Analyse & Kritik 26/2004 (© Lucius & Lucius, Stuttgart) p. 258–278

Andreas Flache

How May Virtual Communication Shape Cooperation in a Work Team?

*A Formal Model Based on Social Exchange Theory**

Abstract: This paper addresses theoretically the question how virtual communication may affect cooperation in work teams. The degree of team virtualization, i.e. the extent to which interaction between team members occurs online, is related to parameters of the exchange. First, it is assumed that in online interaction task uncertainties are higher than in face-to-face contacts. Second, the gratifying value of peer rewards is assumed to be lower in online contacts. Thirdly, it is assumed that teams are different in the extent to which members depend on their peers for positive affections, operationalized by the extent to which team members are interested in social relationships for their own sake, independently from their work interactions. Simulation results suggest both positive and negative effects of team virtualization on work-cooperation.

1. Introduction

Firms increasingly rely on so-called hybrid or semi-virtual teams (Griffith/Neale 2001), i.e. teams whose members interact at least partly via information and communication technologies (e.g. email) rather than in face-to-face to contacts. Managers and organization researchers point to large efficiency gains of virtual communication because team membership can cross dysfunctional physical and organizational boundaries. In particular, it is argued that synergies arise from the combination of diverse knowledge and skills of employees in different physical locations in the organization (Kirkman/Rosen/Gibson/Tesluk/McPherson 2002). At the same time, the available literature emphasizes negative effects of social distance and lack of face-to-face contacts in virtual teamwork on trust and cooperation between team members (Jarvenpaa/Leidner 1999; O'Mahoney/Barley 1999; Kirkman et al. 2002).

Previous research on semi-virtual teams is mainly based on case studies. These studies have suggested a range of possible threats to trust and cooperation in the team, as well as strategies for organizations how to resolve the problems (Kirkman et al. 2002). While this work has generated valuable insights, there has also been little attention to systematic model building and deduction of testable hypotheses. Where theory formulation and hypothesis derivation has

* I am indebted to Martin Beckenkamp and two anonymous reviewers for their insightful comments on an earlier version. The research of the author has been made possible by a fellowship of the Royal Netherlands Academy of Arts and Sciences.

been undertaken in previous work (e.g. Griffith/Neale 2001), model building has not been formalized nor have underlying behavioral assumptions been made sufficiently explicit to evaluate the consistence of derivations.

We argue that formal models of semi-virtual teams may help to better analyze *structural* conditions that shape cooperation in teams. Accordingly, we propose a formal model based on social exchange theory that focuses on cooperation and informal social interaction in a semi-virtual team. We aim to show that this model can generate plausible hypotheses about the conditions under which virtual communication may impede – or sometimes facilitate – cooperation between team members. At least one study prior to ours has also proposed a formal model of semi-virtual teamwork (Wong/Burton 2001). However, the model of Wong and Burton focuses primarily on the problems that team virtuality may generate for the efficiency of task completion in a work group. Instead, our model focuses on how virtual communication may shape informal social processes, in particular social control and peer pressure. Informal processes are known from industrial sociology as major mechanisms through which cooperation problems in team work may be resolved[1] (e.g. Homans 1951; Seashore 1954; Petersen 1992).

In section 2 we discuss from a social exchange perspective how virtual communication may affect social control and cooperation in teamwork. Section 3 presents the formal model. Section 4 uses computer simulation to derive hypotheses. Finally, results are discussed and suggestions for future research are formulated.

2. Social Exchange and Cooperation in Semi-Virtual Teamwork

At the workplace, the problem of cooperation in work teams arises in the 'workers' dilemma' whether to 'work' or 'shirk'. Workers share a common interest in maximizing productivity, if, for example, weak performance by the firm leads to the loss of jobs, or wages are tied to production norms by bonus payments or group piecerate schemes (Edwards/Scullion 1982, 182). Particularly in so-called self-managed teams, workers' individual payment is often tied to evaluations of group performance, for example by group bonuses. Moreover, even without group rewards, employees' outputs and thus monetary outcomes or career and promotion chances are often interdependent due to organization or technology of their work (Petersen 1992).

Cooperation in work teams may be problematic, because workers face an individual incentive to 'free ride' by 'shirking' while others shoulder the burden of maximising task performance (Olson 1965; Alchian/Demsetz 1972). Homans (1974) argued that peer pressure may be a central mechanism to solve free

[1] In classical studies of industrial sociology, the emphasis was often put on a particular form of cooperation, collusion between team members that is directed against the interest of the firm, for example output restriction. We neglect this complication here and focus on situations in which cooperation in the work process is in the best interest of all team members, as for example under group bonus payment.

rider problems. Homans describes peer pressure as an exchange between group members of compliance with group obligations in return for social rewards, such as 'approval' or affirmation of one's status in the group. Since "some degree of ostracism is the penalty for failing to conform to a norm" (1974, 156), peer pressure can be an effective instrument of informal social control. The more cohesive the group, the stronger the pressure to conform, because a cohesive group is "one in which many members reward one another" (1974, 156).

Another solution based on social exchange is reciprocity in the work task. In terms of social exchange theory, this is a 'group generalized exchange' (Yamagishi/Cook 1993), in which actors exchange work effort in return for a share of the collective benefit produced by the group as a whole. Even without peer pressure, workers may resist the temptation to free ride in group generalized exchange. This is possible when workers expect that their colleagues likewise pull their weight, but do so only conditionally upon sufficient contributions from others. Then, a worker who is sufficiently interested in future outcomes may refrain from shirking in the present, because he knows that this may have the undesirable effect to undermine colleagues' willingness to work in the long run. Game theory has shown that such a solution to free rider problems is consistent with enlightened self-interest in repeated interactions (cf. Friedman 1971; 1986; Axelrod 1984; Taylor 1987; Raub 1988).

Research on virtual teamwork has identified potential threats to the effectiveness of informal solutions of the free rider problem. We use in the following the term team virtuality to refer to the extent to which members of the team work and communicate purely through online means. One of the major problems for trust in a virtual team may be the lower strength of social ties in more virtualized teams. For example, Caproni (2001) states that "high quality relationships may be particularly difficult to achieve in teams in which team members are geographically dispersed". And Griffith and Neale (2001, 397) conclude from a literature review that in more virtualized teams members may feel less psychologically safe and be less likely to identify with the team as a salient social referent. In a similar vein, Wong and Burton (2001) suggest that it is hard to build in online communication the strong social ties that bind team members into a group and facilitate mutual confidence and reciprocity. Instead, they argue, the larger the extent to which people interact virtually, the weaker are the social ties between them in the sense that ties consist mainly of instrumental information exchanges but create little social interdependence between team members.

To model the weakness of ties in electronic communication, we assume that the rewarding value of informal rewards, such as praise and approval, is lower to the extent that team members communicate mainly virtually. However, this effect may be shaped by a number of context conditions, such as the general organizational culture, or the degree to which firms employ strategies that combine online collaboration with regular offline meetings between team members. For example, firms may reduce negative effects of weaker online ties by deliberately creating offline contacts between members of virtual teams (Lipnack/Stamps, 1997). To capture such conditions, our model contains a parameter for the extent to which online communication depreciates the gratifying value of peer rewards.

A second problem is the higher uncertainty team members face about others' behavior and intentions in a virtual team. Virtual information exchanges are much less effective than face-to-face encounters to communicate the social context information through which people get to know and trust each other (Handy 1995; Jarvenpaa/Leidner 1999). In particular, workers face larger uncertainties about the real reasons why things in the work process may fail or go well. Uncertainty can be a major problem for cooperation based on task reciprocity. Under uncertainty, workers may observe only the *results* of colleagues' contributions to a group effort, but these results may be an unreliable indicator of actual efforts (cf. Bendor/Mookherjee 1987). The problem for task-reciprocity is that in such situations conditionally cooperative strategies need to impose at least some retaliation in order to credibly deter group members from free-riding. As a consequence, 'erroneous' defections caused by uncertainty may severely curtail the efficiency of task reciprocity (Bendor/Mookherjee 1987; Kollock 1993; Wu/Axelrod 1995).

To incorporate uncertainty in virtual communication into our model, we follow Bendor and Mookherjee and assume an exogenously given error probability that is shaped by features of the work task of a team. This task uncertainty is scaled with a corresponding model parameter that is independent of the assumed extent of virtualization of teamwork. However, to express the lack of social information in virtual contacts, we assume that in local interaction workers know whether a lack of contribution can be attributed to a mishap or a lack of effort. By contrast, in virtual communication team members only see the output but not the actual efforts of their colleagues.

Previous research also indicates that weaker ties may sometimes facilitate teamwork. Wong and Burton (2001) argued that with weaker social obligations, team members can more readily reject superfluous information requests from colleagues and thus conduct their tasks more efficiently. However, the problem identified by Wong and Burton does not question the potential of strong ties to foster cooperation. On the contrary, the authors argue that strong ties may be detrimental for individual efficiency because they elicit more cooperation from team members than would be optimal in terms of task efficiency. Flache and Macy (1996) go further and challenge the conventional wisdom that strong ties may always facilitate social control. In a nutshell, their argument focuses at the desire of actors to obtain social rewards, such as affection or approval, from other group members. Particularly in a closely knit network of exchanges of social rewards, actors may be reluctant to sanction deviants who fail to act in the group's interest, because actors fear to loose rewards from those deviants. Accordingly, so the argument goes, dependence of group members on peer approval may give shirkers the leverage to insulate themselves from pressures to conform. Informal control may flow into the maintenance of strong ties at the expense of the common good. In this view, the weaker ties in virtual teams may reduce actors' social dependence on shirkers and thus improve conditions for effective informal control.

To integrate in our analysis both positive and negative effects of strong ties, we follow Kitts, Macy and Flache (1999) and distinguish between two forms of social dependence on the team, normative dependence and affective dependence. Normative dependence refers to the extent to which team members need behavioral confirmation from their colleagues that they do their work well. Normative dependence may for example be high in research and development teams where researchers put a high value on their professional reputation. Affective dependence is the extent to which team members wish to be liked by their colleagues and want to have pleasant social interactions that are not dependent on task performance. Affective dependence may be high in teams where workers lack outside sources of social approval or where work tasks have low professional status such that behavioral confirmation can better be gained through socializing with peers than through work effort. We expect that effects of team virtualization may interact with the primary source of social dependence. In teams with high normative but low affective dependence, virtual communication may mainly limit the effectiveness of peer pressure to perform and thus impede cooperation. In teams where affective dependence is high as compared to normative dependence, weaker ties in virtual communication may prevent the dysfunctional prevalence of friendship ties over the work task. To test the consistence of these intuitions, we elaborate in the following a formalized model.

3. The Formal Model

Game and Payoff Structure

Team production is modeled as a repeated N-person game in which players take simultaneously both work decisions and social decisions that have side effects on the payoffs of all other team members. Actors value group output and approval of their peers, and they weigh these values against the effort required to obtain them. For simplicity, we will denote in the following all direct and indirect benefits that a worker obtains through the group output as the workers' wage payment. Wage payment is directly tied to team performance, i.e. the more workers contribute to the team effort, the higher the individual payment each of them obtains. Actors face two decisions: whether to invest in collective effort ('work') and whether to invest in their relationships with other members of the group ('approval'). To simplify, we assume actors must choose between just two options for each decision: to work or shirk, and to approve or not approve. We refer to the aggregated amount of work contributions in the group as 'task performance', while the aggregated amount of approval between group members is denoted 'group cohesion'.

Equation (1) represents the strategy of player i in iteration t of the repeated game as vector σ_{it}.

$$\forall i : \sigma_{it} = (w_{it}, a_{i1t}, .., a_{iNt}). \qquad (1)$$

The symbols i *and* t in (1) index actors and time, respectively, w and a identify each of the two decisions, work effort and social approval. The work decision of actor i in iteration t is denoted w_{it}, where $w_{it} = 0$ for shirkers and $w_{it} = 1$

for contributors. i's approval of j is indicated by a_{ijt}, where $a_{ijt} = 1$ when i approves of j and $a_{ijt} = 0$, otherwise. To preclude narcissism, the restriction $a_{iit} = 0$ is employed. Within one iteration, actors take decisions simultaneously and independently.

The payoff a team member derives is shaped both by benefits from wage payment and social approval and by the effort costs that the worker incurs. Technically, group wage is modeled as a linear function of aggregated individual outputs, where the maximum wage a worker can earn is scaled by the wage parameter α. For simplicity, we neglect asymmetrical positions in the team organization and assume that each actor receives $1/N$th of the bonus earned by the group, regardless of contribution, where the output of one worker increases the group bonus by one unit.

To include task uncertainty, the model assumes that wage payment is not a deterministic function of individual efforts. Following Bendor and Mookherjee (1987), task uncertainty is modeled with a given probability ε that due to some mishap an individual's contribution fails to be effective ($0 \leq \varepsilon \leq 1$), where ε is equal for all group members. The task uncertainty parameter ε reflects the degree of uncertainty that is inherent to the particular technological and organizational properties of the team task. The occurrence of a mishap for worker i in iteration t is denoted m_{it}, where $m_{it} = 1$ indicates a mishap and $m_{it} = 0$ if the effort investment was successful. When a mishap occurs, a worker still incurs the costs of effort investment, but the effect of his efforts on the wage payment of his colleagues is nil. Equation 2 formalizes the wage payment W_{it} that worker i derives from the outcome of iteration t of the game.

$$W_{it} = \frac{\alpha}{N} \sum_{j=1}^{N} (1 - m_{jt}) w_{jt}. \tag{2}$$

The analysis focuses on games with a Prisoner's dilemma structure, where cooperation in the exchange of work effort is collectively desirable, but actors face incentives to free ride. This implies that loafing is more cost-effective than working and that everyone realizes a Pareto optimal collective benefit when everyone pulls his weight, or

$$\frac{\alpha}{N} < c < \alpha, \tag{3}$$

where c expresses the costs that a worker incurs from one unit of effort investment. Working costs are zero when no effort was invested.

The second source of benefit a worker can obtain is peer approval. We assume that the rewarding value of informal interactions ('approval') is higher in direct face-to-face interactions than it is in purely online communication. Technically, the team comprises two types of team members, local team members and virtual team members. Local team members spend their entire work day on the local site of their firm, where they have physical access and daily face-to-face interactions with all other local team members. Virtual team members have no physical access to their colleagues. They communicate and work with all other colleagues purely through electronic means. To formalize the access properties of relationships between team members, let l_i denote worker i's location where $l_i = 1$ for local workers and $l_i = 0$ for virtual team members. The virtuality of a team, V, is obtained by $V = \frac{1}{N}\sum_{i=1}^{N}(1 - l_i)$.

The social payoffs of a worker are shaped by his location in the team, while local and virtual team members receive the same wage payment and are to the same degree dependent on the work input of their colleagues. The effect of virtual communication on social payoffs is modeled as follows. For a worker i, the benefit of being approved of in face-to-face interaction by some other group member $j(a_{ji} = 1)$ is given by his social dependence β on peer approval. We will introduce the distinction between normative and affective dependence further below where we model the way how workers evaluate their work behavior and their approval decisions, respectively. For simplicity, it is assumed that all workers are equally dependent on peer approval. A high value of β models for example that workers live in a company town, where they are highly dependent on colleagues' approval due to lack of alternative social contacts outside their work group. However, to express the difference in the rewarding value of on- vs. offline social communication, we assume that the full reward value of β is only obtained when both i and j are local team members ($l_i l_j = 1$). When one of the two parties in a relationship is a virtual team member, then for both of them the value of being approved of by their colleague reduces to $\omega\beta$, where the parameter $\omega(0 < \omega < 1)$ refers to the depreciation of the value of peer approval that is due to online interaction. Equation (4) expresses the benefits from social rewards A_{it} that worker i derives from the outcome of iteration t of the game.

$$A_{it} = \sum_{j=1}^{N} \beta a_{jit}(l_i l_j + (1 - l_i l_j)\omega). \tag{4}$$

To include effects of task uncertainty, we assume that local workers always have perfect information on the true effort investments of all other local team members in the past. By contrast, a virtual team member only knows the outputs $(1-m_j)w_j$ that his colleagues j generated in all previous iterations, but he does not know their true effort investments and whether a mishap occurred. Correspondingly, the colleagues of a virtual team member i also only know the output generated by i but they are not aware of i's true effort.

Decision making on basis of reinforcement learning

To model workers' decision making in the repeated game, we employ a backward-looking learning model that assumes that actors follow a simple decision heuristic (cf. Flache/Macy 1996; Flache 1996). In this model, actors optimize by learning and adaptation rather than by calculating the marginal return on individual investment. In other words, actors adjust both their effort level and their attitudes toward other members in response to social cues that signal whether the investment was worthwhile. The actors thus influence one another in response to the influence they receive, creating a complex adaptive system. Such systems lend themselves more readily to computational rather than analytical models (Axelrod 1997; for 'backward-looking' computer simulations of collective action and social exchange, see Macy 1989; 1990).

The computational model consists of three basic components: a decision rule, a reward function by which outcomes are evaluated as satisfactory or unsatisfactory, and a learning rule by which these evaluations modify choice propensities. We describe these components in turn.

Decision rule

The decision process is stochastic rather than deterministic. Learning actors follow choice propensities that are altered after they experience the consequences of their behavior. The stochastic decision rule assumes that each actor i has some propensity p_{it} representing the probability that i will work at time $t(w_{it} = 1)$. With probability $1 - p_{it}$, i will shirk ($w_{it} = 0$). Similarly, p'_{ijt} represents the probability that i will approve of j at time $t(a_{ijt} = 1)$. With probability $1 - p'_{ijt}$, i will not approve of $j(a_{ijt} = 0)$.

Reward function: the evaluation of work and approval

Actors economize in our model on cognitive effort with three shortcuts: reliance on propinquity as a lowcost proxy for causality, 'satisficing' as a lowcost proxy for the identification of global optima, and separate evaluation of decisions as a proxy for analysis of the joint effects of simultaneous actions. Reliance on propinquity is modeled by the 'law of effect': when an action is associated with a satisfactory outcome then increase your probability to repeat the action. Conversely, when a dissatisfactory result obtains, decrease the probability to repeat the associated behavior. 'Satisficing' (Simon 1982) implies that the better the outcome, the more likely the actor will deem it to be 'good enough' rather than risk an inferior result by searching for something better. The poorer the outcome, the more likely the actor will be to take the risk. For simplicity, the model formalizes this by evaluating outcomes relative to the midpoint of the payoff distribution. Finally, separate evaluation of actions implies that actors adapt their propensities to work or to approve separately per decision, based on their satisfaction only with some components of the outcome of the preceding iteration.

Satisfaction with the work decision increases with the actor's share of the total group wage and decreases with the costliness of the decision. In addition, local workers always evaluate their local colleagues' true effort investment rather than their output, because even under task uncertainty it is seen as success when a colleague tried to cooperate. Moreover, effort is deemed worthwhile to the extent that it is associated with high levels of approval. More formally,

$$S_{it} = W_{it} + l_i \frac{\alpha}{N} \sum_{j=1}^{N} l_j m_j w_j + A_{it} - c w_{it} - S_{e,i}. \qquad (5)$$

S_{it} is i's satisfaction with current work effort, such that the sign of S_{it} indicates positive or negative evaluation. W_{it} and A_{it} are defined in (2) and (4) above. It is important to note that the effect that others' work has in comparison with others' approval on an actors' satisfaction with his work decision is scaled by the parameters α and β. These parameters enter equation 5 indirectly via the terms for wage payment, W_{it}, and approval from peers, A_{it}, respectively. The term $l_i \frac{\alpha}{N} \sum_{j=1}^{N} l_j m_j w_j$ in equation (5) is needed to correct for the difference in the situation of local workers compared to virtual team members. This term assures for local workers that not only the outputs but also the true cooperation of their local colleagues is taken into account. $S_{e,i}$ is the reference point that determines whether actor i evaluates the outcome of iteration t as success or as failure. For simplicity, we position for each actor the reference point at the midpoint of the range of possible payoffs that this actor can obtain. This implies that local team members have a higher expectation level than virtual team members, because local team members can obtain a higher maximal social reward level than their virtual colleagues. Moreover, in their expectation level team members take the number of local and virtual colleagues into account. Equation 6 specifies the ensuing reference points for satisfaction with the work decision.

$$S_{e,i} = \begin{cases} \frac{1}{2}(\alpha + (N - NV - 1 + NV\omega)\beta - c), & \text{if } l_i = 1 \\ \\ \frac{1}{2}(\alpha + (N-1)\omega\beta - c), & \text{if } l_i = 0 \end{cases} \tag{6}$$

The decision by i to approve of j, a_{ijt}, is evaluated in the same way except that the collective action problem is now disaggregated into a matrix of dyadic games, one for each of the possible dyads. Rather than taking into account overall group effort and overall approval received from the group, i considers only i's benefit from j's effort and the approval received from j. Since i's benefit when all N members work is α, i's benefit when one individual j works is α/N.

We use the evaluation of j's approval in our model to incorporate the distinction between normative and affective dependence of workers. Workers can obtain behavioral confirmation from their peers mainly for their investments in work effort, because with respect to the decision to work or shirk all team members have a clearly defined common interest in high effort of their colleagues. Technically, normative dependence is expressed with the parameter β in equation (6) that scales the extent to which peer approval reinforces an actors' work decision.

Affective dependence refers to the extent to which team members wish to be embedded in ties of mutual social approval ('friendship ties') with their colleagues, independently from their work behavior. A worker's desire for affective rewards can not be satisfied by his colleague's obedience with collective work norms, but it can be satisfied when the worker receives approval from a colleague in response to his own relational investment into the tie with the colleague. Accordingly, we use the symbol β' to distinguish affective dependence from normative dependence β. Affective dependence shapes the extent to which a worker Ego deems it as a success of his approval decision with respect to a particular colleague Alter, when Alter approved of Ego. Like in the evaluation of the work decision, approval that is expressed in online interaction is less valuable to the recipient than approval received in face-to-face interaction, scaled with the online-depreciation parameter ω. In addition, we assume that the working situation always affects at least to some extent workers' social interactions. That is, Ego always deems it as success of his approval decision when Alter invested in work effort. Finally, the evaluation of approval decisions also takes into account that local workers can see the true effort levels of their local colleagues and take these true efforts as basis for success or failure of their own approval decisions. In this, the aggregate benefits Ego obtains in his relationship with Alter are evaluated against the relationship-specific expectation or reference point $S'_{e,ij}$:

$$S'_{ijt} = \frac{\alpha}{N}(l_i l_j + (1 - l_i l_j)(1 - m_j))w_{jt} + (l_i l_j + (1 - l_i l_j)\omega)\beta' a_{jit} - S'_{e,ij}. \quad (7)$$

According to (5) and (7), the parameters β and β' represent the weight i places on others' approval relative to their work effort. With $\beta = \beta' = \alpha/N$, i values others' face-to-face approval equally with work effort both in evaluating his work decision and in evaluating his approval decisions. With $\beta = \beta' > \alpha/N$, others' approval of i has a stronger effect on i's satisfaction than work effort. Conversely, with $\beta = \beta' < \alpha/N$ others' work effort has a stronger effect on both i's work behavior and his investment in social relations than others' approval of i. The difference between normative dependence β and affective dependence β' expresses whether peer approval mainly affects an actors' evaluation of his work behavior, or whether approval decisions are also evaluated in terms of approval received. With $\beta > \beta' > 0$, workers deem approval more as normative confirmation of their work decision than as affective reward for their social behavior. With $\beta > \beta' = 0$, they even give approval exclusively in response to the effort decisions of their peers. Finally, with $\beta = \beta' > 0$, actors make their approval decisions contingent on both work behavior and relational investments of their peers, a situation in which social interactions in the group are related to both work and social ties. We exclude the possibility that relational dependence exceeds normative dependence ($\beta < \beta'$), because this seems implausible for the situation of a professional team where wage payments are based on collective work output.

$S'_{e,ij}$, finally, is the relationship-specific reference point that corresponds to the midpoint of the reward distribution in the evaluation of approval. Again, the maximum satisfaction that can be obtained in a relationship between two local workers is higher than in a relationship with at least one virtual team member. Equation (8) specifies the corresponding expectation levels:

$$S'_{e,ij} = \begin{cases} \frac{1}{2}(\frac{\alpha}{N} + \beta'), & \text{if } l_i l_j = 1 \\ \frac{1}{2}(\frac{\alpha}{N} + \omega\beta'), & \text{otherwise} \end{cases} \quad (8)$$

The evaluation of each decision is transformed into a positive or negative reinforcer constrained to the interval [1,+1]. Let R_{it} be the reinforcer corresponding to S_{it}. Then

$$R_{it} = \frac{r\ S_{it}}{S_{\max,i}}, \tag{9}$$

where r is a learning parameter that scales the magnitude of reinforcement and $S_{\max,i}$ is the highest possible absolute value that the worksatisfaction S_{it} can take for worker i. Analogously the reinforcer R'_{ijt} for the approval decision is obtained as follows

$$R'_{ijt} = \frac{r\ S'_{ijt}}{S_{\max,ij}} \quad . \tag{10}$$

Learning function

The final component of the model is the learning function by which propensities to work and approve are modified by satisfaction or dissatisfaction with the outcomes associated with those behaviors. The learning function is adapted from a conventional Bush-Mosteller stochastic learning model (Bush/Mosteller 1955). Actor i's propensity to work, p_{it}, is reinforced when effort seems to pay ($w_{it} = 1$ and $S_{it} > 0$) or when shirking is costly ($w_{it} = 0$ and $S_{it} < 0$):

$$p_{i,t+1} = p_{it} + R_{it}(1 - p_{it})w_{it} - R_{it}(1 - p_{it})\,(1 - w_{it}). \tag{11}$$

The benefits of hard work and the costs of free-riding are indicated in the equation by two adjustments to p_{it}, one positive (when $w_{it} = 1$) and the other negative (when $w_{it} = 0$). Hence, the reward to workers is added to the propensity when $w_{it} = 1$, while the penalty for shirkers is subtracted when $w_{it} = 0$, causing the propensity to increase in either case. Conversely, if feckless behavior pays off or hard work is suckered, then the propensity to shirk $(1 - p_{it})$ is reinforced, i.e., $1 - p_{it}$ is substituted for p_{it} on both sides of the equation and $1 - w_{it}$ is substituted for w_{it}, giving

$$p_{i,t+1} = p_{it} + R_{it}p_{it}w_{it} - R_{it}p_{it}(1 - w_{it}). \tag{12}$$

The propensity for approval p'_{ijt} is modified in the same way. If $a_{ijt} = 1$ and $S'_{ijt} > 0$, or a_{ijt} and $S'_{ijt} < 0$, then:

$$p'_{ij,t+1} = p'_{ijt} + R'_{ijt}(1 - p'_{ijt})\,a_{ijt} - R'_{ijt}(1 - p'_{ijt})\,(1 - a_{ijt}). \tag{13}$$

Conversely, if $a_{ijt} = 0$ and $S'_{ijt} > 0$, or $a_{ijt} = 1$ and $S'_{ijt} < 0$, then:

$$p'_{ij,t+1} = p'_{ijt} + R'_{ijt}p'_{ijt}a_{ijt} - R'_{ijt}p'_{ijt}\,(1 - a_{ijt}). \tag{14}$$

The terms that moderate the effect of the reinforcement, $(1 - p)$ in equations (11) and (13) and p in equations (12) and (14), assure that propensities remain within the valid range [0..1]. This implies in particular that learning curves tend to flatten when the same action is repeatedly rewarded ($S > 0$) or repeatedly punished ($S < 0$) and propensities approach their limit. However, with the high learning rates that we choose for our simulation experiments (see below), this does not imply inertia in the learning process. Particularly in the region close to the boundaries, learning is highly sensitive to adverse experience. The higher the propensity for a certain action, the stronger is the effect that negative reinforcement ($S < 0$) has on the corresponding propensity. Conversely, the lower the propensity for a certain action, the stronger is the effect that positive reinforcement ($S > 0$) has.

4. Results

We use simulation experiments to explore the three mechanisms through which virtual communication may shape the performance of work teams, task uncertainty, normative tie strength and affective tie strength. In all simulation experiments, we vary systematically the level of average team virtuality V of teams of 10 members (N=10) from purely local teams (V=0) to purely virtual teams (V=1), in steps of 0.1. More precisely, the simulations use 100 replications per level of virtuality, where V indicates the probability that a particular team member is a virtual member. Per level of team virtuality, we measure the level of cooperation as the average propensity in iteration 1000 of a team member to work hard (w=1). Furthermore, we use in all simulations the starting conditions that the maximum wage is fixed at unity ($\alpha = 1$), workers are initially indifferent between working and shirking ($p_{i0} = 0.5$) as well as between approval and shunning in all dyadic relationships ($p'_{ij0} = 0.5, i \neq j$). This indifference may seem a rather pessimistic assumption, as there is rarely a company where on average only half of the employees work. However, we believe initial indifference is an appropriate starting assumption for our analysis, because we want to explain how workers learn to cooperate rather than assume that cooperation has been established from the outset. Moreover, as Macy (1989) showed, the equilibria to which the stochastic learning model converges in the long run are robust against variation of initial propensities within a large range. Finally, we assume that all workers have a learning rate of r=0.75, a condition that makes behavioral responses sufficiently flexible to allow the emergence of stable cooperation through random coordination (cf. Flache/Macy 2002).

Simulation experiment 1: the interaction of task uncertainty and team virtuality

Task uncertainty may undermine trust and thus cooperation between team members, and virtual communication may even exacerbate the trust problems generated by task uncertainty. Particularly in teams where task uncertainty may result in unintended failures by members to deliver their contributions to the work task, colleagues may more readily interpret this as a deliberate free riding and, as a consequence, withhold their own efforts for the group task. To test whether our model can reproduce this expectation, we simulated a team situation in which cooperation based on mutual reinforcement is possible but not trivial in a purely local team. For this, we assumed that costs of effort are more than twice as large as the marginal individual gains of a work contribution ($c = 0.25 > 1/N = 0.1$). To focus on effects of virtual communication on pure task reciprocity, we set both normative and affective dependence to zero and thus excluded social pressure ($\beta = \beta' = 0$). Finally, to explore the interaction of team virtuality with task uncertainty, we varied task uncertainty between low ($\varepsilon = 0.01$), medium ($\varepsilon = 0.05$) and high ($\varepsilon = 0.10$). Figure 1 shows the results.

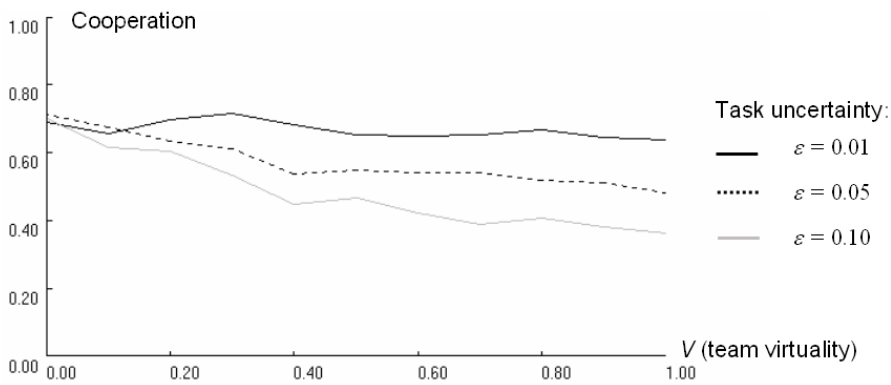

Figure 1: Interaction of team virtuality with task uncertainty ε on level of cooperation. Average cooperation rate measured as average individual propensity to work in iteration 1000, based on 100 replications ($N = 10, \alpha = 1, c = 0.25, \beta = \beta' = 0, r = 0.75$).

Figure 1 confirms[2] the expected interaction between task uncertainty and team virtuality. The simulation parameters are tuned such that in a purely local team (V=0), task reciprocity can sustain an average cooperation rate in iteration 1000 of about 70%. From this starting condition, increasing team virtuality reduces cooperation rates downto about 40% in a fully virtual team under high task uncertainty. The negative effect of team virtuality is somewhat weaker under medium task uncertainty, with a decline from 70% cooperation to about 50%, and it is hardly discernible in teams with low task uncertainty. The underlying reason is the distortion of cooperative equilibria when task uncertainty makes intended cooperations fail. To explain, previous simulation studies with the same learning model and similar starting conditions showed that without task uncertainty, cooperation will sooner or later emerge and stabilize through random coordination of a critical mass of contributors. With the parameters underlying Figure 1 ($N = 10, \alpha = 1$, and $c = 0.25$), the only stable equilibria of the individual learning processes are situations in which seven or more team members work. Only then all team members, including shirkers, can be satisfied with their work decisions and their learning curves will stabilize on the corresponding outcome after a sufficient number of repetitions (cf. Macy/Flache 2002).

[2] We are aware that this is a purely theoretical statement. To avoid complicated prose, we use in the following terms as 'confirm' and 'test' in the sense of 'show that the formal model is consistent with the informal reasoning'.

Task uncertainty can distort equilibria of the learning process. Moreover, the likelihood and frequency of such distortions increases with team virtuality. When for some worker a mishap occurs, this reduces for all virtual colleagues the satisfaction with their work decision, because they interpret the lack of contribution as a defection. Moreover, when it was a virtual worker who failed, then also all his local colleagues interpret the failure as a defection. Thus, even when everybody is satisfied because there are seven or more contributors, the expected share of team members who may become dissatisfied with their work decision after some unintended defection is $V+(1-V)V$, a number that increases with team virtuality V. The learning mechanism implies increased likelihood for behavioral change after dissatisfaction. After a mishap, the majority of team members who work hard may at least temporarily reduce their propensity to work and explore defection. After a while the critical mass of contributors may be restored and stabilize, until the next distortion occurs. This explains the interaction effect in figure 1. The larger the probability of unintended defections (task uncertainty) and the larger the share of team members who become dissatisfied after such a distortion (team virtuality), the more likely it is that emergent cooperation may collapse temporarily, or even fail to stabilize at all when task uncertainty becomes too large.

Simulation experiment 2: the interaction of online-tie strength and team virtuality without affective dependence.

A common argument in the study of virtual teams is that trust may be fostered by deliberate offline meetings that increase the strength of ties between team members who otherwise interact only online. In terms of our model, such policies reduce the extent of online depreciation ω of the value of peer approval. To test whether our model can replicate the expected interaction between offline-embeddedness of virtual communication and team virtuality on cooperation, we adapted the starting conditions of simulation experiment 1 such that cooperation is much harder to attain without social control. For this, we increased the costs of effort to one third of maximum wage, i.e. $c = 0.33$, as compared to one fourth in experiment 1 ($c = 0.25$). To test whether peer pressure is needed in this new scenario, we kept all other conditions equal to experiment 1 and simulated the cooperation rate in the fully local team ($V = 0$). As expected, the cooperation rate dropped to 34.2% from the level of about 75% shown in figure 1.

We created a situation in which informal social control can considerably improve cooperation between team members in offline interaction. Based on previous work we assumed that the normative reward value of a unit of approval is about twice as large as the marginal benefits of a work contribution (cf. Flache/Macy 1996), i.e. $\beta = 0.2$. To focus furthermore in this simulation experiment on the motivational aspect of interpersonal relationships alone and let aside information exchange, we assumed that task uncertainty plays no role in the simulated team ($\varepsilon = 0$). Our main interest in this experiment is the potential of social relationships to mediate informal social control. Accordingly, we neglect the possibility that ties may be used for the mere production of positive affections and assume zero affective dependence, i.e. $\beta' = 0.0$. All other assumptions are equal to those used in simulation experiment 1.

To test the interaction of offline-embeddedness with team virtuality, we varied the online-depreciation of tie strength ω between low, medium and high depreciation, where a unit of approval received in online communication has 75%, or 50%, or 25% of its rewarding value in face-to-face interaction, respectively ($\omega = 0.75, \omega = 0.50, \omega = 0.25$). Figure 2 below shows the results.

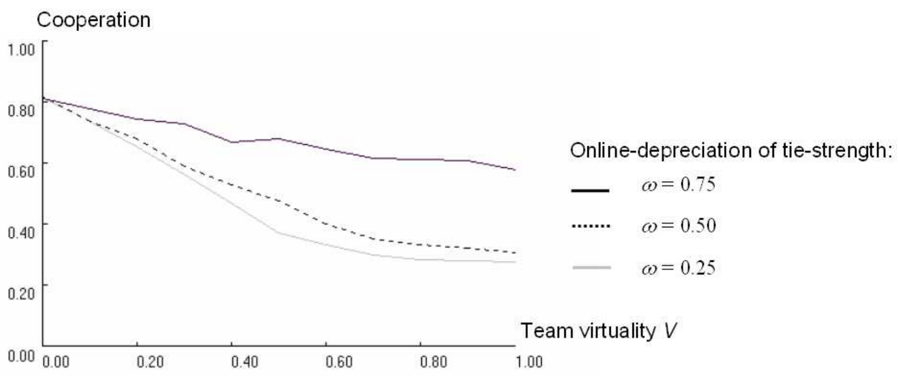

Figure 2: Interaction of team virtuality with online depreciation of tie-strength (ω) on level of cooperation with high normative dependence ($\beta = 0.2$) and no affective dependence ($\beta' = 0$). Cooperation rate measured as average individual propensity to work in iteration 1000, based on 100 replications ($N = 10, \alpha = 1, c = 0.33, \beta = 0.2, \beta' = 0, \varepsilon = 0.0, r = 0.75$).

Figure 2 shows a cooperation rate of about 80% in a fully local team ($V = 0$), where all social ties have their full strength ($\omega = 1$) by definition. Social control more than doubled the cooperation rate as compared to the benchmark simulation that we conducted without normative dependence ($\beta = 0.0$) and otherwise equal conditions. But figure 2 also shows that team virtuality undermines social control. At all three levels of the depreciation of tie strength, the cooperation rate considerably declines with the degree of team virtuality. When online ties have 75% of the strength of offline ties ($\omega = 0.75$), cooperation drops from the rate of 80% in fully local teams ($V = 0$) to about 60% in fully virtual teams ($V = 1$). As expected, the decline is much sharper when online ties are weaker relative to offline relationships. With $\omega = 0.50$, the cooperation rate in fully local teams exceeds that of fully virtual teams by about 45% and with $\omega = 0.25$ this difference is even somewhat larger.

To understand how weaker ties erode social control in the learning model, consider Flache/Macy's (1996) explanation of why social control effectively sustains cooperation in the absence of virtual communication. Like in experiment 1 in the fully local team, cooperation is achieved through a self-reinforcing learning dynamic where actors' random search generates by chance an outcome that satisfies all group members with all their decisions. There is only one way how all group members can be simultaneously satisfied with both types of decisions in a fully local team under the parameters used in experiment 2. This is when everyone works hard and all group members

approve of their peers. If some group member takes it easy in his work, then all others will remain dissatisfied with their approval decision with respect to the shirker and keep changing their approval behavior. As a consequence, the shirker will sooner or later experience low levels of approval and be dissatisfied with his corresponding work decision. This, in turn, leads shirkers to change their work behavior so that at some point group members coordinate on the equilibrium of hard work combined with mutual approval. The level of 80% cooperation in fully local teams ($V = 0$) in figure 2 indicates that in iteration 1000 this point has on average not yet been reached for 20% of the group members. However, further simulation tests confirmed that the cooperation rate always increases up to 100% after a sufficient number of iterations (typically about 5000).

The larger the proportion of weak online ties, and the weaker these ties are as compared to face-to-face contacts, the more this may change the dynamics of backward-looking social control. For all group members, higher levels of team virtuality reduce the benefits from social rewards that actors can obtain in the evaluation of their work decisions (equation 4). For local team members, the approval of their virtual colleagues becomes less valuable, and for virtual team members it is the approval of every other team member that is less highly regarded. This also reduces actors' corresponding expectation level. As a consequence, the higher the degree of team virtuality, the smaller the impact that changes in the amount of approval for an actor can have on the actor's satisfaction with his effort investments. In other words, team virtuality reduces the power of the group to make workers satisfied and shirkers dissatisfied with their effort investments. This effect is particularly strong for virtual group members. To be sure, team virtuality does not change the basic assumption in experiment 2 that approval decisions are considered by every actor as dissatisfactory as long as they are directed towards a shirker. However, team virtuality makes shirkers less vulnerable to social pressures. In particular, the larger the proportion of weak virtual ties, the larger is the possible number of shirkers who may be shunned by most or even all of their colleagues, but who still remain satisfied with their shirking behavior. They remain satisfied, because they put much more weight on the wage benefits generated by their working colleagues than on their loss of social status in the group. This explains why in figure 2 cooperation rates consistently decline with increasing team virtuality and why this effect becomes stronger when online ties become relatively weaker.

Simulation experiment 3: the interaction of online-tie strength and team virtuality with affective dependence.

In the third simulation experiment we tested how team virtuality may interact with the negative effect of strong ties proposed by Flache/Macy (1996). The possible weakness of strong ties identified by Flache and Macy suggests an interesting new possibility for the effects of virtual communication on cooperation on work teams. Greater social distance of online interactions may avoid possible negative effects of social cohesion in those teams where members are highly affectively dependent on their peers. As a consequence, weaker ties in online interaction may promote cooperation in the work task, because they make it harder for affectively dependent team members to be satisfied by social contacts alone.

To test this argument, we adapted the conditions of simulation experiment 2 such that without affective dependence cooperation can thrive even in virtual teams. For this, we reduced the costs of work effort to $c = 0.15$, a level at which the group faces a moderate social dilemma. Furthermore, we kept the assumption of experiment 2 that normative pressure is a powerful motivator ($\beta = 0.2$), but online communication considerably reduces tie strength both normatively and affectively ($\omega = 0.25$). Finally, to test how affective dependence may change the effects of team virtualization, we varied affective dependence β' between a low, medium and high level, where the high level corresponds to a situation in which affective rewards are valued equally to normative rewards, while at the low level affective rewards are only 25% as valuable as normative rewards. That is, we used in the simulations $\beta' = 0.05, \beta' = 0.1$ and $\beta' = 0.2$, respectively. All other conditions were kept equal to simulation experiment 2. Figure 3 shows the results.

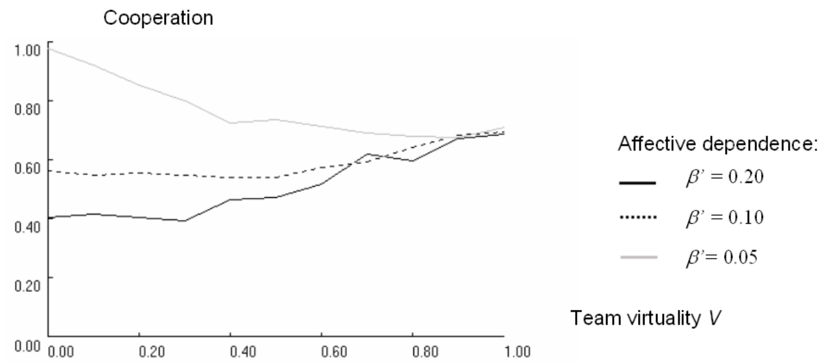

Figure 3: Interaction of team virtuality with affective dependence (β') on level of cooperation with high normative dependence ($\beta = 0.2$) and high rate of online-depreciation of tie-strength ($\omega = 0.25$). Cooperation rate measured as average individual propensity to work in iteration 1000, based on 100 replications ($N = 10, \alpha = 1, c = 0.15, \varepsilon = 0.0, r = 0.75$).

Figure 3 confirms the expected interaction of affective dependence with team virtuality on cooperation. More precisely, the figure shows that when actors' affective dependence is low ($\beta' = 0.05$), team virtuality reduces cooperation from a level of almost 100% in a fully local team ($V = 0$) down to about 70% in a fully virtual team ($V = 1$). Higher levels of affective dependence invert the effect of team virtuality. With $\beta' = 0.1$, team virtuality slightly increases cooperation levels from a rate of about 58% in a fully local team ($V = 0$) up to approximately 70% in a fully virtual team. This effect is even more pronounced when affective dependence is high ($\beta' = 0.2$), with a rise in cooperation from 40% in local teams ($V = 0$) to 70% in virtual teams ($V = 1$).

The negative effect of team virtuality under low affective dependence in figure 3 is generated by the same mechanism that shaped the negative effects of V displayed in figure 2. In a fully local team and with affective dependence much lower than normative dependence ($\beta = 0.2 = 4 * \beta'$), the unique equilibrium in which all players can be simultaneously satisfied with their work decisions and their approval behavior remains the state of universal cooperation and universal mutual approval. Just like without affective dependence, the learning process sooner or later converges on this equilibrium. Furthermore, as team virtuality increases, both normative and affective rewards loose their gratifying value in an increasing proportion of relationships in the team, and social control becomes less effective as a solution to the free rider problem.

When affective dependence exceeds the critical level of $\beta' = 0.1$, social control is even in fully local teams no longer effective. Equations 7 and 8 imply that now new equilibria in the learning mechanism arise in which all group members can be satisfied with their approval decisions as long as approval is reciprocated, regardless of the work effort of their colleagues. At the same time, universal mutual approval undermines the need to work, due to the still high normative value of peer approval, β. With sufficient affective dependence, this peer approval may now in equilibrium also be given to shirkers. On the other side, with $\beta = 0.2$, sufficient approval can make both workers and shirkers be satisfied with their work decision, even when most group members fail to contribute. Figure 3 shows the consequence of this, the level of only 40% cooperation in a fully local team with high affective and normative dependence ($\beta = \beta' = 0.2$), as compared to almost 100% cooperation in a fully local team with low affective dependence ($\beta = 0.2, \beta' = 0.05$). In this condition, an increasing level of team virtuality fosters rather than undermines cooperation. The reason is that with sufficient online-depreciation of tie strength, mere mutual approval is no longer enough to satisfy group members with their online social relations with shirkers. As a consequence, as time virtuality rises, an increasing proportion of the group is required to work hard before the learning process obtains an equilibrium state in which all members can be satisified with both work and approval decisions. As figure 3 exemplifies, this results in a positive effect of team virtuality on cooperation rates in those conditions where affective dependence is medium or high.

5. Discussion and Conclusion

We have proposed in this paper a formal model of the effects of virtual teamwork on trust and cooperation in a team. With this, we move beyond the existing literature in the field that is mainly based on case studies or employs theoretical arguments that lack explicit deductive model building. Our model incorporates three mechanisms identified in previous research that may underlie effects of team virtuality on cooperation at the workplace, lack of social context information in virtual communication, weaker ties in online interaction and lower affective dependence of team members on peer approval in weak online relationships.

Computer simulations revealed conditions that interact with the effects of increasing team virtuality. Our model implies that task uncertainty greatly exacerbates the negative consequences of lack of social context information on trust and thus cooperation between team members. Moreover, the simulations suggest that negative effects of the weakness of ties in online communication on informal control may be reduced when companies adopt policies that reduce the extent to which online interaction depreciates the gratifying value of peer rewards. This formal result replicates the emphasis that the literature puts on the need to flank virtual teamwork with regular offline meetings between team members. Finally, our analysis suggests a new hypothesis not recognized by previous research. Particularly in primarily local teams, social control may badly fail to sustain cooperation when team members are overly dependent on their peers for affective rewards, such as friendship relations. In such teams, higher virtualization of teamwork may facilitate cooperation, because with weaker ties workers are less prone to tolerate free riders for the sake of maintaining their social relations with them.

We believe that testing implications of our theoretical work may be a fruitful direction for experimental research on effects of virtual team work. Flache (1996) used an experimental exchange game with virtual communication between participants to test the hypothesized negative effects of bilateral exchange relations on collective good production. The experiments showed that such negative effects mainly occur when subjects have relatively low interest in high team performance. Future experiments may test whether this effect interacts with the extent to which communication between players is virtual. Negative effects of virtual communication may mainly show up in teams where incentives to cooperate are high, but virtual communication may help to reduce free rider effects when incentives are low. In a similar way, the conjecture derived from our simulations may be tested that team virtuality can have positive effects on cooperation when affective dependence of team members is high. To do this, experiments could directly manipulate affective dependence through variation in prior private exposure of subjects to each other. Another possibility is to use established measurement instruments from personality psychology to measure prior to an exchange experiment personality traits of subjects that affect their need for peer approval.

Our study employs a number of simplifying assumptions that prevent us from modeling the full richness of possible mechanisms through which virtual communication may shape teamwork. We assume in particular homogeneity of team members, while the literature points out that diversity in skills and backgrounds is particularly high in geographically dispersed virtual teamwork (Griffith/Neale 2001). Moreover, a virtual team often consists of employees in different organizational locations or departments, with different skills and backgrounds, who work together for a specific task (see e.g. Jarvenpaa/Leidner 1999). In its present form, our model does not represent this situation well. Instead, it rather matches the situation of one local team with a number of isolated external members who can only communicate via electronic means. However, our approach can be readily extended to include heterogeneity of team members, for example in terms of their dependence on peer approval and their capability to contribute to the team task. This can be done in particular by modeling a production function in which each team member needs to make his specific contribution to the common effort and each team member has different opportunity costs of effort that reflect specific demands from the team members' own 'home' department.

Another weakness of our study is that we have only insufficiently explored the parameter space of the model and the possible interactions effects between the three mechanisms we addressed. In particular, in order to complete our simulation study, it would be necessary to test whether the positive effects of team virtuality that we found for affective dependence would remain when the team also faces task uncertainty. We expect that task uncertainty combined with affective dependence may generate a tipping point in the effects of team virtuality on cooperation. It seems plausible that this tipping point arises from a combination of the negative effects of team virtuality under task uncertainty, shown in simulation experiment 1, and the positive effects shown in experiment 3 in the conditions with high affective dependence. Such a non-linear interaction effect would clearly be a new and innovative hypothesis in the field. Future research may show whether the model proposed in this paper is consistent with this intuition. In any case, we believe to have demonstrated that a formalized model of semi-virtual teamwork can both replicate findings from previous empirical work and generate new testable hypotheses that generalize beyond a small number of case studies.

Bibliography

Alchian, A./H. Demsetz (1972), Production, Information Costs and Economic Organization, in: *American Economic Review 62*, 777–795

Axelrod, R. (1984), *The Evolution of Cooperation.* NewYork

— (1997), *The Complexity of Cooperation*, Princeton

Bendor, J./D. Mookherjee (1987), Institutional Structure and the Logic of Ongoing Collective Action, in: *American Political Science Review 81*, 129–154

Bush, R. R./F. Mosteller (1955), *Stochastic Models for Learning*, New York

Caproni, P. J. (2001), *The Practical Coach: Management and Skills for Everyday Life*, Upper Saddle River

Edwards P. K./H. Scullion (1982), *The Social Organization of Industrial Conflict,* Oxford

Flache, A. (1996), *The Double Edge of Networks*, Amsterdam

— /M. W. Macy (1996), The Weakness of Strong Ties: Collective Action Failure in a Highly Cohesive Group, in: *Journal of Mathematical Sociology 21*, 3–28

— (2002), Stochastic Collusion and the Power Law of Learning: A General Reinforcement Learning Model of Cooperation, in: *Journal of Conflict Resolution 46*, 629–653

Friedman, J. W. (1971), A Non-Co-operative Equilibrium for Supergames, in: *Review of Economic Studies 38*, 1–12
— (1986), *Game Theory with Applications to Economics*, New York
Griffith, T. L./M. A. Neale (2001), Information Processing in Traditional, Hybrid and Virtual Teams: from Nascent Knowledge to Transactive Memory, in: *Research in Organizational Behavior 23*, 379–421
Handy, C. (1995), Trust and the Virtual Organization. in: *Harvard Business Review 73*, 40–50
Homans, G. C. (1951), *The Human Group*, New York
— (1974), *Social Behavior. Its Elementary Forms,* New York
Jarvenpaa, S. L./D. E. Leidner (1999), Communication and Trust in Global Virtual Teams, in: *Organization Science 10*, 791–815
Kirkman, B. L./B. Rosen/C. B. Gibson/P. E. Tesluk/S. O. McPherson (2002), Five Challenges to Virtual Team Success: Lessons from Sabre, Inc., in: *Academy of Management Executive 16*, 67–79
Kitts, J./M. W. Macy/A. Flache (1999), Structural Learning: Attraction and Conformity in Task-Oriented Groups, in: *Computational and Mathematical Organisation Theory 5*, 129–146
Kollock, P. (1993), An Eye for an Eye Leaves Everyone Blind: Cooperation and Accounting Systems, in: *American Sociological Review 58*, 768–786
Lipnack, J./J. Stamps (1997), *Virtual Teams: Reaching Across Space, Time and Organizations with Technology*, New York
Macy, M. W. (1989), Walking out of Social Traps. A Stochastic Learning Model for the Prisoner's Dilemma, in: *Rationality and Society 2*, 197–219
— (1991), Learning to Cooperate: Stochastic and Tacit Collusion in Social Exchange. in: *American Journal of Sociology 97*, 808–843
— /A. Flache (2002), Learning Dynamics in Social Dilemmas, in: *Proceedings of the National Academy of Sciences USA 99*, 7229–7236
Olson, M. (1965), *The Logic of Collective Action,* Cambridge
O'Mahony, S./S. R. Barley (1999), Do Digital Telecommunications Affect Work Organization?, in: *Research in Organizational Behavior 21*, 125–161
Petersen, T. (1992), Individual, Collective and Systems Rationality in Work Groups: Dilemmas and Nonmarket Solutions, in: *Rationality and Society 3*, 332–355
Raub, W. (1988), Problematic Social Situations and the Large Number Dilemma, in: *Journal of Mathematical Sociology 13*, 311–357
Seashore, S. E. (1954), *Group Cohesiveness in the Industrial Work Group,* Ann Arbor: University of Michigan Institute for Social Research
Simon, H. A. (1982) (first published 1955), Models of Bounded Rationality, in: *Behavioral Economics and Business Organisation 2*, 239–258
Taylor, M. (1987), *The Possibility of Cooperation*, Cambridge
Wong, S. S./R. M. Burton (2001), Virtual Teams: What are their Characteristics and Impact on Team Performance?, in: *Computational and Mathematical Organization Theory 6*, 339–360
Wu, J./R. Axelrod (1995), How to Cope with Noise in the Iterated Prisoner's Dilemma, in: *Journal of Conflict Resolution 39*, 183–189
Yamagishi, T./K. S. Cook (1993), Generalized Exchange and Social Dilemmas, in: *Social Psychology Quarterly 56*, 235–248