Cheap Talk, Cooperation, and Trust in Global Software Engineering: An Evolutionary Game Theory Model with Empirical Support

Yi Wang and David Redmiles
Department of Informatics
University of California, Irvine
Irvine, CA 92697
{yiw, redmiles}@ics.uci.edu

ABSTRACT

In our studies of global software engineering (GSE) teams, we found that informal, non-work-related conversations are positively associated with trust. Seeking to use novel analytical techniques to more carefully investigate this phenomenon, we described the non-work-related conversations by adapting the economics literature concept of "*cheap talk*" and studied it using Evolutionary Game Theory (EGT). More specifically, we modified the classic Stag-hunt game and analyzed the dynamics in a fixed population setting (an abstraction of a GSE team). Doing so, we were able to demonstrate how *cheap talk* over the Internet (*e-cheap talk*) was powerful enough to facilitate the emergence of trust and improve the probability of cooperation where the punishment for uncooperative behavior is comparable to the cost of the *cheap talk*. To validate the results of our theoretical approach, we conducted an empirical study that analyzed the logged IRC development discussions of Apache LUCENE[1] using both quantitative and qualitative methods. The results fit the theoretical predictions well. We discuss our findings and the theoretical and practical implications to GSE collaborations and research.

Categories and Subject Descriptors

D.2.9 [**Software Engineering**]: Management—*Programming teams*; K.4.3 [**Computer and Society**]: Computer-supported collaborative work

General Terms

Human Factors, Management, Theory, Economics

Keywords

Cheap Talk, Cooperation, Virtual Teams, Trust, Global Software Engineering (GSE), Evolutionary Game Theory (EGT), Stag-hunt Game, Apache LUCENE

[1]http://lucene.apache.org/

If a deer was to be taken, every one saw that, in order to succeed, he must abide faithfully by his post: but if a hare happened to come within the reach of any one of them, it is not to be doubted that he pursued it without scruple, and, having seized his prey, cared very little, if by so doing he caused his companions to miss theirs.
-Jean Jacques Rousseau: *On the Origin of the Inequality of Mankind*, The Second Part, 1754.

1. INTRODUCTION

You are chatting with a remote colleague on Facebook Messenger, sharing several well-lit photographs of last night's homemade dinner. You are so focused that you fail to notice that your manager standing behind you. Your manager becomes angry, and yells: "*Stop your stupid IM! It's wasting work time.*" This is a common reaction for most managers when they see employees using working hours to chat about something irrelevant to the job. Conventional wisdom claims that "talk is cheap," and it means nothing to your work except occupying your valuable time! Indeed, economists Farrell and Rabin [13] claim that *cheap talk* "*does not generally lead to efficiency.*"

However, our study finds that *cheap talk* in work environments may in fact have surprising benefits. Previously, we have conducted intensive field studies of Global Software Engineering (GSE) teams, focusing on their trust of remotely-located collaborators [1]. The data we collected reveals that those who engage in "*cheap talk*" (e.g., non-work-related online conversational behavior) in their cross-site communication with remote collaborators generally have higher trust (see section 2). *Cheap talk* over the Internet does incur some cost, yet many interviewees indicated the willingness to pay the cost when interacting with remote colleagues.

Proceeding from the result that cost-incurring *cheap talk* correlates with higher trust, we can hypothesize whether it also brings about better cooperation. We seek to investigate this question from a novel cost-benefit perspective (rather than, for instance, a social relationship perspective) in order to precisely and dynamically describe individuals' **strategic** behavior. Enabling us to analytically study interpersonal cooperation dynamics, Evolutionary Game Theory (EGT) provides insight into and techniques for exploring social group interaction trends [25]. Leveraging EGT, we can examine how *cheap talk* over the Internet influences interactions between GSE practitioners and potentially gives rise to the emergence of trust, and, in the long run, cooperation. Moreover, EGT can describe team level dynamics by predicting the proportions of members using different strategies.

The Stag-hunt game, which is introduced by Rousseau (see the prologue), is a natural description of mutual cooperation [33], and can be used as an abstract description of collaborations in GSE. We modify its classic form and add a new strategy to Stag-hunt by associating the concrete "cooperate" action with *cheap but not costless* talk. The modified game is played by a fixed number of players, allowing us to describe the dyadic interactions among team members and enabling players to update their strategies through social learning. Using this approach, we can investigate following research questions (RQs):

- RQ1: Can *cheap talk-cooperate* (*C-C*) self-reinforce if it is secured by situation-intrinsic incentives?
- RQ2: Can trust emerge and eventually become a cooperation-ensuring team convention if defectors' punishment is comparable to the cost of *cheap talk*?
- RQ3: What are the long-term dynamics (including frequency) of using *cheap talk*, particularly as cooperation and trust are established over time?

To validate the results derived from our theoretical model, we performed a case study on Apache LUCENE by mining logged IRC discussions. Our analyses provided general support to the theoretical results and predictions. For example, we observed the consistency between *cheap talk* and cooperation development, their precedence relationship, and *cheap talk's* disappearance in the long run. From a methodological perspective, this study demonstrates the feasibility of a novel approach, which integrates theoretical game theory model with empirical study, in developing generalizable, rigorous GSE knowledge.

The rest of this paper is organized as follows. Section 2 briefly introduces the prior empirical study motivating the present work. Section 3 introduces the Stag-hunt game, and related work on *cheap talk* and trust in GSE research. Incorporating the results presented in [37], Section 4 elaborates on the evolutionary game theory model, and Section 5 presents the analysis method and results. An empirical case study to Apache LUCENE's development IRC discussions is presented in section 6 to validate the model and its analytical results. Finally, sections 7 and 8 respectively discuss related issues and conclusions.

2. A MOTIVATING EMPIRICAL EXAMPLE

Investigating of trust in distributed teams (e.g., [1]), we found rich evidence of user's favorable attitude toward and frequent use of *cheap talk* during interactions with remote colleagues. Moreover, we noticed an association between *cheap talk* and trust. When we interviewed software developers in distributed teams, some of them reported that non-work-related *cheap talk* help build trust. According to the interviewees' narratives, we found that *cheap talk's* potential to, for instance, build common ground, develop close interpersonal relationships, and deal with cultural differences.

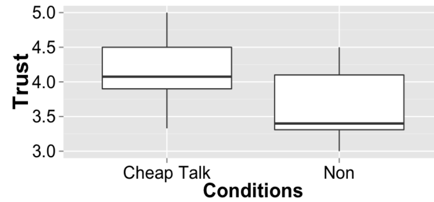

Figure 1: Collaborators engaging in *cheap talk* express higher trust levels compared to those who do not.

For example, one interviewee emphasized *cheap talk's* trust building role:

> *Yes, I think it's critical* [*for building trust*]. *We do try to bring people over at key planning junctures or transfers of technology. So some of the Poland engineers were here in early Q1 for cross training. A couple of them are here this week. I took them out for beer* [*and*] *laughs last week. One thing we do is we have a quarterly, we call it off site, where we just go out and do a social activity for team building. So that happens every quarter. When we have visitors we try to do something social in addition to the planning.*

In a GSE setting, it is difficult to maintain the face-to-face context of "real world" *cheap talk* at a satisfying level. However, collaboration tools allow for the transfer of *cheap talk* to the Internet. The interviewees mentioned that they spent extra effort and time on non-work-related activities via various tools, such as casual talk over IM, sharing personal pictures, discussing hot topics. For example, one interviewee reported a preference for instant messaging because "you can put in little characters like a smiley face or a wink." Another interviewee described the type of *cheap talk* afforded through remote online communication–"*Where are you calling from?..what's the weather like? is it hard to have to work at home in the evenings?*"–and how it can be used "*to maybe build up some sympathy.*"

However, some interviewees did not express any interest in *cheap talk* with remote colleagues, and in fact considered *cheap talk* valueless. Based on their opinions on *cheap talk*, the interviewees were coded into two categories (*non-Cheap talk* and *Cheap talk*). We also computed each individual's average trust score towards their collaborators.[2] In total, 43 interviews were collected. However, 2 of these were incomplete and did not include a trust score. Thus, in the end, we coded and analyzed 41 of these classifying 9 as *non-Cheap talk* and 32 as *Cheap talk*.

To identify whether there was a difference between these two categories, we performed a simple *independent sample t-test*. The results showed significant difference between these two groups' trust: *P-value: 0.013*, *Effect Size: 0.921 (Cohen's d)*, and hence significance at the 0.05 level while the *effect size* indicates the sample size is sufficient. The interviewees in the *Cheap talk* category exhibited higher trust (mean:

[2]Each interviewee was asked to locate her collaborators on a trust spectrum, which was then coded into a 5-level interval scale to produce her aggregated trust score.

4.152) than those in *non-Cheap talk* category (mean: 3.607). Fig. 1 illustrates the results.

3. BACKGROUND

3.1 Prior Research on Cheap Talk in SE

We first developed the formal concept of *cheap talk* in a previous paper [37], building on SE literature on non-work social workplace interactions. These social interactions are usually conceptualized in terms such as "socialization" [11], "small talk" [7, 34], and "water cooler" [18], and their importance has been noted in [12]. Dittrich and Giuffrida [11] identified socialization as one of four usage dimensions of IM in their qualitative study of a Danish/Indian global software team. They found that a few of the *Skype* chats were purely social, such as everyday chats around the water cooler in co-located settings, and argued that informal communications provide a channel for building trust and social relationships. However, they neither explained why the social chats helped to build trust, nor did they assess the measurable influence on the cooperation. Similar results were also reported by Cramton and Hinds [10], who argued that casual interactions smoothed the cooperation among individuals from three different cultures.

Guzzi et al [17] reported on a qualitative study of the LUCENE mailing list focusing on the communication patterns of open source developers. Three of their four "social interaction" categories were work-related and only one ("social norm": 3 in 506) had nothing to do with work. The other three ("acknowledgement of effort," "coordination," and "new contributors") were at least partially related to work, as their labels suggest. In general, SE researchers are beginning to pay more attention to how personal and affective factors influence collaboration in the development process. Some preliminary work by Calefato et al. [6] demonstrates that informal information from social media can augment social awareness and improve trust.

3.2 Moving Toward A Novel Perspective and New Approach

Prior studies reviewed above emphasize the role of a "*social relationship*" in informal interactions. However, the concept of social relationship cannot fully explain an individual's strategic choice nor how a communication strategy evolves into a norm at the team level. Adapted from the Economics literature, *cheap talk* affords us a unique cost-benefit perspective on studying non-work-related interactions among developers and enables us to use a variety of analytical techniques. Whereas economists develop Evolutionary Game Theory (EGT) models to explain the social behaviors in generative way, software engineering researchers are familiar with empirical field study to develop practice-oriented knowledge. With the goal of developing rigorous, elegant theoretical explanations and predictions (which EGT does well), while maintaining the validity and relevance of theoretical results (via empirical field study), our study uniquely combines these two approaches.

By leveraging EGT techniques, we can dynamically investigate the strategic interactions among a fixed number of individuals (an abstraction of a "*team*") as well as, to derive analytical results and predictions for describing long-term individual strategy changes and team dynamics in the long run. Descriptive studies focusing on social aspects are more static and often fail to characterize team level dynamics. Furthermore, with simple assumptions (the Stag-hunt game and strategic behavior change rule), EGT enables us to deductively establish propositions to answer "how" *cheap talk* influences trust and cooperation. We can then use empirical study to validate these generatively-developed propositions, which forms the integrated Deductive-Nomological (D-N) model [22] of scientific knowledge development that ensures both rigorous and relevance.

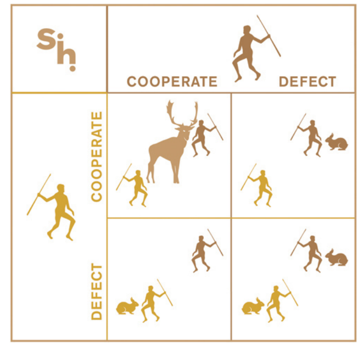

Figure 2: A visual illustration of Stag-hunt game, ©*Michael Nelson*.

$$\begin{array}{c c} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} R & S \\ T & P \end{pmatrix} \end{array} \qquad \begin{array}{c c} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} 2 & 0.5 \\ 1.5 & 1 \end{pmatrix} \end{array}$$

Figure 3: Payoff structure of a general Stag-hunt game along with a numerical example.

3.3 The Stag-Hunt Game

The classic Stag-hunt game is a non-zero-sum, 2 by 2 game in which each player has two strategic choices: *cooperate* or *defect* (see Fig. 2). In ancient times, two men hunt for food. If both defect, they would hunt individually, and each would get a hare. If both cooperate, they could kill a stag, and each would receive one half stag. If one cooperates while the other defects, the *cooperator* would receive nothing and the *defector* would receive a hare. Formally, theStag-hunt game can be represented by the first payoff matrix in Fig. 3 if $R > T > P > S$. Compared to the Prisoner's dilemma (if $T > R > P > S$), "*cooperate*" is not strictly dominated by "*defect*" in this game. The state of (*cooperate*, *cooperate*) is a payoff-dominated equilibrium, while (*defect*, *defect*) is a risk-dominated equilibrium. Which one can be achieved is determined by players' belief in her opponent: namely, her trust [32].

Compared to the Prisoner's Dilemma, the Stag-hunt game is generally less used in investigating the evolution of human cooperation. However, it is a better and more natural representation of real world cooperation [32]. The most significant advantage of the Stag-hunt game is that it allows "*cooperation*" to be achieved by rational players. In the Prisoner's Dilemma, one cannot be "cooperative" while "rational" because the only equilibrium is (*defect*, *defect*). Stag-hunt has no such restriction; (*cooperate*; *cooperate*) is also an equilibrium.

3.4 Software Development as Stag-Hunt

The Stag-hunt game is a natural metaphor of dyadic (one-to-one) collaborations[3] in software engineering activities. In many cases, developers do not necessarily need to cooperate with others to get their jobs done ("receive a *Hare* as payoff"), even when their work items are highly interdependent. However, less cooperation may influence the quality of their work. Cataldo et al. [8] pointed out that the communications among developers can have significant influence on the quality of a software system even though work items can be finished independently. Thus, collaboration can produce higher quality work ("receive a half *Stag* as payoff"). In some cases, a software engineer may believe that her colleague will cooperate, but things do not go as she expects. Thus she may experience some "unfavorable" results (e.g., fail to deliver a commitment on time) due to the other's "defect," while the other is still able to achieve the utility of individual action ("receive a *Hare* as payoff"). Hence, dyadic collaboration in software development can be analogous to Stag-hunt, allowing us to use standard EGT techniques to investigate collaborations in software development.

3.5 The Stag-Hunt Game's Evolution in Fixed Population Setting

In software development, developers are often organized into teams comprising many more than two individuals. Considering Rousseau's scenario in the quotation at the beginning of this paper, the Stag-hunt game is an excellent abstraction to this multi-player scenario. Supposing a group of people play this game together, it is possible to study whether all of them adopt the "cooperate" strategy after long-term interaction. For the Stag-hunt game, both "cooperate" and "defect" are evolutionarily stable in the infinite population setting [32]. In the numerical example in Fig. 3, "all-cooperate" has no significant evolutionary advantage to "all defect," since it requires that over 50% of individuals have already adopted "*cooperate*" in the initial state to reach the final "all-cooperate" state.

3.5.1 Fixed Population Game

Software development teams are not infinite; they are usually very stable in their life cycle [5]. For instance, a software project team often consists of the same staff, or often experiences only small changes. Still, we need to investigate human interaction in software development teams under the assumption of fixed population. In a fixed population game with two strategies $\{A,\ B\}$, an increase of individuals using strategy A will definitely lead to a decrease of individuals using strategy B. No strategy switch is independent. Therefore, evolutionary dynamics in a population of finite size requires a stochastic theory [14]. To study the long-term interaction, fixed population game, Nowak et al. used stochastic process to develop new techniques [15, 26] (see section 5), yet the results remain similar; both "all-cooperate" and "all-defect" are quite stable. For the numerical example, the time spent on both homogeneous states is almost the same in the long run, while the probabilities of switches occurring between them are fairly small [39].

3.5.2 Trust Helps!

We can now conclude that cooperation cannot be established spontaneously in the classic Stag-hunt game when it is repeatedly played by a fixed number of players. As [33] pointed out, cooperation requires a moderate level of trust to overcome the worry of potential loss. Cooperation and trust-building develop are in an interrelated, co-evolving process. The implicit trust-building process results in explicit cooperative action in interpersonal interactions. We have pointed out that *cheap talk* does correlate to GSE team members' trust; thus, it is reasonable to assume that *cheap talk* may facilitate cooperation and trust.

[3]In the scope of this paper, the cooperation is restricted to dyadic interactions to simplify the analysis and discussion.

4. THE ANALYTICAL MODEL

Given the discussion in section 3, we will extend the classic Stag-hunt game to analytically explore the role of *cheap talk* in trust and cooperation development. In this section, we develop a new game that allows *cheap talk* to be associated with a new strategy in interpersonal interaction.

4.1 Talk is Still Cheap, but NOT Free

A typical way to model *cheap talk* is to treat it as a costfree *signal* with no predefined meaning. Imagine that you talk about your dog with your officemates; you pay nothing for this type of conversation. Furthermore, although irrelevant to your work, but it does convey some kind of signal. These signals gain meaning with the progress of interaction, and thereby increase the possibility and frequency of collaboration [29]. However, in GSE, *cheap talk* often occurs over the Internet via various collaboration tools like IM. *Cheap talk* requires individuals to expend extra time and effort. Thus, while not free, this type of interaction is *cheap* when compared of the benefits to cooperation. In this sense, *signal* is no longer a good abstraction; *cheap talk* is actually a concrete action rather than a costfree signal, although it is still cheap. We denote this type of *cheap talk* as "*e-cheap talk*."

4.2 The Stag-hunt Game with Cheap Talk

To capture the essence of *e-cheap talk*, we make a slight change to the classic Stag-hunt game. The new game has three strategies instead of two. To set up an *e-cheap talk* over the Internet, the proposer must pay a small management cost (e.g., spend extra time to upload pictures). We reasonably assume that the cost is small compared to the benefits from the cooperation ($e << R$). It may not be constant, but it is likely that the fluctuations do not span different orders of magnitude. Furthermore, to simplify the discussion, we suppose that players' preferences remain consistent (i.e., there is no execution noise). If a player decided to start *e-cheap talk*, she would use the "*cooperate*" strategy in the following interaction. So, we add a new strategy called "*C-C*" and make the new game contain three strategies $\{C\text{-}C, C, D\}$.

If two players chose $C\text{-}C$ in their interaction, they would share the cost of *e-cheap talk*, and thereby each could receive $R\text{-}e/2$ payoff. Note that, even in cases that only one pays the cost, the **average** payoff of playing ($C\text{-}C$, $C\text{-}C$) is still $R\text{-}e/2$ in the long run. If one plays $C\text{-}C$ while the other plays C, the first will pay the cost all by herself. Her payoff is ($R\text{-}e$, R). If a player of $C\text{-}C$ meets another player of D, the second player may be punished for refusing to cooperate.[4] We assume that the punishment equals g and the $C\text{-}C$ player receives

[4]Punishment may take many forms, e.g., reputation loss.

$$\begin{array}{cccc} & C\text{-}C & C & D \\ C\text{-}C & R\text{-}e/2 & R\text{-}e & S\text{-}e\text{+}g \\ C & R & R & S \\ D & T\text{-}g & T & P \end{array} \qquad \begin{array}{cccc} & C\text{-}C & C & D \\ C\text{-}C & 1.9 & 1.8 & 1.3 \\ C & 2 & 2 & 0.5 \\ D & 0.5 & 1.5 & 1 \end{array}$$

e=0.2, g=1

Figure 4: The payoff structure of the Stag-hunt game with *e-cheap talk* and a numerical example ($e = 0.2$, and $g = 1$).

a compensation (the same amount as the punishment), and thus the payoff of this interaction is *(S+g-e, T-g)*. Retaining this part of the payoff structure as it is in the classic form,[5] Fig. 4 illustrates a modified Stag-hunt game with *e-cheap talk* and a numerical example. For this numerical example, "all-cooperate" is the only evolutionarily stable state for in population setting. However, how "all-cooperate" is achieved with *e-cheap talk* is still unclear, and the result does not fit the fixed population setting.

5. THEORETICAL ANALYSIS & RESULTS

To simulate the team setting, the new Stag-hunt game will be played by a fixed number (N) of players. Using the analysis technique to be introduced in section 5.1, we reveal the long-term dynamics of cooperation with a 100-member team as an example, and conditions to enable long-term cooperation (see section 5.2). The findings provide answers to the research questions highlighted in the introduction.

5.1 Analysis Method

Our analysis is based on EGT methods for finite populations (e.g., [24, 26]) and stochastic process analysis techniques (e.g., [15, 36, 16]). In EGT, the individuals' payoff represents their *fitness* or *social success* [27]. A population's strategy change is followed by learning dynamics, i.e., the most successful individual will tend to be imitated by the others. In our discussion, we use simple standard birth and death chains[6] to describe the switch between strategies. We follow the method in [24] to assume that in any period there are at most two coexisting strategies (for convenience: i and j). Suppose one player decides to try i in a state in which the whole population takes strategy j, this would eventually lead to two situations: first, this single i-player may bring the whole population to play i; second, the i-player may return to play j. The probability of the first situation is called as fixation probability: ρ_{ji}, while the probability of the second situation is 1-ρ_{ji} (see Fig. 5 for a more intuitive description).

If $\rho_{ji} = 1/N$, i has no evolutionary advantage over j, for $1/N$ represents pure neutral selection [15]. The switches from all-j and all-i result in a Markov Chain. With these assumptions, we can write the fixation probability ρ_{ji} in the following form if $j \neq i$:

$$\rho_{ji} = \frac{1}{1 + \sum_{k=1}^{N-1} \prod_{l=1}^{k} \frac{g(l)}{f(l)}} \tag{1}$$

[5]It is reasonable to assume that, in the classic game, the player who plays *defect* would not be punished since there is no reason for her to give up a risk dominated strategy without any hint to predict her opponent's action.

[6]Informally, for a fixed population, a single individual strategy switch from j to i can be viewed as the "*death*" of a j-player and the "*birth*" of an i-player.

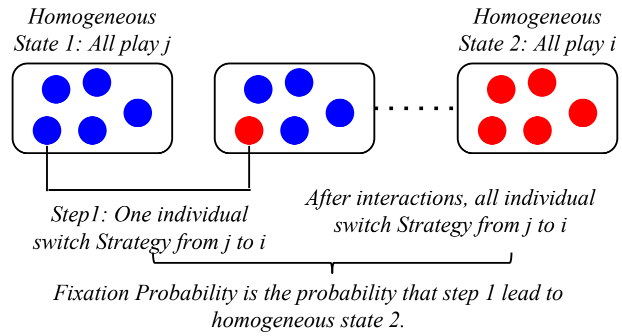

Figure 5: Strategy switch process and fixation probability.

Here, $g(l)$ and $f(l)$ refer to the fitness of playing j or i when there are l individuals playing strategy i. Using π_{ij} to denote payoff in an i-j interaction, they are given by (2) and (3):

$$g(l) = \frac{\pi_{ji} l + \pi_{jj}(N - l - 1)}{N - 1} \tag{2}$$

$$f(l) = \frac{\pi_{ii}(l - 1) + \pi_{ij}(N - l)}{N - 1} \tag{3}$$

After calculating all ρ_{ij}, and assuming that the mutation limit is $\mu > 0$, we can form an irreducible Markov process to describe the transition between strategies. The diagonal element of the transition matrix is $1 - \mu \sum_{j \neq i} \rho_{ij}$. We can calculate the long-term stationary distribution for all homogeneous states ("all-cooperate," "all-defect," and "all-C-C").

5.2 Analysis Results

5.2.1 Dynamic Long-Term Analysis

In this section, we show the analytical results of the specific numerical example in Fig. 4 by using the method introduced in section 5.1. Supposing in a 100-member team (N=100), the stationary distribution and fixation probabilities (those are stronger than neutral, i.e., $\rho_{ji} > 1/N$) of the three homogeneous states are described in Fig. 6[7]. In this example, the result is very sharp. "all-defect" and "all-C-C" would disappear in the long run, which indicates that almost all individuals eventually learn cooperation and build trust. In this example, the punishment (g in Fig. 4) is large enough so that "*defect*" strategy is strictly dominated by "*C-C*," which leads to the disappearance of "all-defect." Besides, "cooperate" also strictly dominates "*C-C*." However, if the punishment (incentive) was small enough, e.g., $S - e + g < P$, we could expect the "all-defect" might survive in the long run.

The strengths of the transitions differ, which helps us to identify precisely how transition occurs. As figure 5 indicates, the transition from "all-defect" to "all-C-C" is rather strong while the transition from "all-C-C" to "all-cooperate" is not so strong. The other transitions are relatively weak, for example, the transition probability from "all-cooperate" to "all-C-C" is only 2.62×10^{-5}. This indicates the important

[7]The arrows between the three homogeneous states are neither necessary nor possible to indicate how the actual transition happens, they just indicates the pairwise transitions with probability (calculated using equation 1, 2, and 3) stronger than neutral. For example, it is possible that while some "defectors" are still in process to change themselves to "*C-C*" players, some "*C-C*" players have already become "cooperators."

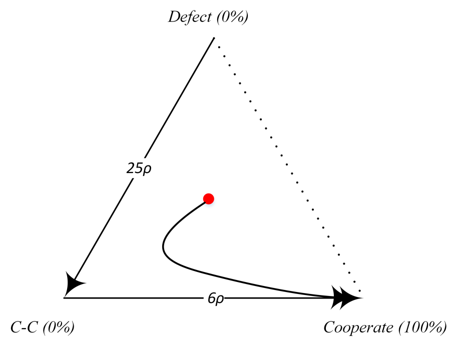

Figure 6: The simplex describes the fixation probability between three homogeneous states and their stationary distribution in the long run ($N = 100, \mu = 1, \rho = 1/N$). Only transitions stronger than ρ are shown. A possible route for a non-homogeneous state (represented by the red point in the middle) to reach the stable state is depicted.

catalytic effect of *C-C* in moving the individuals from *defect* to *cooperate*, although it would disappear in the long run.

For hybrid states consisting of populations with different strategies, there is a similar way to reach a final "all-cooperate" state. At an individual level, a "defector" will first become a "*C-C*" player and then become a "cooperator." A hybrid state (indicated by the red point in the central of the simplex) may follow the transition patten described in Fig. 5. Some defectors change to "*C-C*" players, while some "*C-C*" players change to cooperators in parallel. However, in the long run, all hybrid states cannot survive, therefore the transition is temporary. In our analysis, "*C-C*" disappears eventually, but it plays a central role in bringing the system from the unfavorable state full of defectors to satisfying "all-cooperate."

In some cases, keeping to "*C-C*" is also an acceptable and possible alternative. When compared to the cost of setting up or managing the *e-cheap talk*, *C-C* player can avoid being exploited by the defectors (Defect), while maintaining approximately equally good payoff against the pure cooperators (Cooperate) for $\epsilon << R$.

5.2.2 Conditions for Long-term Cooperation

Independent of the above numerical example, in general, what conditions ensure the transition from *defect* to *C-C*, and from *C-C* to *cooperate*? If these conditions can be identified, they could be applied to high-level organization or computer supported collaborative systems design to promote cooperations in a straightforward way. To answer this question, we use an important analytical measurement to identify pairwise evolutionary advantageousness in the long run [24]. For the two strategies i and j, if the following condition holds, the transition from j to i is more probable:

$$(N-2)\pi_{ii} + (2N-1)\pi_{ij} > (N+1)\pi_{ji} + (2N-4)\pi_{jj} \quad (4)$$

If N is large enough, the above condition can be reduced to:

$$\pi_{ii} + 2\pi_{ij} > \pi_{ji} + 2\pi_{jj} \quad (5)$$

The transition from *C-C* to *cooperate* is guaranteed to be more probable if:

$$R + 2R > R - e + 2(R - \frac{e}{2}) \ \Rightarrow -2e < 0 \quad (6)$$

which automatically holds when $e>0$. Obviously, this transition is guaranteed by the payoff structure in this model. The transition from *defect* to *C-C* is guaranteed to be more probable if:

$$R - \frac{e}{2} + 2(S + g - e) > T - g + 2P \ \Rightarrow \quad (7)$$

$$g > \frac{T + 2P - R - 2S}{3} + \frac{5e}{6} \quad (8)$$

So far, we have presented analytical and numerical results. Both indicate that *e-cheap talk* is sufficient to improve the probability of cooperation so long as the punishment to *D-player* is comparable to her opponent's cost of using *C-C* and the transition from *C-C* to *cooperate* is almost destined. Moreover, this result is independent of team size for "N" has been eliminated in equation (8).

5.3 Analytical Answers to Research Questions

The main analytical findings are summarized in three propositions:

- PROPOSITION 1. *e-cheap talk is sufficient to promote cooperation if punishment to a defector is comparable to his opponent's cost of using C-C.*
- PROPOSITION 2. *Trust is developed implicitly with the explicit improvement of cooperation, and further ensures the cooperation.*
- PROPOSITION 3. *e-cheap talk decreases or even disappears once trust and cooperation are fully developed, and it functions as a catalyst in this process.*

These three propositions provide answers to the research questions in section 1. Proposition 1 and 2 provide confirmative answer to RQ1 and RQ2. Proposition 3 answers the long-term dynamics of *e-cheap talk* (RQ3). They can be validated empirically. We can expect the following empirical observations: (1) there is strong correlation between *e-cheap talk* and cooperation. If a pair of individuals use *cheap talk*, they are likely to also cooperate on work-related issues. (2) *e-cheap talk* should occur between individuals prior to work-related talk. (3) *e-cheap talk* will gradually decrease with the progress of cooperation.

For a real world GSE team, the theoretical model provides a possible explanation for how trust develops within the team using *e-cheap talk*. At the beginning of GSE cooperation, team members have less confidence about whether or not their remote colleagues will behave cooperatively. Therefore, they may prefer to use *e-cheap talk* to exhibit their willingness to cooperate. The collaboration then establish whether remote colleagues respond cooperatively (either using *e-cheap talk* or directly cooperate). The individuals who initiate *e-cheap talk* would not experience significant loss even if the others decide not to cooperate for the defectors' punishment ensures the cost of *e-cheap talk* will be compensated. However, once cooperation has established, people may feel they can directly devote all their effort toward collaborating with remote colleagues without using *e-cheap talk* as a costly "probe." Although others may still defect, they are willing to take this risk, and they begin to trust that others will not defect. In GSE practices, we can expect that team members will use less *e-cheap talk* as cooperation progresses.

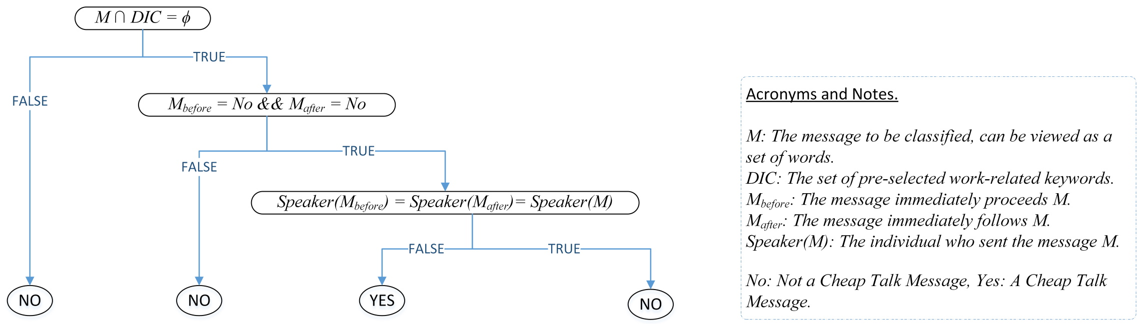

Figure 7: The decision tree for classifying *cheap talk* messages and corresponding rules.

6. CASE STUDY: APACHE LUCENE'S IRC DISCUSSIONS (#LUCENE-DEV)

To validate the results derived from the analytical model, we performed an analysis of Apache LUCENE's IRC discussion. The results of this empirical study provided general support to the theoretical propositions, thus supporting the validity of the analytical model and its results in a real world GSE setting.

6.1 Case Study Design

LUCENE is an open source information retrieval framework and API. We chose LUCENE and its IRC channel #lucene-dev because: (1) LUCENE is a mature project with stable core development team, which enables us to study long-term interactions. (2) LUCENE has two IRCs: general IRC channel #lucene, and logged channel #lucene-dev, and since #lucene-dev exists solely for the purpose of discussing and recording issues related to development among developers. This allows us to be more focused as well as reduces "noisy" general user message interference. (3) Compared with email archival, the interactive, near-synchronous IRC chats are more similar to day-to-day offline conversations. According to [17], pure *cheap talk* email threads only account for 0.6% of all emails (see section 3.3). An email may contain both *cheap talk* and work-related talk, making it difficult to classify. Besides, developers participate in less than 75% of all email threads, while development related threads only account for 35% [17].

Our study sample comprised all logged messages from 04/15/2010 to 12/31/2012, which we collected from #lucene-dev's plain text file online archive. We downloaded and extracted message with three elements: time, sender, and content, excluding the auto-generated login (out) messages. In total, we have 18216 messages (excluding the simple greeting or confirmation message, e.g., yes/no, "thanks" or "good morning"). Using the three expectations (see section 5.3) derived from theoretical propositions as working hypotheses, our empirical analysis consisted of the following steps: (1) We classified all messages into two categories: *cheap talk* messages and work-related messages. A lightweight qualitative analysis was performed to all *cheap talk* messages in order to gain basic understanding about *cheap talk* in LUCENE. They were open coded and merged in later analysis. (2) We identified all work-related dyadic cooperation pairs and *cheap talk* pairs to explore the relationships between *cheap talk* and cooperation (Proposition 1 and 2). (3) We applied statistical methods to study the dynamic pattern of *cheap talk* (Proposition 3). In general, the empirical data provides moderate level support to the theoretical predictions, and no contradiction was found.

6.2 Data Preparation: Message Classification

We developed a simple, rule-based, decision-tree classifier to automatically classify the messages into two categories: *cheap talk* messages and work-related messages. Three heuristics determined classification: (1) *Cheap talk* should not contain a set of specific keywords (dictionary[8]) such as: issue, bug, or Java. (2) If messages immediately before and after an unclassified message are work-related, there is a near impossibility the message is *cheap talk*. (3) *Cheap talk* is usually more interactive than work-related talk, whereas the latter may comprise several messages in clarifying a problem. Therefore, if a message is surrounded by messages from same sender, it is less likely to be a *cheap talk*. Simple greeting or confirmation messages (e.g., "yes/ok,") were not classified, but they were retained for the rule (3) requireing their presence as context. Fig. 7 describes the decision process and the rule applied to each decision step. The classification resulted two sets of labelled messages. The number of *cheap talk* messages (n=1296) is far less than the number of work-related ones (n=16920).

Given that, the number of *cheap talk* messages are far less than work related talk, we simply performed a manual post-classification results check. The decision rules ensured that it is almost impossible for a *cheap talk* message to be classified as "work-related." Specifically, the classification method almost only generates *false positive cheap talks*. We randomly sampled 500 messages classified as "work-related" and found only one instance of *cheap talk* message ($precision =$ 99.8%). After the classification finished, we read through all of them and manually excluded all false positives ($n =$ 38). Compared with more sophisticated techniques (e.g., *D-tree* induction), our simple approach avoided the tricks in constructing proper training set, and works well for this specific classification. The dictionary of pre-selected work-related keywords integrated common and domain knowledge into the classifier and is highly extensible.

6.3 Empirical Study Results

6.3.1 e-Cheap Talk in #lucene-dev

e-cheap talk covers various topics, including weather, food, hometown, politics, or even personal life[9]. Compared with

[8] This study's dictionary contains 66 keywords.

[9] We quote three representative examples (example 1-3) literally except for some formatting.

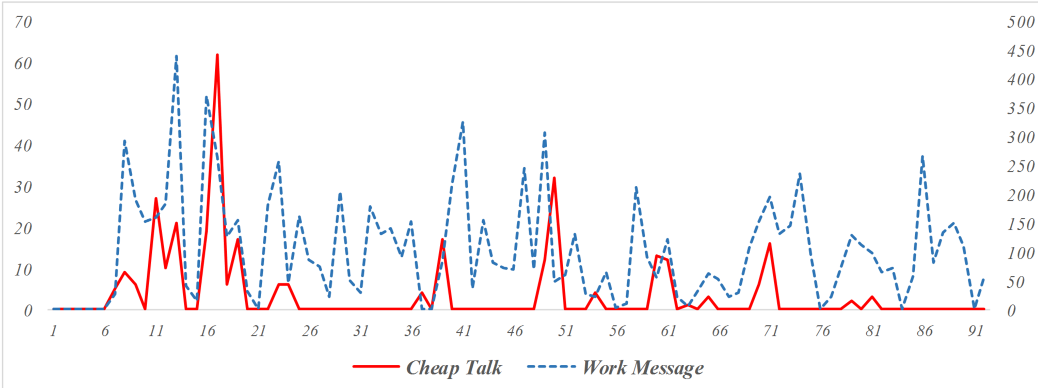

Figure 8: The dynamics of *cheap talk* and work-related message over time (left axis: *cheap talk*, right axis: work message).

the social interactions messages in mailing list [17], the topics are much more diverse. Furthermore, *cheap talk* can be intentional or impromptu. Intentional *cheap talk* is usually used to show one's friendliness and minimize social distance [7], for example, presenting some information may be unfamiliar and interesting for others (example 1), or introducing one's backgrounds(example 2). The latter is more situational and often triggered by some event. For instance, example 3 was triggered when a Russian developer joined the #lucene-dev. In general, intentional *cheap talks* are more common than impromptu ones.

> Example 1: *state vs federal rights is still a big topic in the US. do you know about the health care legislation that recently passed the US congress? (American Politics)*
> Example 2: *hamburg is near but its also a separate region. and hanover but it does not share. hannover is the capitol of lower Saxony, so bremen is an island :-) (Hometown)*
> Example 3: *my girlfriend can speak Russian, she is a super hot Estonian. (Personal Life)*

As our model predicts, ignoring *cheap talk* is not a proper behavior. Punishment to uncooperative responses to *cheap talk* does exist and takes various forms. The most common punishment is rejecting a *cheap talk* defector's future cooperation request. In our sample, there are 6 instances of explicit punishments via direct refusals to defector's cooperation request. In one extreme case, the defector left #lucene-dev since no one was interested in cooperating or talking with him any longer.

6.3.2 e-Cheap Talk and Cooperation

Our study found strong correlation between *cheap talk* and cooperation. We extracted all dyadic cooperation pairs by identifying "send-reply" patterns from work-related messages. For *cheap talk* messages, we identified dyadic pairs using the same method. In total, there are 136 pairs of cooperators engaging in work-related discussions, and 101 pairs of *cheap talks*. Almost 70% work-related pairs (95 in 136) are also in the set of dyadic *cheap talk* pairs. Only 6 *cheap talk* pairs did not have any work-related talk. We further explored the temporal relationship between a *cheap talk* pair and its corresponding work-related pair. 90.5% (86 in 95) *cheap talk* pairs appeared before the corresponding work-related pairs. These results at least partially indicate: (1) *Cheap talk* correlates to cooperations. If two individuals use *cheap talk*, it is probable that they also cooperate. (2) A cooperative relationship may result from *cheap talk*. At least, *cheap talk* is not caused by cooperation for most cooperations are behind of the appearance *cheap talk*. These form some support to Propositions 1 & 2. Although we cannot directly measure trust in this study, the literature on virtual collaboration often uses the establishment of cooperation as a good indicator of trust [3].

6.3.3 The Dynamics of Cheap Talk over Time

The frequency of *cheap talk* changed drastically since the launch of #Lucene-dev. From 04-15-2010 to 04-30-2011, #lucene-dev was very inactive except for the first two weeks. During that period, there were few number of *cheap talk*, and the number of work-related message was also small. Specifically, there were zero chats in 90 consecutive days (12-04-2010 to 03-03-2011). In May 2011, the LUCENE project decided to better utilize the #lecune-dev to ensure the discussions among code contributors would be logged, and discussions did increase in frequency.

However, the dynamic patterns of *cheap talk* and work-related message are quite different. The number of *cheap talks* continued to decrease. *Cheap talk* also almost disappeared eventually in about three months after the migration of development activities to #lucene-dev. Fig. 8 visualizes the differing dynamics of both *cheap talk* and work-related message from 05-01-2011 to 07-31-2011. Unlike the decreasing trend of *cheap talk*, there are no significant variations for work-related talk except for a weekly cyclical effect. There were several boosts in *cheap talk*, but those were mainly due to the several core developers joining the new IRC channel later than usual.

By modeling the dynamics of *cheap talk* and work-related message as two time series (from 05-01-2011 to 07-31-2011), we statistically tested their cointegration[10] to examine their distinctiveness. We followed *Engle-Granger* two-step method: we first constructed the spread through OLS and then tested the unit root with the *Augmented Dickey-Fuller* (ADF) test. The test was performed using **R** package ***fUnitRoots***. The ADF *p-value* is 0.162, hence these two dynamics are not

[10]Two time series are cointegrated if they share a common stochastic drift, see [28] for more details.

cointegrated and do not exhibit similar change patterns.

Exactly as the model predicted, the *e-cheap talk* plays important role in developing cooperation and trust. Once cooperation and trust becomes stable, an individual may not be willing to pay the cost of *e-cheap talk*, directly switching to "cooperate" mode since she can expect (and "*trust*") the others will have similar expectation or behavioral choices. This supports the theoretical proposition 3's prediction of the decreasing trend of *cheap talk* in the long run.

7. DISCUSSIONS

7.1 e-Cheap Talk and Trust Development

Combining game theory deduction and empirical study, the study described in this paper provides an alternative explanation of how, in the presence of punishment, *e-cheap talk* can create trust. In the Stag-hunt game, cooperation requires at least moderate trust. Without trust, individuals may not expect others to choose the cooperate strategy in their interaction, and thereby defect to avoid risk. With *e-cheap talk* acting as a **catalyst**, trust emerges from the cooperation and ensures cooperation. The *e-cheap talk* guarantees the loss in a failed "cooperation trial" can be offset by punishment/incentive enforcement, leading to increased willingness to explore cooperation. In this process, trust toward others, or more precisely, trust of others' "rationality," eventually develops and "cooperation" becomes the mainstream choice. The improvement of cooperation can be observed while trust development is more implicit, however, they are essentially two faces of the same process. Our study's model employs cost-benefit perspective to study "social interactions" among software developers in strategic level brings new insights. For example, our model predicts that *e-cheap talk* will gradually disappear with the progress of the cooperation, which is rarely mentioned in prior literature. And we furthermore demonstrate *e-cheap talk's* positive impact in GSE collaboration.

7.2 Cooperation & Trust in A Social Network

The model we proposed does not consider a network effect. All players are equally important with respect to their positions in a fully connected network. However, in the real world, team members are often located in their social network with different positions. The network structure influences the evolution of cooperation and trust development. In such cases, the social network plays a key role in enhancing organizational learning with key members being a source of information for software engineering activities [35]. For example, people in different locations may communicate through specific individuals as "hubs." If trust were first built among these "hubs", it may take much less time for the whole team to development trust. Moreover, top-down, dictator-style communication may be disadvantageous to the emergence of cooperation and trust [4]. We plan to extend the model presented in this paper to incorporate social network effects.

7.3 Design Implications

Our theoretical and empirical results lead to some design implications. For example, as equation (8) indicates, ensuring the transition from *defect* to *C-C* requires the punishment/incentive to be comparable to the cost of *e-cheap talk*. Without drastically increasing the punishment, reducing the cost of *e-cheap talk* is a matter-of-course (see the right part of the equation(8)). Innovative tools may help to fulfill this requirement, and organizational networks will potentially improve or hinder the cooperation development. Hence, redesigning organizational structure would help. We will discuss the implications to both collaboration management and tools.

7.3.1 Implication to Collaboration Management

Sharing non-work-related information should be encouraged, especially in the early phase of cooperation and trust development (see our propositions in section 5.3). Prior studies [31] show that even a personal picture may be very helpful to trust-building. Furthermore, organizational communication structure affects collaboration, work performance, and the quality of software deliverables [19] [21]. Specific communication structures promote or hinder the trust and collaboration development among developers. As we mentioned in section 7.2, the top-down, dictator-style communication is generally disadvantageous to the emergence of cooperation and trust. Therefore, cooperation and trust would benefit from increased participations of general developers who are not in central positions. Furthermore, although some communication network structures are very efficient, they are not stable enough for the imbalance of cost. For example, the individual (often leaders of project) in the center have to pay most of the cost since all communications rely on her as a "repeater." If the cost is high, the network may break down before the development of cooperation. hence, reducing the cost is crucial. Open communication will help to reduce the cost and mitigate the imbalance of cost distribution among members, and thus, should be encouraged in management practices (e.g., logging all conversations).

7.3.2 Implications to Tools Design & Usage

Web 2.0 tools are primary *e-cheap talk* channels. However, [2] pointed out that their utilization is not encouraging, for instance, managers often believe these tools cause interruptions to normal work, hence do not want to support the use of them at the organizational policy level. Our analysis shows that *e-cheap talks* over Web 2.0 tools are worth a try. Managers may need to be more open to the usage of Web 2.0 tools in order to promote *cheap talk*, and a more proactive/aggressive alternative may be integrating *cheap talk* to normal workflow. A developer does not need to intentionally interrupt work to initiate *cheap talk*, for instance an automatically-captured photo of the developer shared on a group page offers a form of cheap information. This approach can serve as an alternative to integrating IDE with social media, e.g., internal "Facebook" plug-ins for Eclipse IDE. These tools would also help to reduce the cost of *cheap talk*. In some situations, although *cheap talk's* cost is small, its distribution may be very imbalanced, i.e., a few people always pay the cost (usually several core members). A simple tool that balances the individual effort can solve this problem. For example, the tool can identify the members less frequently initiating *e-cheap talk* by analyzing the logs, and then suggest they take initiative of *e-cheap talk*.

7.4 Methodological Implications

Studying human aspects of SE activities has flourished since last decade. A large body of empirical literature has focused on many aspects of human interactions in software development including coordination and trust. Empirical studies contribute rich evidence of real world practice, but are relatively void of explicit theory. While greatly informing research, approaches that can combine empirical studies and predictive theories have obvious advantages. When assumptions are clearly articulated, theory can provide predictive power and avoid costly "trial and error" decisions.

Particularly in studying cooperative and human aspects of software engineering, we argue that game theory provides a good framework for developing theoretical knowledge. Software engineering process consists of human decision making activities. Developers have to decide proper strategies for team member cooperation. Game theory has demonstrated its capability in studying human decision making processes and the long-term attributes of social systems since 1950s, and continues to bring new perspectives to cooperation research [23]. Via game theory model reasoning, we can deductively develop propositions characterizing real world phenomena, which provides generative causality and explanation[9].

We believe the generative approach of game theory models comports well with current empirical practices in SE research. All models and theoretical reasonings, no matter how sophisticated, are imperfect abstractions of the real world. Their external validity must be validated through comparison to empirical/experimental results. This process forms a feedback loop between empirical and theoretical work. SE research may benefit from the combination of theoretical and empirical study, which helps to build generalizable and rigorous knowledge while maintaining strong connections to reality. Leveraging EGT, we made some preliminary attempts in this direction. The study was motivated by real world phenomenon (section 2), and presented theoretical explanations for it (section 3, 4, & 5). We validated the theory through an empirical study (section 6). Our study demonstrates the feasibility of this approach and shows how to use it to develop sense-making theory and generalizable empirical knowledge. However, we admit a limitation of this methodology is that the theoretical model and its propositions are hard to validate using direct by empirical evidences directly in some situations. Researchers may need to pay extra attention to empirical study design or employ several different empirical methods.

7.5 Threats to Validity

The research method helps us to achieve high internal and external validity. Game theory modeling requires only minimal assumptions that do not involve too much subjective bias. The empirical study of LUCENE relies on open human communication records, and hence suffers less the validity issues raised in data collection practices. The message classification was automatically executed with relative little subjective intervention, further preventing significant internal validity threats. The theoretical reasonings also help to solve the generalizability problem of empirical study. However, a potential threat to validity is that the team is fixed in its life cycle, whereas OSS teams are usually not so fixed. In its life cycle, new comers may join and some familiar faces may leave. However, this does not mean the model's results are essentially wrong. LUCENE's core team are very stable and the timeline for achieving universal cooperation is relative short (at most several months). Nevertheless, this issue needs to be further investigated in more stable software development teams.

8. CONCLUSIONS AND FUTURE WORK

In this paper, we investigate how informal non-work related conversations over the Internet (*e-cheap talk*) help to promote cooperation and trust in software development teams. We employ a unique "cost-benefits" perspective using a novel EGT model inspired by a previous field study. We performed a subsequent assessment by data – mining LUCENE's development IRC channel. Together, our model and studies lead us to conclude that *e-cheap talk* can help distributed teams build cooperation and trust. In addition, some results cast doubts on conventionally held assumptions. For instance, *e-cheap talk* works as catalyst and tends to disappear with the progress of trust and cooperation development.

We believe that studies of trust and other human factors in software development will benefit from rigorous models that enable analytical study and computer simulation and, in particular, employ EGT to better examine the emergence of complex social behavior. Doing so will inform to organizational concerns as well as software tool development. Furthermore, this study at least partially demonstrates the feasibility of combining theoretical modeling and empirical study towards developing rigorous, generalizable knowledge that can reflect and guide real world practices. More empirical work is needed to show how the model and real-world are connected. Until then, it is an open question how much EGT can tell us about the dynamics of human interaction in software engineering activities. We have not yet provided a definitive answer to this question, but the preliminary results reported in this paper are encouraging, at least for trust research in GSE. We will further collect empirical data to validate our model and its analytical results. For instance, we plan to collect longitudinal trust data to directly assess the dynamics of trust (Proposition 2), which this study has not done.

The model can be extended to incorporate other factors. For instance, the current model only considers the "punishment/incentives" mechanism, but in the real world, other factors (e.g., commitment, emotion, culture) also regulate the trust and cooperation process. For instance, by imposing a "commitment" mechanism, it is possible to investigate the trust damage and repair process [1, 30] and how to motivate individuals to deliver their commitment [38]. People form subgroups to exercise different strategies to confirm their subgroup identities. It is possible to integrate the EGT model and Social Network Analysis to explore complex real world interpersonal relationships in real world [20]. The discussions in section 7.2 also make us believe this is a promising combination. We will continue our research in this direction.

9. ACKNOWLEDGMENTS

This work is supported by NSF grant 1111446. We appreciate Dr. Ban Al-Ani for collaborating on the empirical data in Section 2, and Dr. Erik Trainer for reviewing the early version of this paper. Finally, we thank our technical editor, Colleen Jankovic, for her efforts. Any remaining errors are our responsibility.

10. REFERENCES

[1] B. Al-Ani, M. J. Bietz, Y. Wang, E. Trainer, B. Koehne, S. Marczak, D. F. Redmiles, and R. Prikladnicki. Globally distributed system developers: their trust expectations and processes. In *Proc. CSCW*, pages 563–574, 2013.

[2] B. Al-Ani, Y. Wang, S. Marczak, E. Trainer, and D. Redmiles. Distributed developers and the non-use of web 2.0 technologies: A proclivity model. In *Proc. ICGSE*, pages 104–113. IEEE Computer Society, 2012.

[3] N. Bos, J. Olson, D. Gergle, G. Olson, and Z. Wright. Effects of four computer-mediated communications channels on trust development. In *Proc. CHI*, pages 135–140, 2002.

[4] R. S. Burt, M. Kilduff, and S. Tasselli. Social network analysis: Foundations and frontiers on advantage. *Annual Review of Psychology*, 64(1):527–547, 2013.

[5] B. Caglayan, A. Bener, and A. Miranskyy. Emergence of developer teams in the collaboration network. In *Proc. CHASE*, 2013.

[6] F. Calefato, F. Lanubile, and F. Sportelli. Can social awareness foster trust building in global software teams? In *Proc. SSE*, pages 13–16, 2013.

[7] J. Cassell and T. Bickmore. Negotiated collusion: Modeling social language and its relationship effects in intelligent agents. *User Modeling and User-Adapted Interaction*, 13(1-2):89–132, 2003.

[8] M. Cataldo, J. D. Herbsleb, and K. M. Carley. Socio-technical congruence: a framework for assessing the impact of technical and work dependencies on software development productivity. In *Proc. ESEM*, pages 2–11. ACM, 2008.

[9] L. Cederman. Computational models of social forms: Advancing generative process theory. *American Journal of Sociology*, 110(4):pp. 864–893, 2005.

[10] C. D. Cramton and P. J. Hinds. Intercultural interaction in distributed teams: Salience of and adaptations to cultural differences. In *Proc. AOM Annual Meeting*, pages 1 – 6, 2007.

[11] Y. Dittrich and R. Giuffrida. Exploring the role of instant messaging in a global software development project. In *Proc. ICGSE*, pages 103–112, 2011.

[12] N. Ducheneaut. Socialization in an open source software community: A socio-technical analysis. *Computer Supported Cooperative Work (CSCW)*, 14(4):323–368, 2005.

[13] J. Farrell and M. Rabin. Cheap talk. *The Journal of Economic Perspectives*, 10(3):103–118, 1996.

[14] S. Ficici and J. Pollack. Effects of finite populations on evolutionary stable strategies. In *GECCO*, pages 927–934, 2000.

[15] D. Fudenberg and L. A. Imhof. Imitation processes with small mutations. *Journal of Economic Theory*, 131(1):251 – 262, 2006.

[16] D. Fudenberg and L. A. Imhof. Monotone imitation dynamics in large populations. *Journal of Economic Theory*, 140(1):229 – 245, 2008.

[17] A. Guzzi, A. Bacchelli, M. Lanza, M. Pinzger, and A. van Deursen. Communication in open source software development mailing lists. In *Proc. MSR*, pages 277–286, 2013.

[18] J. D. Herbsleb, D. L. Atkins, D. G. Boyer, M. Handel, and T. A. Finholt. Introducing instant messaging and chat in the workplace. In *Proc. CHI*, pages 171–178. ACM, 2002.

[19] J. D. Herbsleb and R. E. Grinter. Splitting the organization and integrating the code: Conway's law revisited. In *Proc. ICSE*, pages 85–95. ACM, 1999.

[20] M. Jackson. *Social and Economic Network*. Princeton University Press, 2010.

[21] I. Kwan, M. Cataldo, and D. Damian. Conway's law revisited: The evidence for a task-based perspective. *Software, IEEE*, 29(1):90–93, 2012.

[22] E. Montuschi. *The Objects of Social Science*. Continuum International Publishing Group, 2003.

[23] M. Nowak. *Evolution, Games, and God*. Harvard University Press, 2013.

[24] M. A. Nowak. *Evolutionary Dynamic: Exploring the Equations of Life*. The Belknap Press of Harvard University, 2006.

[25] M. A. Nowak. Five rules for the evolution of cooperation. *Science*, 314(5805):1560–1563, 2006.

[26] M. A. Nowak, A. Sasaki, C. Taylor, and D. Fudenberg. Emergence of cooperation and evolutionary stability in finite populations. *Nature*, 428(6983):646–650, 2004.

[27] M. A. Nowak, C. E. Tarnita, and E. O. Wilson. The evolution of eusociality. *Nature*, 466:1057–1062, 2010.

[28] B. Pfaff. *Analysis of Integrated and Cointegrated Time Series with R*. Springer, 2008.

[29] F. C. Santos, J. M. Pacheco, and B. Skyrms. Co-evolution of pre-play signaling and cooperation. *Journal of Theoretical Biology*, 274(1):30 – 35, 2011.

[30] E. Schniter, R. M. Sheremeta, and D. Sznycer. Building and rebuilding trust with promises and apologies. *Journal of Economic Behavior & Organization*, 94:242–256, 2013.

[31] J. Schumann, P. C. Shih, D. F. Redmiles, and G. Horton. Supporting initial trust in distributed idea generation and idea evaluation. In *Proc. GROUP*, pages 199–208, 2012.

[32] B. Skyrms. The stag hunt. In *Presendential Address of the Pacific Division of the APA, Proceedings and Addresses of the APA 75*, pages 31–41, 2001.

[33] B. Skyrms. Trust, risk, and the social contract. *Synthese*, 160(1):21–25, 2008.

[34] A. Steed, M. Spante, I. Heldal, A.-S. Axelsson, and R. Schroeder. Strangers and friends in caves: an exploratory study of collaboration in networked ipt systems for extended periods of time. In *Proc. I3D*, pages 51–54. ACM, 2003.

[35] D. A. Tamburri, P. Lago, and H. v. Vliet. Organizational social structures for software engineering. *ACM Comput. Surv.*, 46(1):3:1–35, 2013.

[36] A. Traulsen, M. A. Nowak, and J. M. Pacheco. Stochastic dynamics of invasion and fixation. *Phys. Rev. E*, 74:011909, Jul 2006.

[37] Y. Wang and D. Redmiles. Understanding cheap talk and the emergence of trust in global software engineering: An evolutionary game theory perspective. In *Proc. CHASE*, pages 149–152, 2013.

[38] M. Winikoff. Implementing commitment-based interactions. In *Proc. AAMAS*, pages 128:1–8, 2007.

[39] H. P. Young. *Individual Strategy and Social Structure: An Evolutionary Theory of Institutions*. Princeton University Press, 1998.