2008

Indirect Reciprocity in Contributions to a Peer-to-Peer Music Sharing Network - An Empirical Analysis of Individual Level Data

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INDIRECT RECIPROCITY IN CONTRIBUTIONS TO A PEER-TO-PEER MUSIC SHARING NETWORK – AN EMPIRICAL ANALYSIS OF INDIVIDUAL LEVEL DATA

Réciprocité indirecte des contributions dans un réseau d'échange de musique pair à pair – une analyse empirique de données individuelles

Completed Research Paper

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Abstract

This study assesses the influence of indirect reciprocity on individual contribution to a peer-to-peer network. We find that individuals' level of contributions increases with number of contributors in the peer-to-peer network but decrease with number of free riders in the networks, indicating that individual contributions are reciprocal in nature. Moreover, we show that individuals have strong incentive to punish free riders and reward contributors in the peer-to-peer network. They do so through the setting of servers that allows discrimination among downloaders. When number of free riders increases, individuals are more likely to change the server settings to provide priority services to contributors and lesser services to free riders. The phenomena are consistent with findings from economic experiments which suggest that reciprocity and the ability to punish free riders could sustain contribution to pubic goods. The findings have important implications on the design and practical management of peer-to-peer networks.

Keywords: Indirect reciprocity, peer-to-peer network, music sharing, free riders, public goods

Résumé

Cette étude évalue l'influence de la réciprocité indirecte sur la contribution individuelle à un réseau de pair-à-pair. Nous trouvons que les contributions sont réciproques par nature. De plus, les individus ont de fortes incitations à punir les passagers clandestins et à récompenser les contributeurs. Ces phénomènes sont en ligne avec les résultats des expérimentations en économie qui suggèrent que la réciprocité et la capacité à punir les passagers clandestins pourraient soutenir la contribution aux biens publics.

Introduction

A noted feature of many peer-to-peer networks is the high ratio of purely consuming users, often called free riders, over contributing users. Asvanund et al. (2004) find that 42% of users of Gnutella are free riders. Center for the Digital Future shows that 64% of peer-to-peer network users report that they have never contributed any content (Center for the Digital Future 2008). The ratio is even higher in other peer-to-peer network studies (Adar and Huberman 2000; Hughes et al. 2005; Parameswaran et al. 2001; Saroiu et al. 2002).

The free riding phenomenon is known as a result of the Tragedy of Commons problem (Hardin 1968). Contributions to peer-to-peer networks are public goods. They benefit others in the networks except for the contributor who have already owned a copy of the digital resources contributed. In addition, the action of contributing often incurs significant costs to the contributor. These costs involve network connection costs,[1] administrative costs, and potential legal risks in intentionally or unintentionally sharing pirated or privileged contents. The combination of zero benefits and high costs indicate that economically rational individuals will provide no contribution to peer-to-peer networks. The proposition is, however, challenged by the persistent growth of large scale peer-to-peer networks. While a significant number of users in these networks free ride on others' contributions as predicted by the economic theory, there are also a substantial number of contributors that consistently provide resources to such networks.

Extant research has proposed a variety of theories explaining user contribution in online peer-to-peer networks (Asvanund et al. 2004; Butler 2001; Krishnan et al. 2003; DangNguyen and Penard 2006). Most of the theories focused on the economic benefits of contributions, ranging from reduction in congestion to reputational incentives. A number of economic experiments on private contributions to public goods, however, reveal that individuals contribute not only out of economic benefits but also out of reciprocity (Ostrom 2000). In this paper, we develop a new theoretical framework based on indirect reciprocity (Nowak and Sigmund 1998) and validate the theory on a large scale peer-to-peer music sharing network.

Reciprocal behavior has long been observed in human society. Individuals repay kindness with kindness and insults with insults. Reciprocity is especially important in social dilemmas where private interests conflict with collective interests (Rabin 1993). Both social network and economic literatures have studied reciprocity behavior in depth. The focuses of the two streams of research are different and complement each other. Social network analysis emphasizes reciprocity at the network level. It studies the collection of dyadic and triadic relationships in a network and compares them with the corresponding relationships in a random graph (Wasserman and Faust 1994). Economic literature takes a different perspective. It focuses on individual behavior and identifies factors that influence reciprocal behavior using well-controlled experiments. A series of economic experiments find that reciprocity enables individuals to overcome social conflicts and take collective actions (Fehr and Gachter 2000a; Fehr and Gachter 2000b). More importantly, these experiments reveal that individuals are not only reciprocal in nature but also have strong incentives to punish free riders and reward contributors. This self-enforced punishment mechanism could sustain contribution to collective interests. Each approach has its advantages and disadvantages. Social network research's focus on network overlooks variation and richness in individual behavior. Moreover, a majority of social network analysis on reciprocity is based on static analysis of network structure, ignoring the dynamic nature of reciprocity. On the other hand, experimental economic studies' approach of using lab experiments raises concerns of their validity in real economy. In particular, the validity of their applications to large-scale networks has rarely been tested. The objective of this study is to bridge the gap between the two streams of the literatures. Similar to the economic literature, we take a dynamic view of indirect reciprocity and focuses on

[1] Such costs mainly manifest in the form of opportunity costs instead of outright financial costs. For example, contributions of digital contents could significantly slow down the contributor's network connection and delay or disrupt software applications that share the same network connection.

its influence on individual behavior. But different from the economic literature, we conduct our analysis using data from a large scale peer-to-peer network to validate our hypotheses.

Reciprocity exists in two forms: direct reciprocity and indirect reciprocity. Direct reciprocity arises when individuals have repeated one-to-one interactions, which enables them to respond in kind to each other. A variety of economic experiments on social dilemmas, e.g., trust game, sequential prisoner's dilemma game, etc., have been designed in direct reciprocity settings. These experiments consistently find that individuals are willing to sacrifice private gain to reward selfless behaviors and to punish selfish behaviors (Clark and Sefton 2001; Fehr and Gachter 2000a, 2000b). However, in many online environments, individuals cannot directly reciprocate to each other. Peer-to-peer networks present a typical case. In these networks, contributors decide whether and how much to contribute but not *who* receives the contribution. The design prevents one-to-one contribution, thus limiting direct reciprocity. Indirect reciprocity arises in such a case when individuals respond in kind to a third-party or to the network in general. The third-party who benefits from the reciprocal behavior could further reciprocate to others, leading to a potential chain effect. Recent studies by Faraj, Wasko and Johnson (Faraj and Johnson 2005; Johnson and Faraj 2005; Faraj, Wasko, and Johnson 2007) show that indirect reciprocity exists at the network level for a variety of virtual communities. Wasko and Faraj (2000) also find through survey that individuals are motivated by indirect reciprocity in making contributions to online communities. The objective of the paper is to take a step further to characterize indirect reciprocity behavior and its influence on individual contribution behavior in a large scale music sharing network.

We conduct the analysis using individual level data. Our approach contrasts with prior studies on peer-to-peer networks that conduct analysis at the network level (Asvanund et al. 2004). The network level data present a number of challenges to researchers. First, aggregate level analysis cannot distinguish causality from correlation since it does not control for individual heterogeneity. An association could be due to a spurious cross-section correlation or a casual relationship between file sharing and a motivation factor. Second, aggregate level analysis cannot identify whether a change in contribution is due to changes in individual behavior or changes in network composition. The distinction between the two has significant implications for both theoretical modeling and practical management of peer-to-peer networks. Third, aggregate analysis often focuses on number of files shared as a measure of contribution in a peer-to-peer network. However, amount of files shared is the results of both supply and demand of contribution. As such, it is endogenous and cannot represent contribution level. We leverage a unique individual level data collected from a large peer-to-peer music sharing network to overcome these limitations. We focus on individual peer-to-peer users and analyze how a user's contribution behavior changes in responding to changes in network environment while controlling for individual heterogeneity using fixed effects. In doing so, we isolate factors that influence individual contribution behavior from spurious cross-sectional correlation. The fix effects also remove the influence of network dynamics as changes in network composition is fully captured by the fixed effect. Furthermore, to measure contribution activities, we identify the contribution status of each network user instead of number of files shared. These measures are not influenced by demand for contribution, thus providing an unbiased measure of an individual's contribution.

Our results indicate that peer-to-peer users demonstrate a rich set of dynamic behaviors consistent with indirect reciprocity theory. We find that an individual's contributions increase with number of contributors in the peer-to-peer network but decrease with number of free riders in the networks, indicating that individual contributions are reciprocal in nature. The level of indirect reciprocity is significant in both statistical and practical terms. For each 10% increase in number of contributors, an individual increases her contributions by about 6-14%. Similarly, for each 10% increase in number of free riders, an individual decreases her contributions by about 6-10%. We also find evidence that the level of reciprocity is not uniform towards all contributors. Individuals show significantly less reciprocity towards contributors who have never downloaded from the network. The finding is consistent with the theory of reciprocity that suggests that reciprocity is not necessarily in kind. Individuals who only contribute but never download do not need more music files and, therefore, network users are less likely to contribute music files in responding to their contributions.

More importantly, we find that network users are not only reciprocal in nature but also have strong incentive to punish free riders and reward contributors. They do so through the setting of servers that allows discrimination among downloaders. When number of free riders increases, we find that individuals are more likely to change the server settings to provide priority services to contributors and lesser services to free riders. The phenomena are consistent with findings from economic experiments which suggest that reciprocity and the ability to punish free riders could sustain contribution to pubic goods. Overall, our results suggest that indirect reciprocity plays a pivotal role in motivating individual contributions to peer-to-peer network.

Our analysis also considers the other motivating factors such as reputation or congestion reduction. We find that both reputation and congestion affect individual contributions. Our analysis indicates that a network user significantly increases her level of contribution after being labeled as a *Value User*. We also find that individuals with high download needs tend to increase their contribution when they face more network congestions, although the magnitude of the influence is small.

The rest the paper is organized as follows. We discuss theoretical foundation of private contribution to public goods in the next section. We then develop hypotheses for the indirect reciprocity theory on private contribution to peer-to-peer network. We describe data and measures afterward, followed by a discussion of empirical analysis and results. We conclude the paper by identifying the limitations and future research of the paper.

Private Contribution to Public Goods

Contribution to peer-to-peer networks resembles private contribution to public goods. We start the literature reviews by considering prior studies on private contribution to public goods. Extensive voluntary contribution experiments consistently show that individuals have incentive to contribute more than the zero contribution predicted by the public good theory. However, contributions decline over time and approach zero towards the end of the experiment (Dawes and Thaler 1988; Ledyard 1995). A number of mechanisms have been proposed to address the issue, ranging from preannounced subsidy and tax schemes that reward (punish) individuals who contribute more (less) than the average (Falkinger et al. 2000).

Contrast to the results of public goods experiments, peer-to-peer networks appear to receive consistent contributions from network users without explicit punishment or incentive mechanisms. It is, therefore, necessary to examine the differences between peer-to-peer networks and the standard setting of public good games. First, a significant difference between the two is the nature of digital goods. While private contribution of public goods deprives the contributor the use or service of the contributed good, contribution of digital files does have such an effect as digital files can be freely copied. The difference indicates that content contribution to peer-to-peer network by itself does not have a conflict between self interest and collective interest as in a typical public good game. The conflicts lie in the contribution of uploading bandwidth (Casadesus-Masanell and Hervas-Drane 2007).

Second, different from a voluntary contribution games where all players make simultaneous contribution decisions, contribution is sequential in peer-to-peer networks. The difference is crucial. Players in voluntary contribution games face not only economic incentive to free ride but also the fear of being taken advantage of in case of over-contribution. The combination of the two effects significantly reduces contribution. In peer-to-peer networks, an individual observes others' contributions before making his contribution decisions. The sequential process removes the fear, thus increasing individual contributions. Moreover, the sequential nature enables reciprocal behavior.

Third, player-initiated rewarding and punishing mechanisms are often available in peer-to-peer networks. These mechanisms allow individual contributors to impose restriction on the types of users that can receive the contribution. The restriction could be based on user's tenure, level of contribution or other user characteristics. Lab experiments show that the ability for individuals to punish free riders and reward contributors has a significant impact on contribution to public goods (Fehr and Gachter 2000b). Figure 1 shows the level of contribution to public goods when individuals can not punish free riders verusus the level of contribution when individuals are allowed to punish free riders as reported in Fehr and Gachter (2000b). The figure indicates that, when no punishment is allowed, individual contribution decreases over time and gradually approaches zero. But allowing individuals to punish free riders increases the overall contribution level dramatically.

These characteristics of the peer-to-peer network indicate that contribution to the network resembles a repeated voluntary contribution game. Experiment results suggest that a significant proportion of individuals in such scenarios reciprocate (Falkinger et al. 2000), but reciprocity alone is not sufficient to sustain contribution. User-initiated punishment mechanism is needed to sustain contribution in such environments.

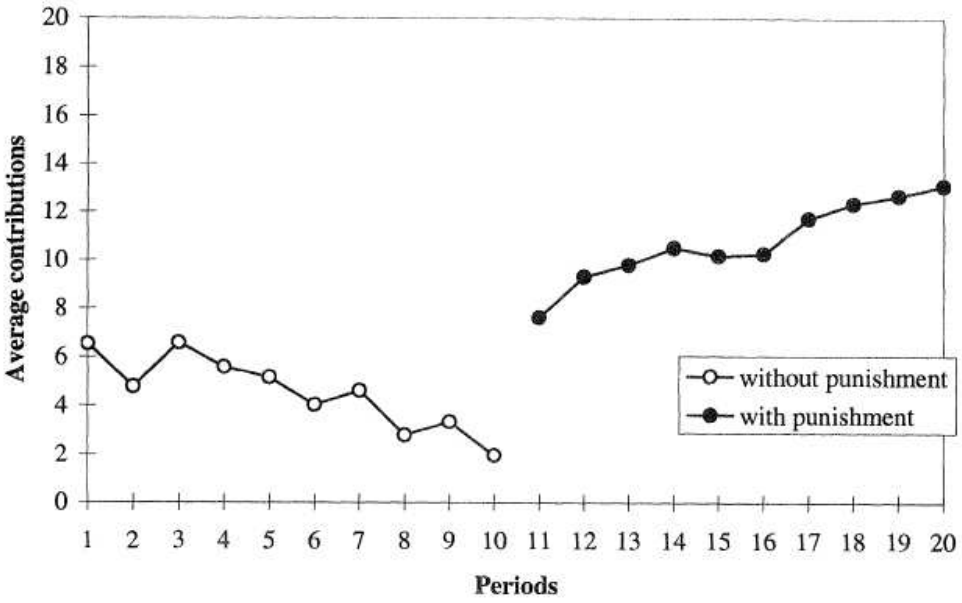

Figure 1: Comparison of contribution level in repeated public good game without punishment mechanism against contribution level with punishment mechanism (obtained from Fehr and Gachter 2000b, Figure 1b).

Theory and Hypotheses

We consider two sets of hypotheses. The first set identifies individuals' motivations to reciprocate and contribute to the peer-to-peer network. The second set identifies individuals' incentive to punish free riders and reward contributors.

Indirect Reciprocity

Reciprocity has been documented in a variety of economic experiments (see Fehr and Cachter 2000 for a review). For example, in an ultimatum game, a proposer and a responder bargain about the distribution of an asset. The proposer offers a share of the asset to the responder and responder decides whether to accept or reject the offer. If the responder rejects the offer, both the proposer and responder receive zero value. While economically motivated responder is expected to accept any positive offer, laboratory experiments shows that the responder frequently rejects positive offers if she is offered much less than 50% (Oosterbeek et al. 2004). Studies show the phenomenon persists in a variety of settings, indicating the presence of negative reciprocity (Henrich et al. 2004). Similarly, in a trust game, a proposer receives an endowment and then sends a portion of the endowment to a responder. The experimenter then triples the amount sent and the responder is free to return anything between zero and the amount to the proposer. Self-interested responder is not expected to return anything to the proposer. However, laboratory experiments show that the responder frequently reciprocates and the amount reciprocated increases with the original contribution from the proposer (Fehr and Schmidt 1999).

While reciprocity often prevails in direct one-to-one economic exchanges, it goes beyond one-to-one interactions. An individual's helpful action, or a gift, can be returned by a third party other than the recipient (Alexander 1987). The recipient of a helpful action could also return favors to third-party. Such action of indirect reciprocity contrasts with direct reciprocity where an individual returns favor directly to the contributor, and pure altruism where an individual contributes merely out of the concerns of others' welfare.

The advent of e-commerce makes indirect reciprocity an important consideration in numerous experimental and theoretical investigations among social scientists and economists (Novak and Sigmund 2005). This is because the Internet has enabled increasing amount of transactions among anonymous partners in electronic markets. While reputation mechanism provides an important tool in such environment, studies show that the effectiveness of such

mechanism is limited as individuals can easily change online identifications and contribution of negative feedbacks is often retaliated with negative feedbacks (Novak and Sigmund 2005). However, we do not observe rampant fraud in e-commerce environment. Indirect reciprocity offers an important explanation of widely observed cooperation among strangers in online environments.

Online peer-to-peer sharing networks provide a particularly valuable context to study indirect reciprocity. In these networks, there are rare repeated interactions among the participants in the network. Moreover, a key feature of these networks is that a contributor can determine whether, how much, to which group of users to contribute, but not individual recipient(s) of the contribution. Once a contributor makes the contribution decision, any user that meets the criteria set up by the contributor can download from her. Therefore, by design, peer-to-peer networks preclude direct reciprocity. Indirect reciprocity, however, does not require obtaining benefits directly from the recipients, which fits well with the environment of online peer-to-peer networks.

Studies show that one determining factor for the indirect reciprocity is the availability of information about the cooperative quality of other participants in the group (Brandt and Sigmund 2005; Greiner and Levati 2005; Nowak and Sigmund 1998; Tullberg 2004). The information allows individuals to reciprocate based on others' cooperative status. In peer-to-peer networks, a user can easily determine the cooperative environment in the network through the efficiency of searching and downloading the files he inquires, which would either positively or negatively influence his future contribution behavior. Indirect reciprocity in this case makes individuals behaving as "conditional cooperators" (Ostrom 2000). They are willing to contribute as long as a significant number of others contribute in return as expected and the amount of their contribution increases with number of contributors in the network. We therefore propose:

H1: Positive reciprocity - a user's probability of contribution increases with number of other contributors in a peer-to-peer network.

A key difference between indirect reciprocity and altruism is that the contribution of the former is conditional upon others' contribution while the latter is conditional upon others' needs. Most of the online peer-to-peer networks are free to join and open for participation, which provides the incentive to be a free rider in the network. In a one-to-one situation, free riding can easily be discouraged by a tit-for-tat strategy. But in a larger-scale online network, where contributions and benefits are pooled and shared, free riders could flourish. Extant research suggests that individuals reciprocate negative actions with negative actions (Panchanathan and Boyd 2004; Rockenbach and Milinski 2006). That is, individuals will reduce their contribution level when more network users choose to free ride.

We, therefore, propose the following hypothesis:

H2: Negative Reciprocity - a user's probability of contribution decreases with number of free riders in a peer-to-peer network.

Contributor Characteristics

Individuals motivated by indirect reciprocity are not only influenced by others' contribution behavior, but also by contributor characteristics. Contributor characteristics influence indirect reciprocity in two ways. First, prior studies suggest reciprocity is not necessarily in kind. Instead, reciprocity depends on contributors' needs. In many social environments, a contributor does not expect in kind reciprocation from beneficiaries either because beneficiaries cannot afford to (e.g., charity giving) or because contributors prefer reciprocation in other kinds (e.g., love or affection). In the setting of music sharing networks, a contributor may already own a large number of music files and does not need to download any music files from the peer-to-peer networks. In such cases, reciprocation of music files provides little value to contributors. Second, prior studies showed that intentions have significant influence on both positive and negative reciprocity (Rabin 1993; Falk et al. 2008). A contribution intended to benefit the recipient or an action intended to harm the recipient is more likely to be reciprocated than actions that produce accidental benefits or harms. In a series of experiment studies, Falk et. al. (2008) demonstrate that when the action choice of the first mover is limited to either grossly unfair to himself or grossly unfair to his counterpart, the choice of the option that harms the counterpart is less likely to lead to retaliation than the first mover makes the choice in an unconstrained environment. The latter choice sends a clear signal of intention to harm while the former choice is out of necessity. In the context of music sharing network, individuals may respond to the intention of contributors in determining reciprocity level.

The most common observable contributor characteristics in many peer-to-peer networks are their downloading and uploading activities. The observation enables users identify different types of contributors. Some contributors are pure contributors who simply share files without any downloading activities from the network. Other contributors are both downloaders and contributors. The observation of pure contributors indicates that these contributors do not need reciprocity in kind in the form of music files. It also indicates the intention of these contributors could be to promote certain music groups or artists instead of benefiting the community. In either case, reciprocal minded individuals are less likely to reciprocate to these contributors with music files.

H3: Pure Contributors – a user's probability of contribution is less influenced by number of pure contributors than by number of non-pure contributors in a peer-to-peer network.

Experience

An important observation from experimental studies of reciprocity is that individuals reach contribution equilibrium over time. Figure 1 illustrates the finding of Fehr and Gachter (2000b) which suggest that, in a public goods game without punishment mechanism, individuals' contribution levels gradually decreases, while in a public goods game with punishment mechanisms, individuals' contribution levels gradually increases. A variety of self-enforced mechanisms have been proposed by Fehr and Gachter (2006b) and Falkinger et al. (2000) to sustain contribution to public goods. A key feature of these mechanisms is that individual can impose penalty on free-riders or provide rewards to other contributors. This feature is available in many peer-to-peer networks, including the one being studied in this paper. We therefore have:

H4: Experience– a user's probability of contribution increases with her experience with the peer-to-peer network.

Incentives

A number of experiment studies find that incentives could increase private contribution to public goods (Falkinger et al. 2000; Fehr and Gachter 2000b). The incentive could be reputational, monetary, or in other forms. A majority of peer-to-peer network adopts a combination of reputational incentive and service incentive. Frequent contributors often receive special titles as an encouragement for contribution. Individual contributors may also provide higher levels of services to other contributors such as giving priority in download queue or allowing multiple downloads. The influence of incentive is, however, controversial and could subject to crowding out effect (Osmo 2000). Frohlich and Oppenheimer (1996) find that extrinsic incentive reduces individual intrinsic motivation to reciprocate and the net effect could be negative. It is therefore an empirical question to assess the influence of incentive mechanisms on user contribution.

H5: Reputation - A user's probability of contribution increases after she receives special title in recognition of her contribution activities.

H6: Incentive - A user's probability of contribution increases when more incentive is provided to contributors.

Congestion

Another explanation of individual contribution to peer-to-peer network suggests that individuals may contribute resources to reduce network congestions, which in turn decreases contributors' costs of obtaining resources from the network (Casadesus-Masanell and Hervas-Drane 2007; Cunningham et al. 2004; Krishnan et al. 2003). Individuals contribute whenever the reduction in congestion costs overweighs the costs of contributions. Krishnan et al. (2003) show that self-interest alone could sustain a peer-to-peer network in the presence of free riders.

To develop an empirical hypothesis from the self-interest theory, we consider how a network user's contributing behavior changes with the network congestion status and, in particular, her wait time for downloads. The congestion argument indicates that she will increases her contribution in response to longer wait time if he needs to download files from the peer-to-peer network. On the other hand, if the contributor has no download needs, she shall have no incentive to increase contribution. The discussion suggests that the self-interest manifests as a moderating effect between wait time and download needs. We therefore propose:

H7: Congestion - A user's probability of contribution increase with wait time when the user has high concurrent download needs.

The above set of hypotheses considers factors that influence indirect reciprocity in the peer-to-peer network. Prior studies show that individuals are not only reciprocal themselves but also willing to punish free riders and rewards contributors to encourage reciprocity on others. In the peer-to-peer network, the punishment and reward mechanism is implemented through server settings. Each individual contributor can change her server setting to give access to all users, give access to to contributors only, or give download priority to contributors. We consider factors that influence individuals' choice of the server setting.

User-initiated Reward and Punishment Mechanism

The notion that individuals have incentive to punish non-cooperators in a social setting has been long observed in human societies. For example, Francis (1985) reports that striking workers take actions to isolate strike breakers that cross the picket line. Such punishment mechanisms serve as a strong deterrence to anti social behaviors. A key feature of user-initiated reward and punishment mechanisms is that they are initiated by individual members of a society instead of orchestrated by any organization or enforced by any formal agreement. A series of economic experiments conducted by Fehr and Gachter (2000b) show that contributors are willing to punish free riders even if "the punishment is costly for them and even if they cannot expect future benefits from their punishment activities". In the context of peer-to-peer sharing network, a contributor cannot punish an individual free rider. However, the technology allows her to punish all free-riders via setting up the servers to provide downloads to only contributors or give priority download service to contributors. The need for such reward and punishment mechanism is at the greatest when the network is overwhelmed with free riders. We therefore propose:

H8: User-initiated Mechanism – a user's probability of providing priority services to contributors decreases with number of other contributors in a peer-to-peer network.

H9: User-initiated Mechanism – a user's probability of providing priority services to contributors increases with number of other free riders in a peer-to-peer network.

The need for activating the reward and punishment mechanism arises not only when a user observes an increase in free riders, but also when he observes an increase in wait time. The increase in wait time indicates not enough contributors in the networks and a rational contributor will change the server setting to motivate others to contribute. We therefore propose:

H10: Wait – a user's probability of providing priority services to contributors increases with her download wait time.

While the user-initiated reward and punishment mechanism could be highly effective in sustaining contributions in peer-to-peer network, it takes time for network users to learn the mechanism. First, from the technical perspective, file sharing servers are usually set to provide access to all users by default. Users need to acquire the necessary technical skill to activate the reward and punishment mechanism. Second, from the economic perspective, the value of the reward and punishment mechanism and its influence on others' behaviors are often not obvious to new users. It takes experience and learning to understand its potential. Therefore, we propose:

H11: Experience – a user's probability of providing priority services to contributors increases with her experience with the peer-to-peer network.

Besides experience, a user's reputation also influences her choice of server settings. Users that obtain specific title from a peer-to-peer network are concerned about the long-term sustainability of network as the value of their reputation depends on the survival of the network. As such, they are more likely use the reward and punishment mechanism.

H12: Reputation – a user's probability of providing priority services to contributors increases after she receives specific title in recognition of her contribution activities.

Data and Measures

Research Context

To test the level of indirect reciprocity in peer-to-peer sharing networks and factors that moderate it, we collected sharing and downloading activities in MP3Passion, a music sharing channel based on Internet Relay Chat (IRC)

networks. IRC is originally designed for instant communication through a collection of topic-oriented chat rooms (called IRC channels). To participate in a channel, a user must first log in with a username – one can use any username as long as it does not conflict with the existing ones. Users often install scripts such as SDFind and OmenServe, which can turn individual personal computers into small file servers and share users' file collections through special channels (called serving channels). Each user must send to the central channel file search and download requests, which are then broadcast to all sharing users, and the script servers will automatically respond to the requester if they have matching files in their local collections.

The serving channels act as automatic peer-to-peer networks like Gnutella and OpenNap. As proposed by Asvanund et al. (2004), P2P network structures can be categorized along two axes: the degree of decentralization of content and that of the catalog. Both of the IRC file sharing channels' content and catalog are decentralized as files are indexed and stored by individual computers. The IRC servers only provide centralized message communication that broadcast requests to all users.

Compared to specialized file-sharing applications, such as Napster, Gnutella, and Kazaa, two unique characteristics make IRC a good representative of sharing communities. First, IRC channels have been very popular for keeping touch with friends and persons with similar interests for many years. Therefore IRC user names are relatively stable and represent real users behind. Second, unlike other P2P file sharing networks, users can also look at others' file collections and check file servers' status. These activities strengthen the community feel and make it possible for users to observe the overall status of the community. Third, while individuals can have direct communications through IRC channels, all music sharing requests and acknowledges are through the broadcast channel and processed automatically. The requests cannot be granted or denied on an individual basis. This preserves the key characteristics of peer-to-peer networks that facilitate anonymous file sharing among users.

We monitored the Mp3passion channel – a music sharing community in the IRC Undernet. The sharing mechanism in IRC is decentralized: users voluntarily share their file collections to others; each user can search all shared files and download the matching ones. A user can also observe how many and what files others provided. IRC servers broadcast all search queries and download requests to each user in the channel. Therefore we can detect pair-wise activities between users. From August 5th to December 3rd in 2003, we monitored 95.5% of total usage time (2772 hours) and observed 9 million file transactions. Based on the IRC broadcasting messages, once a logged-in user turns on the sharing function, we can observe his file server status through automatic reports such as the total number of files provided and sharing workload.

Two types of broadcasting messages are collected for this research. First, we collect all transaction logs associated with each file inquiry or download action. All transaction logs are automatically broadcast to all users in the network, therefore we have a complete collection of all transactions in the network during our study period. Second, we collect all server status reports which are provided by servers. Server status reports provide information on files available and workload. Different from transaction logs, server status reports are reported on a voluntary basis, so we only have information on servers with automatic reporting function turned on. Our analysis indicates that 85% of all servers automatically report server status. We also compare transaction data of servers with automatic reporting on with those servers.

Data Description

A unique aspect of the data is that we observe every transaction and information exchange in the network. This allows us to reconstruct individual level data that identify each individual's sharing and downloading activities on a given day and the environment in which he makes sharing and downloading decisions. The individual level data also allows us to remove inherent heterogeneity across individuals using a fixed effect model and focus on how various network factors influence an individual's contribution level over time.

We construct the following variables for the analyses.

Dependent variable

Contribution Status: We use a dummy variable to identify an individual's contribution status on a given day. Contribution status is obtained from both transaction logs and server reports. Any user who has responded to at least one file download request or whose server report indicates sharing enabled is considered sharing file on that

day. Our definition makes sure that individuals who share files but receive no download requests are counted as contributors rather than free riders.

Reward and Punishment Server Status: Individual's use of reward and punishment mechanism is derived from server reports. We use a dummy variable to indicate that a contributor gives priority download services to other contributors or allows only contributors to download from the server. A contributor may have multiple server settings in a given day. In such cases, we calculate the total server active time for each server setting. Server active time is calculated based on server status report. When file server is connected to the IRC channel, server status report is automatically broadcast every 5 minutes. We estimate server active time based on the number of server status report observed. We then choose the server setting with the longest active time as the server setting of the day.

Independent variables

Number of Non-Pure Contributors and Number of Pure Contributors: We identify contributors based on two pieces of information: server announcement and server related commands. First, when a contributor makes file available, his or her file server will announce server information to the IRC channel periodically, if the announcement function is set to turn on automatically. We identify users associated with these servers as contributors. Second, since not all servers provide automatic server reports, we supplement the data by going through all server related commands and identifying file download and status queries. Using the user ids embedded in the commands, we can identify the remaining contributors who service the channel during the time period. Once we identify all contributors for a given day, we divide them into two groups. Non-pure contributors are the contributors that also download from the peer-to-peer network at least once in the previous week, while pure contributors are those who never download any files from the network in the previous week. The use of download activities in the previous week to separate pure contributors and non-pure contributors could be arbitrary. We test other cutoff windows and find the results are qualitative the same.

Number of Free riders: Free riders are the users who are not involved in any sharing activity in a given time. We identify free-riders based on file request commands. We identify names of all file requesters based on server download requests and then match the name list against the contributor list. Any user whose name is not on the contributor list is a free rider.

Experience: We measure experience by number of days since a user first joined the peer-to-peer network.

Reputation: Based on sharing history and content, the channel operators can assign *Value User* titles to contributors. The contributors with the title will be automatically added to a list that is visible to all network users. In addition, they may receive a higher priority in downloading files if the file sharing server is set up to reward contribution (see incentive below).

Incentive: Each contributor has a choice of three sharing strategies: normal, server-only, and server-priority. The normal sharing strategy treats all requests equally and serves them on a first-come-first-serve basis. The server-only strategy only responds to requests from contributors who are designated as *Value User*. As a hybrid strategy, server-priority will finish all tasks from *Value User* before serving others. We use the proportion of contributors adopting server-only and server-priority strategies to estimate the incentive of the channel provided to encourage sharing.

Wait: Limited number of concurrent transactions can occur on a server. If a server is busy, other requests need to wait in a queue. The measurement *Wait* estimates the average number of tasks a user needs to wait before being served.

Current Download Activity: Total number of files downloaded during the time period.

Table 1. Summary Statistics

	Mean	Std.	Min	Max
# Non-pure Contributors	286.00	33.63	163.00	361.00
# Free Riders	2625.59	299.35	1388.00	3076.00
# Pure Contributors	104.33	13.92	54.00	142.00
Experience	33.20	32.63	0.00	120.00
Reputation	0.17	0.38	0.00	1.00
Current Downloads	22.09	54.82	0.00	3334.00
Incentive	0.48	0.15	0.32	0.61
Wait	13.34	19.59	0.00	321.00

Table 1 shows the descriptive statistics for the key variables used in this paper. The summary statistics suggest that, on average, contributions are provided by about 400 individuals daily in the music sharing network and the network accommodates about 2600 free riders. The ratio of free riders to contributors is about 6.5:1. Of all network users, about 3% are pure contributors who never download from the network and another 9% are non-pure contributors who both contribute files to and download files from the network. The summary statistics also reveal that, on average, network users have been using the network for 33 days. About 17% of all network users receive the title of *Value User*. The percentage is higher than the percentage of all contributors, indicating that some of the *Value Users* do not contribute daily. We also find that, on average, each user downloads 22 music files on a given day with an average wait time of 13 minutes per file. Finally, the summary statistics reveal that 48% of all contributors use some form of reward and punishment mechanism by providing better services to other contributors.

Table 2. Correlation Matrix

	1	2	3	4	5	6	7	8
1. # Non-pure Contributors	1.00							
2. # Free Riders	0.78	1.00						
3. # Pure Contributors	-0.03	0.13	1.00					
4. Experience	-0.02	0.00	-0.00	1.00				
5. Reputation	0.00	-0.02	0.03	0.08	1.00			
6. Current Downloads	0.02	0.02	-0.02	-0.00	0.09	1.00		
7. Incentive	0.13	0.02	-0.22	0.16	-0.01	-0.01	1.00	
8. Wait	0.02	0.02	-0.02	0.08	0.12	0.12	-0.01	1.00

Table 2 shows the correlation matrix for the key variables. The table shows that the correlations among most variables are small except for the correlation between number of free riders and number of non-pure contributors. The correlation between the two variables raises concerns about multicollinearity. To address the concern, we estimate the Variance Inflator Factor (VIF) for the regression model and find that the VIF value is less than 5, indicating that the multicollinearity problem is not severe enough to justify further action.

Empirical Methodology and Results

We use a pair of fixed effect logistic models to test the indirect reciprocity effect.

$$ContributionStatus = \mathbf{B_1 X_{it}} + \mathbf{B}_2 \mathbf{Z_{it}} + t + \theta_i + \varepsilon_{it}$$

$$ServerStatus = \mathbf{\Gamma_1 X_{it}} + \mathbf{\Gamma}_2 \mathbf{Z_{it}} + t + \delta_i + \xi_{it}$$

In the above models, X represents all explanatory variables and Z captures all control variables. The estimation model also control for time effect and fixed effect for individual heterogeneity. The fixed effect allows the models to focus on changes in individual contribution status and use of reward and punishment mechanism. The use of fixed effect also isolates individual level changes from cross-sectional variations and changes in network dynamics. That is, the fixed effect model allows us to understand how changes in the environment of the peer-to-peer network influences individual decision making in making contributions to the network and in using reward and punishment mechanism.

Tables 3 and 4 report the regression results. Table 3 reports the influence of indirect reciprocity on the contribution status of a given user and how the status changes with the network environment. The results provide clear support for all the hypotheses. We find that free riders have a significantly negative impact on an individual's contribution (H2). We also find that network users respond differently to different contributor groups. Their probability of contribution increases significantly with the number of non-pure contributors, i.e., contributors who both contribute to and download from the peer-to-peer network (H1). However, they do not respond to contribution from pure contributors (H3). This corroborates the reciprocity theory that reciprocity is based on contributors' need. As pure contributors do not need any more music files, network users are less likely to reciprocate with music files. Another important finding of the paper is that an individual's probability of contribution increases significantly with her experience with the peer-to-peer network (H4). The increase is consistent with the finding from lab experiments and Figure 1 which suggests that individuals become more reciprocal over time in social environments with punishment mechanisms.

Table 3. Factors Influence Individual Contribution

	Full Model	Hypothesis
# Non-Pure Contributors	1.72*** (0.20)	H1 Supported
# Free Riders	-1.17*** (0.19)	H2 Supported
# Pure Contributors	0.05 (0.05)	H3 Supported
Experience	0.11*** (0.01)	H4 Supported
Reputation	1.84*** (0.03)	H5 Supported
Incentive	1.13* (0.65)	H6 Supported
Wait x Current Downloads	0.02*** (0.00)	H7 Supported
Current Downloads	0.40*** (0.02)	
Wait	-0.04*** (0.02)	
Individual and time fixed effects included but not reported		
Number of Observation	45,125	
Log likelihood	-14,250.372	

Our analysis also reveals that reputation and incentive have significant influence on an individual contribution probability (H5 and H6). Moreover, we find that the coefficient on the interaction term between wait time and download activity is positive (H7). The result indicates that individuals increase their contribution in response to long wait time when they have high download needs from the network.

Table 4 reports individual contributors' use of server settings to encourage indirect reciprocity in the peer-to-peer network. The results provide support for all the hypotheses. We find that increase in number of non-pure contributors significantly reduces a user's probability of providing priority services to contributors (H8). This is consistent with our hypothesis, suggesting that a user is less likely to discriminate against free riders when there are a sufficient number of contributors in the network. On the other hand, we find that the probability of providing priority services increases significantly when the network is overwhelmed by free riders (H9). Similarly, a contributor is more likely to change her server status to punish free-riders when she faces longer download wait time as long wait time indicates the need to encourage contribution behavior (H10). Our analysis also reveals that users in the peer-to-peer network learn about the value and influence of the reward and punishment mechanism over time. As an individual gains experience with the network, his chance of providing priority services to contributors increases (H11). Finally, the results show that individuals with high reputation within the network are more likely to use the reward and punishment mechanism to encourage contribution and discourage free riding behavior. This is consistent with the reputation mechanism that makes these contributors more concerned about the long-term sustainability of the network.

Table 4. Factors Influence Individual Choice of Server Setting

	Full Model	Hypothesis
# Non-Pure Contributors	-1.45** (0.64)	H8 Supported
# Free Riders	1.41** (0.63)	H9 Supported
# Pure Contributors	-0.05 (0.19)	
Wait	0.06*** (0.02)	H10 Supported
Experience	0.15*** (0.05)	H11 Supported
Reputation	1.26*** (0.21)	H12 Supported
Current Downloads	-1.05*** (0.04)	
Incentive	-3.14 (2.16)	
Individual and time fixed effects included but not reported		
Number of Observation	6,495	
Log Likelihood	-1,265.19	

In sum, the analysis above indicates contributions to peer-to-peer network are heavily influenced by indirect reciprocity. The influence reflects in two ways. First, contribution behaviors are reciprocal in nature. Second, each individual contributor has incentive to promote reciprocity to other users by rewarding other contributors and punishing free riders. Both aspects of indirect reciprocity play a significant role in peer-to-peer networks. Contributions motivate contributions and free-riding discourages contribution. As prior studies noted, reciprocity alone is not sufficient to sustain contribution to public goods such as peer-to-peer networks as the invasion of free riders can quickly degenerate the network. An important finding of the study is that individuals can and do punish free riders and reward contributors. These user-initiated mechanisms reduce free riding behavior and promote contribution. Taken together, our results suggest that indirect reciprocity plays a pivotal role in motivating individual contributions to virtual communities.

Discussion

The objective of the paper is to propose a theoretical framework of indirect reciprocity in peer-to-peer network and validate the hypotheses empirically. Peer-to-peer networks have increasingly become a distribution and communication channel of digital files and a variety of mechanisms have been proposed to encourage file sharing and distribution. Some of the mechanisms provide priority service to contributors, which others propose using micropayment system to encourage or compensate contributions. Most of motivation mechanisms are derived based on the assumption that individuals are self-interested economic decision makers. The assumption, however, may not be valid in peer-to-peer networks. Our analysis provides both theoretical basis and empirical evidence to show that indirect reciprocity is an important factor of contribution. It also shows that user-initiated incentive mechanism could play a surprising and significant role in sustaining peer-to-peer network. The analysis enriches our understanding of underlying motivation of contribution and provides new guidance to businesses on peer-to-peer networks.

The analysis also highlights the fact that individual contribution changes in response to network environments. The finding sheds new lights on the composition of network users. Prior studies often assume the presence of altruistic contributors and self-interested free riders. Our analysis indicates that reciprocity could be a key motivating factor for contribution to peer-to-peer networks. The presence of such contributors suggests that peer-to-peer networks exist as a result of interactions between a large number of reciprocal users. More importantly, indirect reciprocity is a double-edged sword. Positive reciprocity could lead to a chain effect that dramatically increases contribution to the network while negative reciprocity could quickly doom the network. Network operators therefore need to take actions to foster positive reciprocity in such networks. We show that one of such actions that could be very effective is to provide contributors with ability to reward each other and to punish free riders. Our analysis also has a number of limitations. First, we focus on changes in individual contribution behavior and identify motivations behind such changes. Our analysis, however, does not explain significant variations across individuals. It also does not consider changes in network composition which is critical to the long term sustainability of peer-to-peer networks. We render these important questions to future research. Second, our data is quite limited compared to economic experiments. In particular, we do not have direct observation of an individual's perception of other's contribution and free-riding behavior. We attribute results to certain motivating factors, but there could exist alternative explanations of the coefficients. In this regard, we consider our study complements earlier experiment studies by considering the empirical validation in real peer-to-peer networks, but at a cost of data quality. Third, we do not observe all server status data since the provision of such data is voluntary. The missing observations could create biases in our analysis if contributors that turn off their server status reporting features are systematically different from contributors that do not. Finally, contributors may have different reciprocity level and our analysis only reveals the behavior of an average contributor. It would be useful in the future to identify reciprocity at the individual level and study how the interactions between individuals with different reciprocity level influence contribution.

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