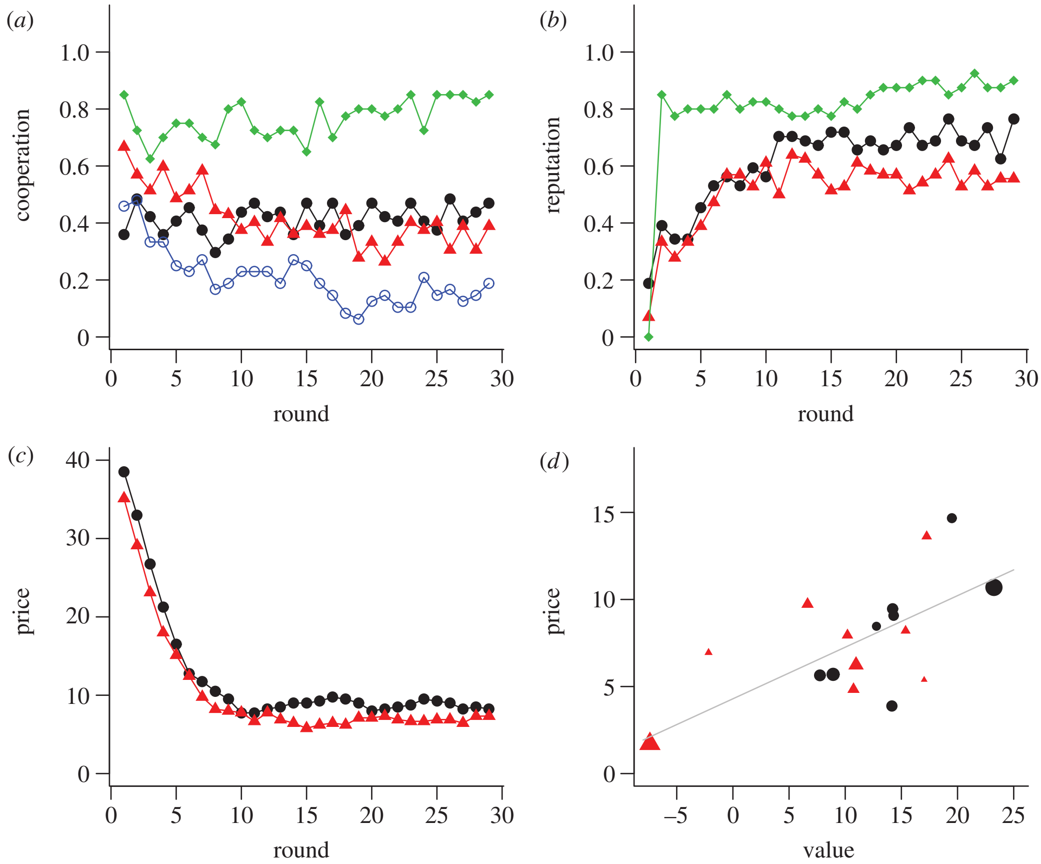

Figure 2. (a,b) Dynamics of cooperation and reputation over the course of the experiments. The experiment for reputation system 1 without trading is shown in green, the control without any reputational information in blue. Reputation system 1 with trading is shown in red, and the alternative system with trading is shown in black. Cooperation is highest in the absence of trading, and lowest in the control without reputational information. In the presence of trading, the frequency of cooperation stabilizes at about 40% for both reputation systems. The participants in our experiments start with a bad reputation, but quickly establish a high frequency of good reputation. (c) Market prices for a good reputation. A market maker is used to facilitate trading and adjusts the prices depending on supply and demand. The market maker price for obtaining a good reputation is initially set to 40. Prices drop rapidly as participants at the beginning of the experiment often sell their reputation in order to exploit the initial overpricing. After about 10 rounds, the prices equilibrate. The price dynamics and the trading volume are similar for both reputation systems. (d) Average market prices for a good reputation versus theoretical value. For each group, average prices and theoretical values for a good reputation are calculated from the strategies and prices observed after round 10, when prices tend to be stable. In the electronic supplementary material, section 5 it is described in detail how the theoretical values are calculated. The size of the symbols scales with the number of trades made in a group. Note that the value of having a good reputation can even become negative when participants preferentially cooperate with players in bad reputation, as is observed in two experiments (see the electronic supplementary material). We observe a strong positive correlation between price and value. This suggests that the participants are capable of responding correctly to the value of a good reputation.

stabilized rapidly within the first 10 rounds (figure 2c), as did the average level of cooperation and the fraction of participants in good reputation (figure 2a,b). The level of cooperation in this setting is lower than in the setting without trading (logistic regression at the level of the cooperation decision, clustered on group to account for the non-independence of observations from subjects in the same group; coefficient $= -1.5$, $p < 0.001$), but higher than in the control setting without any reputational information (coefficient $= 1.0$, $p = 0.004$; figure 2 and §4). Thus, while cooperation can be maintained in the presence of a market for reputation, as is predicted by theory (see the electronic supplementary material), trading has an adverse effect on cooperation levels. Reasons for such an adverse effect are discussed below.

There is substantial variance in the emerging price and in the level of cooperation between different groups of participants. This between-group variance in pricing and behaviour allows us to assess whether there is a relation between the prices at which a good reputation is traded in the market and the theoretical value it has in the PD. This theoretical value depends on the behaviour of the participants in the PD and on the specific assessment rules used in the reputation system; details about how the theoretical value is estimated are given in the electronic supplementary material, §5. In essence, the more likely participants within a group are to preferentially cooperate with partners in good reputation, the more valuable a good reputation is, and the higher the price is expected to equilibrate in the market. In line with this expectation, we find a positive correlation between price and value (nine groups, linear regression, coefficient $= 0.27$, $R^2 = 0.49$, $p = 0.037$). Average within-group prices and theoretical values are shown in figure 2*d*, and details on the statistical analysis are given in §4.

To test whether the relationship between price and value is robust, we also examine a second, modified reputation system. In our first reputation system, two players in a 'bad' reputation must cooperate with each other to earn a good reputation. We now use a second system where two 'bad' players must defect against each other to earn a good reputation (figure 1). Like the first reputation system, the modified system belongs to the set that can theoretically establish and maintain cooperation [4]. However, the change in the assessment implies different optimal strategies and different theoretical price estimates (see the electronic supplementary material). In line with the modified assessment rule, participants do display different strategies in this alternative reputation system (see the electronic supplementary material). The trading frequency was similar to what we observe for the first reputation system (median 109 trades per group of 12; range from 77 to 190), and despite the different reputation system and behaviour, we again observe a positive correlation between price and theoretical value (eight groups, linear regression, coefficient = 0.42, $R^2 = 0.51$, $p = 0.046$; figure 2*d* and §4). Taking the results from both reputation systems together, there is strong evidence for a positive relationship between market price and the theoretical value of a good reputation (17 groups, linear regression, coefficient = 0.30, $R^2 = 0.50$, $p = 0.0014$). One potential interpretation of this finding is that participants have an understanding of the monetary value of reputation: in the PD, they gain experience regarding the value of a good reputation over time, and this experience then influences their trading behaviour. Therefore, in groups where the value of a good reputation is higher, the participants trade a good reputation for a higher price. However, we also observe persistent under-pricing in the second half of the experiment, which might indicate an imperfect understanding of the absolute value of a good reputation. Potential reasons for this under-pricing are discussed further below.

2.2. Fixed-length games

While in the game with stochastic end, trading has an adverse impact on the frequency of cooperation, there may also be situations in which trading reputation can actually promote cooperation. One such example is a fixed-length setting where participants enter, interact for a finite number of rounds and then exit the game. Without trading, there is no mechanism in place to incentivize cooperation in the last round, and thus defection is payoff maximizing. Together with the resulting 'backwards induction', one would expect that reputation systems are relatively ineffective in such situations [20,21]. If, however, reputations can be traded, 'end game' effects might be overcome: a good reputation is valuable even after the final round if it can later be sold. (Such a mechanism requires that new participants enter the game each round as old participants leave, or an external, 'benevolent' market maker that offers a positive price even after the last round; see the electronic supplementary material for a theoretical analysis.) For example, business owners who intend to retire might be more inclined to provide a high-quality service if they can subsequently sell their business, because a business in good reputation will obtain a better price than a business in bad reputation [1].

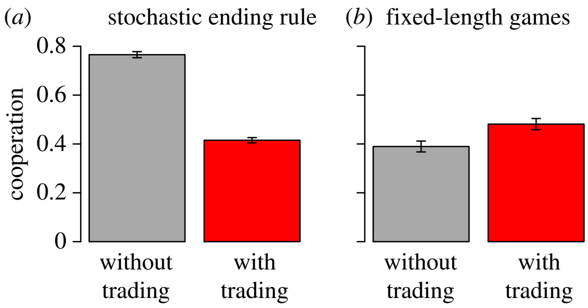

Figure 3. Trading of reputation decreases cooperation in games with stochastic end but increases cooperation in fixed-length games. (*a*) When interacting in short, fixed-length series of Prisoner's Dilemmas, the trading of reputation can increase the frequency of cooperation. (*b*) This is a stark contrast to the games with a stochastic end of experiment. Thus, the trading of reputation can help overcoming problems arising from 'end-game' effects in fixed-length games. Error bars indicate standard error of the mean, clustered on group to account for non-independence of observations from within one group.

To investigate experimentally whether trading can indeed be beneficial for reputation systems, we set up experiments with a fixed number of interactions for each participant (we use four interactions in our experiments; for further details of the experimental set-up, see §4 and electronic supplementary material). Participants enter and leave the reputation system at different points of time, thus giving rise to a long sequence of interactions. In striking contrast to our earlier results with stochastically repeated games, we observe that adding reputation trading leads to significantly more cooperation in this fixed-length setting (logistic regression clustered on group, coefficient = 0.38, $p < 0.001$, figure 3 and §4). Thus, a market for reputation can promote cooperation by mitigating problems arising from end-game effects.

3. DISCUSSION

Our experiments show that the trading of reputation can have a negative or positive impact on the level of cooperation, depending on the details of the setting. In settings with stochastic end, the level of cooperation in the experiments with trading is substantially lower than in the experiments without trading. Such an effect is not expected from our theoretical analysis that shows that cooperative equilibria exist in both games with and without trading. Several factors might contribute to the adverse effects of trading. First, in games with trading, participants might have a lower intrinsic motivation to cooperate. A similar motivational 'crowding out' effect is observed in many real-life situations: people may be less cooperative when receiving direct monetary compensation rather than more implicit intrinsic rewards [22–25]. 'Crowding out' has empirically been demonstrated in the context of blood donations [25], trust in economic experiments [26] and tardiness of child pickups at a daycare centre [24]. Second, when reputation can be traded, it might be perceived as a less reliable marker for the cooperativeness of a player, which in turn may undermine the reputation system and lead to an 'informational' crowding out. A third reason is that when reputation is mispriced in the market, defection is subsidized. If reputation is over-priced, as is the case at the beginning of our experiments, participants have a strong incentive to sell their good reputation. This increases the number of participants in a bad reputation, and thereby subsequently decreases the level of cooperation. Similarly, under-pricing also subsidizes defection, because participants can profit by defecting in the PD and then re-buying a good reputation (see the electronic supplementary material). Interestingly, we observe under-pricing in many of the groups towards the end of our experiment. The reasons for this under-pricing are unclear. Potential factors that might contribute include risk aversion (participants might prefer a guaranteed payoff from the market over an uncertain payoff from the PD), an incorrect perception of the continuation probability of the game towards the end of the experiment, and a hesitancy to trade owing to the mechanisms similar to those behind the no-trade theorem [27]. Exploring these issues further is an important area for future study.

While trading reputation is harmful in settings with stochastic end, our experiments and theoretical analyses suggest that trading can also be beneficial for the functioning of a reputation system, as, for example, in fixed-length games where new players keep entering as old players are leaving, or where a suitable market maker is moderating the trading. Thus, our results can provide guidance for designing and improving reputation systems, particularly in the context of the Internet. Consider, for example, the system used by an online marketplace such as eBay to evaluate sellers. In such a reputation system, a seller who knows he will exit the market soon has little incentive to invest into providing a satisfactory service; while a new seller without a history of transactions is likely to initially make less profitable trades [5]. The trading of reputation could help in both cases: It maintains incentives to be cooperative for sellers that intend to leave, and at the same time helps new sellers get into profitable business. Another context where the trading of reputation is likely to be beneficial involves 'strict' reputation systems. In these systems, one can only gain a good reputation through an interaction with a reputable counter-party. Two individuals with bad reputation can never gain a good reputation from interacting with each other. Such strict reputation systems have a substantial advantage: they prevent non-cooperative individuals from 'gaming the system' by granting each other a good reputation. However, they face a challenge when starting off: If players begin with a bad reputation, then it is very difficult to subsequently establish a high frequency of players with good reputation, and thus it is difficult to reach a high level of cooperation. The trading of reputation may help to jump-start such a strict system. Further theoretical and experimental analysis is required to investigate such a mechanism.

For most people, earning and maintaining a good reputation seems to provide an intrinsic, instinctively satisfying motivation to do good [28–30]. But a good reputation also comes with explicit material value, which might explain why our emotions around reputation have emerged in the context of biological and cultural evolution. This explicit material value is of relevance in many real world economic situations. Credit and driving history can be seen as a part of ones reputation: a good reputation in the appropriate context gives access to less expensive credit and insurance. The opportunity to buy and sell brands and entire companies illustrates that in the corporate world, reputation can be seen as a tradable asset. But even for individuals, mechanisms exist to exchange resources for reputation. Non-anonymous donations to reputable charitable organizations may be seen as a way to polish ones reputation. And there is even some indication that in the context of marriage, resources can be exchanged for reputation, as, for example, when wealthy commoners marry nobility [31]. Our experiments suggest that people are capable of assessing the explicit material value of having a good reputation, even though the persistent under-pricing indicates an imperfect assessment. This capability has fascinating consequences. It provides us, for example, with the capacity to forego social norms and put our reputation at risk when the individual benefits are sufficiently large.

4. MATERIAL AND METHODS

4.1. Participants

Participants were Boston area students recruited by the HBS CLER laboratory, and received a performance-independent fee of USD 10 in addition to the payments earned in the experiment. Written informed consent was obtained from all participants, and the experiments were approved by Harvard University CUHS (F16154-101). During the experiments, which were conducted at the HDSL laboratory, the participants were seated in cubicles and interacted with each others via computer. For implementing the experiments, z-Tree [32] was used. Each participant had an account with an initial endowment of 100 monetary units, equivalent to USD 2. Units were added and subtracted from the account depending on the payoffs earned in the PD interactions and on the trades preformed during trading rounds. We used six different settings: reputation system 1 ('standing') with stochastic ending rule and no trading (S1, five groups, 40 participants); reputation system 1 with stochastic ending rule and trading (S1T, nine groups, 72 participants); reputation system 2 with stochastic ending rule and trading (S2T, eight groups, 64 participants); a control with stochastic end and no reputational information (SC, six groups, 48 participants); reputation system 1 with a fixed number of interactions and no trading (F1); and reputation system 1 with a fixed number of interactions and trading (F1T, 10 groups in cross-design with setting F1, 120 participants).

4.2. Games with stochastic ending (S1, S1T, S2T, SC)

The participants interacted repeatedly within groups of eight. In each round, participants were assigned into random pairs and interacted in a simultaneous PD: Both players have the choice between two options, A and B. The payoff for a player choosing option A is 20 if the other player chooses option A; and −10 if the other player chooses option B. The payoff for a player choosing option B is 30 if the other player chooses option A, and 0 if the other player chooses option B. This corresponds to a PD with $c = 10$ and $b = 30$. Each player has a reputation that is either 'Good' or 'Bad'. When interacting in the PD, players know their own and their opponents' reputation, except in setting SC where no reputational information is provided. They are not, however, provided with identifiers and so cannot track each other across interactions, except by the reputational information we assign. The initial reputation of all players was set to 'Bad'. Reputation was updated depending on a player's choice, the player's own reputation and the opponents' reputation. The assignment rules are shown in figure 1, and were known to the participants. After each round, the player's own choice, the other player's choice, the resulting payoff and the updated reputation were displayed. Players were informed that after each round, there was a 95 per cent chance that there was another interaction, and 5 per cent chance that the experiment ends. We used the same randomization in all our experiments, which ensured that all experiments had the same length (29 rounds). A screenshot of the interface for the PD game is shown in the electronic supplementary material. In the settings with trading (S1T, S2T), participants could trade their reputation in a trading round before the first PD interaction and after each interaction. Participants in 'bad' reputation could buy a 'good' reputation for price X. Participants in 'good' reputation could change their reputation to 'bad' and receive $X - \Delta$ monetary units added to their account. Whenever a participant bought/sold a 'good' reputation, the price X was increased/decreased by Δ. A screenshot of the trading interface is shown in electronic supplementary material, section 1. The initial price was set to $X = 40$, the step size was set to $\Delta = 2$.

4.3. Fixed-length games (F1, F1T)

In the fixed-length game, participants interacted within groups of 12. Each participant interacted in exactly four consecutive rounds with different players. Payoffs and interface were the same as in the setting with stochastic ending rule. Participants entered and left the experiment at different times such that there were nine consecutive trading rounds for each group. An example run is shown in the electronic supplementary material. To avoid a long period of equilibration in this relatively short sequence of PDs, the initial price in the setting with trading was set to 20. Because the fixed-length games were shorter than the games with stochastic end, we could use a cross design for the fixed-length games. Half of the groups started in the setting without trading (F1) and then completed the setting with trading (F1T); while the other half completed the experiments in reverse order.

4.4. Statistical analysis: prices versus value

For each group, we calculate the value of having a good reputation as described in electronic supplementary material, §5, and the average price at which reputation is traded from the data after round 10, at which point behaviour and prices become stable. Because the market maker requires a number of trades to initially converge towards equilibrium prices and requires trading to follow changes in the value of a good reputation, we expect that in groups with many trades, prices are closer to equilibrium. Thus, when analysing the relation between prices and value, we weight the observation from each group by the square root of the number of trades in the group. Using a linear regression between price and value, we find a positive relation between price and value for the standing reputation system (nine groups, coefficient = 0.27, $R^2 = 0.49$, $p = 0.037$), for modified standing (eight groups, coefficient = 0.42, $R^2 = 0.51$, $p = 0.046$), and for the combined data (17 groups, coefficient = 0.30, $R^2 = 0.50$, $p = 0.0014$).

4.5. Statistical analysis: trading and the frequency of cooperation

We use logistic regressions for comparing the level of cooperation depending of whether trading is possible or not, and for comparing the level of cooperation in the setting with trading with the level of cooperation in the absence of reputational information. Our analysis considers each individual decision (0 = D, 1 = C), and clusters at the level of the group to account for the non-independence of observations from within each group. For the games with stochastic end, we observe a strong negative impact of trading (coefficient = −1.5, $p < 0.001$), but a larger frequency of cooperation in the setting with trading compared with the control without reputational information (coefficient = 1.0, $p = 0.004$). For the games with fixed length, we used a cross design, where half the groups started in the setting without trading, and then did the setting with trading, while half the groups did the reverse order. We observe a positive relation between trading and cooperation (coefficient = 0.37, $p = 0.004$, AIC = 1310.6; when including order effects: 0.38, $p = 0.004$, AIC = 1301.0). When including an interaction between order and the presence of trading, the trading effect loses statistical significance (0.22, $p = 0.24$, AIC = 1301.4), but the interaction is not significant and the AIC score favours the model without interaction. We also tested if the frequency of trading depends on whether it is introduced early or late, and found no significant effect (Welch two-sample t-test, means are 15.2 and 14.4, $t = 0.31$, $p = 0.76$).

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The value of reputation - Electronic Supplementary Material (ESM)

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Content

1. The *trade-play-trade* game: overview and notation

To calculate equilibrium strategies for reputation systems that permit the trading of reputation, we first analyze a one-shot Prisoner's Dilemma (PD), where reputation can be traded before and after the PD. We refer to this version of the game as a one-shot *trade-play-trade* game, and determine Nash equilibria for both reputation systems shown in Fig 1 of the main text. In Section 4, we show that for games with a fixed, finite number of PD's, the same strategies and corresponding payoffs prevail. For games with stochastic end, future payoffs need to be discounted to account for the uncertainty that there is a further round of the PD. In Section 5 we derive the theoretical value for having a good reputation from the payoffs of the strategies.

In our analysis, *PR* denotes the price for changing a bad reputation into a good one, *FG* is the frequency of players in good reputation, *pG* is the probability for a player in good reputation to benefit from cooperation of the co-player, *pB* is the probability for a player in bad reputation to benefit from cooperation of the co-player, and *b* and *c* are the costs and benefits of cooperation. A strategy is defined by its behavior in the trading rounds (buy/hold/sell), and by its behavior in the PD. The behavior in the PD is denoted by two characters (C/D) denoting the action towards players in good and in bad reputation. Strategy *buy-CD-sell*, for instance, buys a good reputation in the first trading round, cooperates in the PD only with players in good reputation, and sells its good reputation in the final trading round.

2. Payoffs and equilibrium strategies for the one-shot *trade-play-trade* game with reputation system 1

In reputation system 1, a good reputation is assigned to players that cooperate, except when a player in good reputation meets a player in bad reputation. In this case, the good player must defect to stay in good reputation (see Fig 1 of in the main text). Players start with a bad reputation and can trade before and after the PD. To analyze the performance of the resulting strategies we first look at the final trading round. Because there are no more actions after this round, having a good reputation does not give a future advantage and thus it is always best to sell. Players in good reputation after the PD will therefore receive a payoff of *PR* in the final trading round, while players in bad reputation will receive no additional payoff.

In the PD, cooperation incurs the cost *c* irrespective of the opponent's action. In cases where cooperation results in a good reputation, it is therefore of advantage to cooperate when the cost of cooperation is smaller than the price for a good reputation that can be gained in the final trading round (i.e. $c < PR$). Conversely, defection is optimal for $PR < c$. When cooperation results in a bad reputation, as is the case when a player in good reputation interacts with a player in bad reputation, it is never of advantage to cooperate. This implies that there are only four strategies that can be optimal, depending on *PR* and on the strategies played in the population:

- *buy-DD-sell*: buys a good reputation in the first trading round, always defects in the PD, and sells in the second trading round when having a good reputation (i.e. when the PD partner was in bad reputation)
- *hold-DD-sell*: stays with bad reputation in the first trading round, always defects in the PD, and sells in the second trading round when having a good reputation (this never happens under reputation system 1 for this strategy)
- *buy-CD-sell*: buys a good reputation in the first trading round, follows the social norm in the PD, and sells the resulting good reputation in the second trading round.
- *hold-CC-sell*: stays with bad reputation in the first trading round, follows the social norm in the PD, and sells the resulting good reputation in the second trading round.

The payoffs of these strategies are given in Table 1. Our calculations assume that the price of a good reputation remains constant at *PR* in both trading rounds. In a game where players start with good rather than bad reputations, the strategies *hold-DD-sell*, *sell-DD-sell*, *hold-CD-sell*, and *sell-CC-sell* are analogous to the ones above, and payoffs are increased by *PR*. The equilibrium properties remain the same.

Strategy	Reputation in PD	Payoff	best when	Comment
buy-DD-sell	G	*pG b – FG PR*	*PR < c* and *PR < (pG-pB)b / FG*	Defector exploiting low prices
hold-DD-sell	B	*pB b*	*PR < c* and *PR > (pG-pB)b / FG*	Always defects
buy-CD-sell	G	*pG b – FG c*	*PR > c* and *PR < (pG-pB)b + (1-FG)c*	Aims for a good reputation
hold-CC-sell	B	*pB b – c + PR*	*PR > c* and *PR > (pG-pB)b + (1-FG)c*	Cooperator exploi-ting high prices

Table 1. Key strategies and their payoffs in the repeated PD with trading of reputation.

To analyze equilibrium strategies, we calculate the payoff matrix for pair-wise interactions between the four strategies (see Table 2). These values also approximate the expected payoff of a rare strategy invading a population dominated by a different strategy. In our analysis, we focus on symmetric Nash equilibria, as these correspond to evolutionary stable strategies.

	buy-DD-sell	**Hold-DD-sell**	**buy-CD-sell**	**hold-CC-sell**
buy-DD-sell	*- PR*	*0*	*b - PR*	*b*
hold-DD-sell	*0*	*0*	*0*	*b*
buy-CD-sell	*- c*	*0*	*b - c*	*b*
hold-CC-sell	*PR - c*	*PR - c*	*PR - c*	*PR + b – c*

Table 2. Payoff matrix for pair-wise interactions of the key strategies. The table shows the payoff of the strategy specified in the row when playing against the strategy specified in the column. When, for instance, a buy-CD-sell player is playing against buy-DD-sell, both players buy a good reputation and thus the buy-CD-sell player is cooperating against a defecting opponent. The buy-CD-sell player remains in good reputation which is sold in the second trading round, giving an overall payoff of -*c*.

The payoff matrix reveals the following symmetric Nash-equilibria: for *PR > b*, *hold-CC-sell* is the only equilibrium; for *b > PR > c* there are two equilibria, *buy-CD-sell* and *hold-CC-sell*; and for *PR < c hold-DD-sell* is the equilibrium. In the last case, *hold-DD-sell* is a weak Nash equilibrium because against *hold-DD-sell*, the strategies *buy-DD-sell* and *buy-CD-sell* have the same payoff. Because in contrast to *buy-DD-sell*, *buy-CD-sell* has a positive payoff against itself, a small group of players in a population of players close to this weak Nash equilibrium would have a benefit.

In a dynamic setting where strategy frequencies change depending on their success in competition with other strategies, the outcome depends on the initial distribution of strategies, the dynamics of the strategies in a population, and the price dynamics. If price dynamics are driven by supply and demand, *hold-CC-sell* cannot be a Nash-equilibrium because it leads to decreasing prices. Once it drives prices below *c*, all other strategies can invade. In this case, the strategy *buy-CD-sell* remains as the only strong Nash equilibrium. Simulations of competition of the four key strategies based on replicator dynamics with mutation show convergence towards a population close to this Nash equilibrium (not shown). We do not observe stable interior equilibria.

3. Payoffs and equilibrium strategies for one-shot trade-play-trade game with reputation system 2

In reputation system 2, a good reputation is assigned to players that cooperate with players in good reputation and defect with players in bad reputation. Compared to reputation systems 1, this means that when two players in bad reputation interact, defection rather than cooperation is prescribed. This translates into important consequences for the payoffs of the strategies, and the outcome of competition.

As for reputation system 1, it is always advantageous to sell good reputation in the final trading round. Thus when cooperation results in a good reputation, which for reputation system 2 is the case when interacting with a player in good reputation, it is of advantage to cooperate when $c < PR$, while defection if optimal for $PR < c$. When cooperation results in a bad reputation, i.e. when interacting with a player in bad reputation, it is always of advantage to defect. This means that there are four strategies that can have a maximal payoff: *buy-DD-sell*, *hold-DD-sell*, *buy-CD-sell*, and *hold-CD-sell*. Note that while these strategies are analogous to the key strategies for reputation system 1, *hold-CD-sell* replaces *hold-CC-sell* due to the changes in the reputation system. The payoffs are shown in Table 3.

Strategy	Reputation in the PD	Payoff	best when	Comment
buy-DD-sell	G	*pG b – FG PR*	*PR* < *c* and *PR* < *(pG-pB) b*	Defector exploiting low prices
hold-DD-sell	B	*pB b + (1-FG)PR*	*PR* < *c* and *PR* > *(pG-pB) b*	Always defects
buy-CD-sell	G	*pG b - FG c*	*PR* > *c* and *PR* < *(pG-pB) b*	Aims for a good reputation
hold-CD-sell	B	*pB b - FG c + PR*	*PR* > *c* and *PR* > *(pG-pB) b*	Cooperator exploiting high prices

Table 3. Key strategies and their payoffs in the repeated PD with trading of reputation for reputation system 2.

To analyze equilibrium strategies, we again calculate the payoff matrix for pair-wise interactions between the four strategies.

	buy-DD-sell	**hold-DD-sell**	**buy-CD-sell**	**hold-CD-sell**
buy-DD-sell	*- PR*	*0*	*b - PR*	*b*
hold-DD-sell	*0*	*PR*	*0*	*PR*
buy-CD-sell	*- c*	*0*	*b - c*	*b*
hold-CD-sell	*PR - c*	*PR*	*PR - c*	*PR*

Table 4. Payoff matrix for pair-wise interactions of the key strategies. The table shows the payoff of the strategy specified in the row when playing against the strategy specified in the column.

We find the following symmetric Nash-equilibria: For any $PR > 0$, *hold-DD-sell* is an equilibrium. This Nash equilibrium is a weak one, because *hold-CD-sell* has the same payoff. Additionally, for $c < PR < b$ *buy-CD-sell* is a strong equilibrium, and for $PR > b$, *hold-CD-sell* is a weak equilibrium. In a dynamic setting where prices change depending on demand and supply, all strategies except *buy-CD-sell* changes the prices, and thus cannot be Nash equilibria. However, for $PR = 0$, *hold-DD-sell* and *buy-DD-sell* can co-exists and keep the price constant. In simulations based on replicator dynamics, we observe depending on the initial conditions two stable outcomes: (i) a population consisting mainly of *buy-CD-sell* players and a high price for a good reputation; (ii) a mixed population consisting of *hold-DD-sell* and *buy-DD-sell* players, and a price close to zero (not shown).

4. Repeated *trade-play-trade* games

Above we analyzed properties of the single-shot *trade-play-trade* game. We now extend our arguments to repeated version of this game. First, let's assume that the single shot game is repeated *n* times, resulting in a finite length game denoted by *(trade-play-trade)*$_n$. In this game, optimal behavior in the last round is the same as in the single-shot game. Applying backwards induction, this means that the optimal behavior in any round is the same as for the one-shot game. Because having two subsequent trading rounds (*trade-trade*) is equivalent to having a single trading round a sequence of *n* one shot games *(trade-play-trade)*$_n$ is equivalent to the finite length game of the structure *trade - (play-trade)*$_n$, which we implemented in our fixed-length experiments. The one difference we note is that strategies such as *buy-CD-sell* that always sell after the PD and always buy before the next PD are equivalent to strategies that just keep their good reputation instead of selling and re-buying it.

For repeated games with stochastic end, payoffs depend on how the game ends. In a game with structure *(trade-play-trade)*$_{n,}$ payoffs of the strategies, and thus the resulting properties of the game, are the same as for a fixed length game. For a game with stochastic end after a trading round, i.e. structure *trade-(play-trade)*$_n$, as was investigated experimentally, the payoff of strategies that keep their good reputation has to be discounted by the uncertainty that there is another PD. This is because players with a good reputation keep that reputation and bring into in the next PD, rather than selling and then re-buying it. Assuming that after each trading round the game continues with probability of *w* but ends with probability *(1-w)*, the average payoff per round for strategies that invest into a good reputation is reduced *PR (1-w)/w*; the resulting payoffs are given in Table 5.

Strategy	Reputation in PD	Payoff	best when
buy-DD-sell	G	*pG b – FG PR – PR (1-w)/w*	*PR < c* and *PR < w(pG-pB)b / (1-w+FGw)*
hold-DD-sell	B	*pB b*	*PR < c* and *PR > w(pG-pB)b / (1-w+FGw)*
buy-CD-sell	G	*pG b – FG c – PR (1-w)/w*	*PR > c* and *PR < w(pG-pB)b + w(1-FG)c*
hold-CC-sell	B	*pB b – c + PR*	*PR > c* and *PR > w(pG-pB)b + w(1-FG)c*

Table 5. Key strategies and their payoffs in the repeated PD with trading of reputation and stochastic end under reputation system 1.

The analogous changes for reputation system 2 are given in Table 6. The payoffs shown in Table 5 and 6 directly imply the prices under which it is rational to buy and sell a good reputation in a game with stochastic end. The relation to pricing is given in Section 5.

Strategy	Reputation in the PD	Payoff	best when
buy-DD-sell	G	$pG\ b - FG\ PR - PR\ (1-w)/w$	$PR < c$ and $PR < w(pG-pB)b$
hold-DD-sell	B	$pB\ b + (1-FG)\ PR$	$PR < c$ and $PR > w(pG-pB)b$
buy-CD-sell	G	$pG\ b - FG\ c - PR\ (1-w)/w$	$PR > c$ and $PR < w(pG-pB)b$
hold-CD-sell	B	$pB\ b - FG\ c + PR$	$PR > c$ and $PR > w(pG-pB)b$

Table 6. Key strategies and their payoffs in the repeated PD with trading of reputation and stochastic end under reputation system 2.

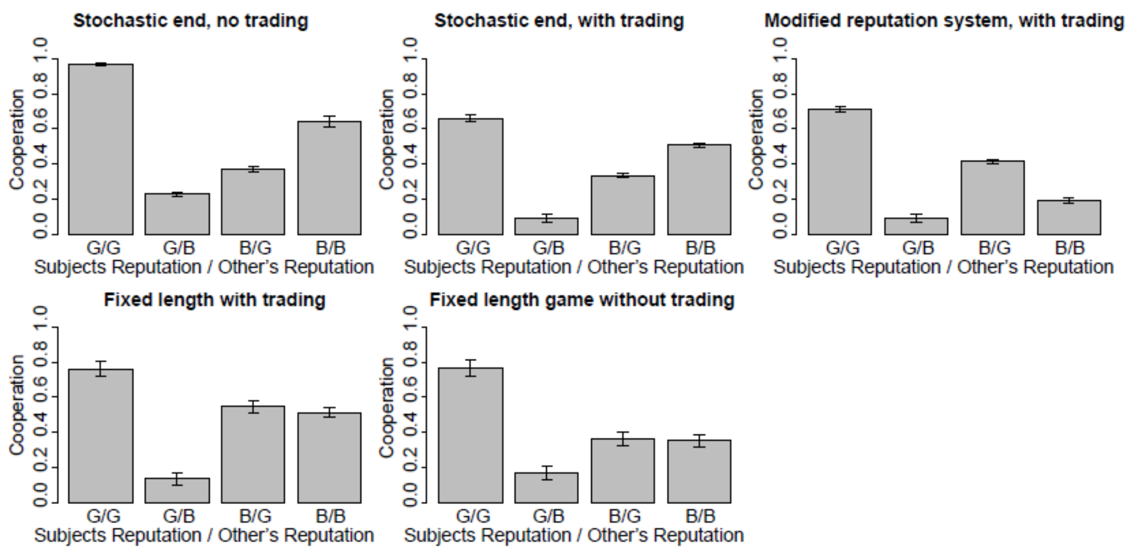
5. The theoretical value of a good reputation

Estimating the value of a good reputation is equivalent to determining the conditions under which the best strategy prescribes buying a good reputation for a player in bad reputation. For games with stochastic end, these conditions are given in Table 5 and 6. Note that when it is advantageous for a player in bad reputation to buy (rather than to hold), it is advantageous for a player in good reputation to hold (rather than to sell); and when it is advantageous for a player in bad reputation to hold (rather than to buy), it is advantageous for a player in good reputation to sell (rather than to hold).

For reputation system 1, a player in bad reputation who knows the values for FG, pG and pB can maximize her payoff by buying a good reputation as long as $PR < c$ and $PR < w(pG-pB)b\ /\ (1-w+FGw)$; or $PR > c$ and $PR < w(pG-pB)b + w(1-FG)c$. Conversely, a player in good reputation maximizes her payoff by selling when $PR < c$ and $PR > w(pG-pB)b\ /\ (1-w+FGw)$; or $PR > c$ and $PR > w(pG-pB)b + w(1-FG)c$. This implies an equilibrium price of PR = $w(pG-pB)b\ /\ (1-w+FGw)$, when c < $w(pG-pB)b\ /\ (1-w+FGw)$; and $PR = w(pG-pB)b + w(1-FG)c$, when c > $w(pG-pB)b\ /\ (1-w+FGw)$. For reputation system 2, we obtain an equilibrium value given by $PR = w(pG-pB)b$. These values are in line with the theoretical value of a good reputation as estimated within the framework of Ohtsuki and Iwasa (2006) for populations close to the cooperative Nash equilibrium.

6. Observed strategies

The strategies used by the players are shown in ESM Fig 4. The histograms describe which option participants choose, given their own and their opponents' reputation. In both reputation systems, maintaining a good reputation requires cooperation when interacting with another player in good reputation, but defection when interacting with a player in bad reputation. We observe that throughout all settings, the frequency of cooperation is highest for players in good reputation when interacting with other players in good reputation, and lowest when players in good reputation interact with players in bad reputation. This is in line with the assessment rules that imply that a good reputation is lost either due to defection towards a player in good reputation, or due to cooperation with a player in bad reputation.

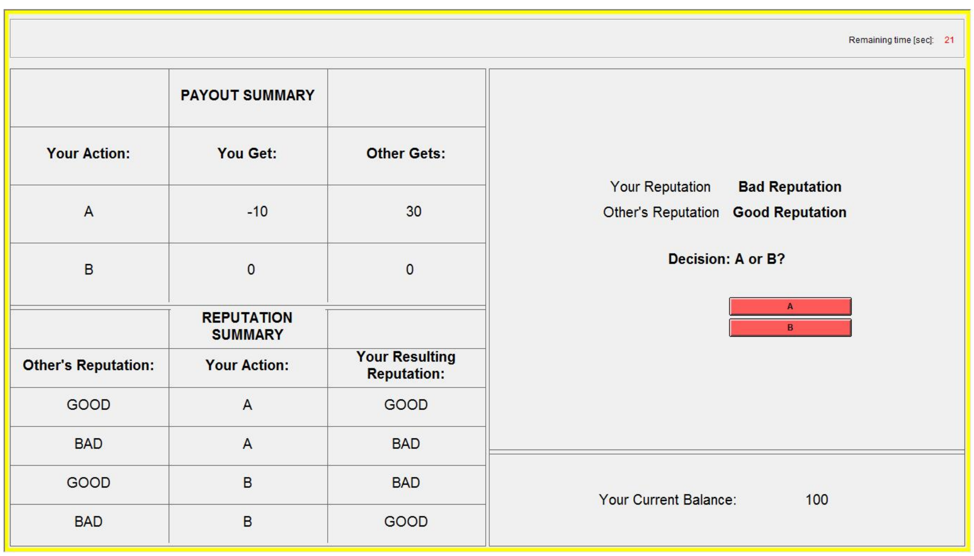


ESM Fig 4. Conditional frequencies of cooperation in the experiments.

We observe an intermediate level of cooperation of players in bad reputation when interacting with a player in good reputation. Thus, a considerable fraction of players in bad reputation are willing to earn a good reputation even if this implies getting "cheated" by the other player. When two players in bad reputation interact with each other, behavior depends on the reputation system. In reputation system 1, where the assessment rules imply that cooperation yields a good reputation in this situation, we observe a comparably high level of cooperation; while in reputation system 2, where defection is prescribed, we observe a low level of cooperation. Thus, the participants in our experiments clearly adjusted their behavior to match the assessment rule. Note that in the experiments with reputation system 1 and stochastic end, players in bad reputation cooperate more frequently with players in bad rather than good reputation. This preference might stem from the fact that a player in bad reputation interacting with a player in good reputation expects to experience defection from the co-player and thus is less inclined to cooperate. As a consequence, the value of having a good reputation can become negative.

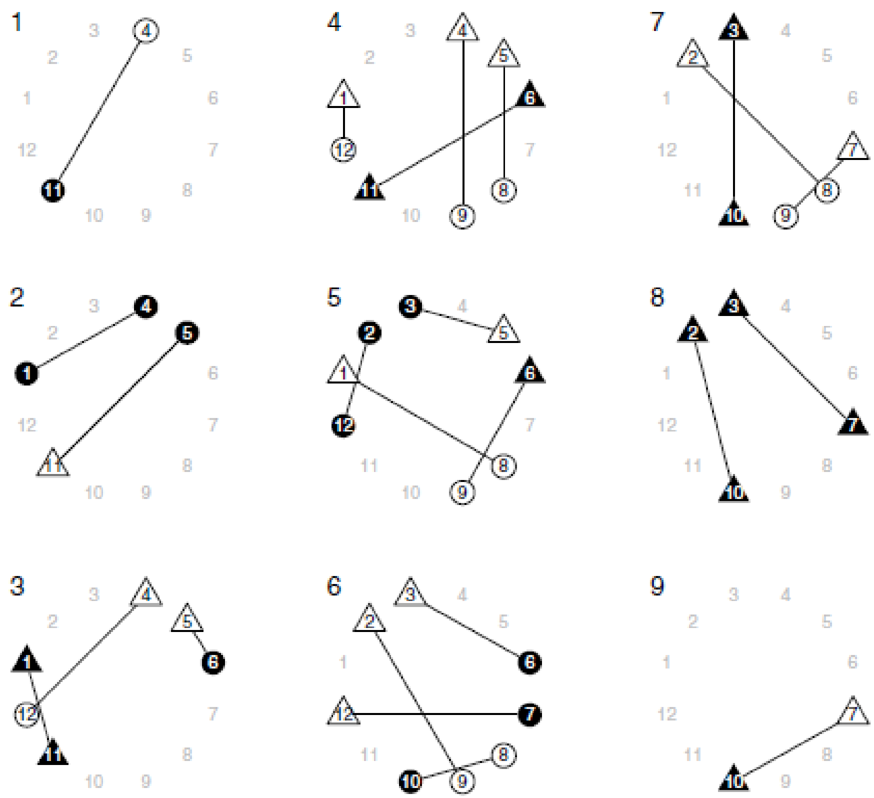
Importantly, the observed strategies in reputation system 1 in the absence of trading are not substantially altered when trading is added. This suggests that the participants use qualitatively similar strategies in both settings, though the overall frequency of cooperation is lower in the setting with trading.

7. Screen shots and visualization of a fixed length experiment



ESM Fig 1. Screen shot for an interaction in the Prisoner's Dilemma. A player can choose between two options, A and B. Option A decreases the own payoff by 10 MU, but increases the other player's payoff by 30 MU. In the PD this option can be seen a cooperation. Choosing option B does not alter the own and others payoff. Players know their own and the other player's reputation, and how their choice will affect their reputation. The interface shown here corresponds to reputation system 2 (see Fig 1 of the manuscript).

ESM Fig 2. Screen shots of the trading interface. In the settings with trading, after each interaction players have the opportunity to buy or sell a "good" reputation. The initial price for a good reputation is set to 40. In the screen shot, the player has a "good" reputation and is offered 40MU for changing it into a "bad" reputation.



ESM Fig 3. Visualization of a fixed length experiment without trading. In each experiment, 12 participants are interacting. Each participant enters at some point, participates in four rounds and than leaves the experiment. The shape of the symbol codes for a player's reputation. Triangles represent "good" reputation, while circles represent "bad" reputation. Solid symbols stand for players that cooperate, open symbols for players that defect. In the first round, players 11 and 4 enter the experiment and interact with each other. Both have initially a "bad" reputation. While player 11 is cooperating, player 4 is defecting. Player 11 gains a "good" reputation, while player 4 remains in "bad" reputation. In the next round, two new players enter. Player 1 interacts with player 4, and player 5 with player 11. Player 1 and 4 cooperate with each other and therefore earn a good reputation. Player 5 cooperates with player 11, who defects. Player 5 gains a "good" reputation, while player 11 maintains a "good" reputation because for a player in "good" reputation" it is "justified" to defect against a player in "bad" reputation. In the subsequent rounds more players enter, and after round 4, the first players start leaving the experiment. In round 9, the last pair of players leaves and the experiment finishes.

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