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NETWORK COOPERATION AND INCENTIVES WITHIN ONLINE COMMUNITIES

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ABSTRACT: The aim of this chapter is to understand the rationale of cooperation within online sharing communities. How can we explain the extent of cooperative interactions between anonymous distant Internet users? We build a game-theoretic framework to study the exchange of services within a virtual community like in a peer-to-peer network. We show that the coexistence of contributors and free-riders is often a stable situation. We also examine the optimal incentive mechanisms to stimulate contributions by community members.

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Introduction

Since its origins, the Internet has always been perceived as a world-wide collaborative network of information sharing, facilitating the emergence of various forms of online gifts and cooperation (Kollock, 1999; Dang-Nguyen and Penard, 2001). Hence many academic or scholarly communities, many non-profit organisations and many individual users are accustomed to releasing and sharing free informational content or providing free advice and assistance. The increasing development of electronic commerce (B2C or B2B) could have endangered online cooperation and informational "gifts" via the Internet. Surprisingly, this did not occur and the well publicised phenomenon of the peer-to-peer exchange of files is the best illustration of the online cooperation vitality. Peer-to-peer (P2P) is a technology based on the direct exchange of resources from computer to computer at the edges of the network. In 2003, the world-wide P2P exchange of audio files was estimated at 150 billions and the exchange of movie files at 1 billion[2]. More than 7 millions Internet users are simultaneously connected on P2P networks (Kazaa, eMule, …) every day.

However many people consider cooperation on the Internet as a puzzle: how can one explain the extent of cooperative behaviours within and outside online communities, given that Internet users are generally anonymous, distant and too numerous to rely on mutual trust and reciprocity? What are the incentives behind cooperating and sharing information content on the Internet?

The aim of this chapter is to analyse the properties and the rationale of online cooperation through a game-theoretic framework. We focus on sharing communities like file-sharing communities or discussion forums. The ease of entering and leaving such communities hinders the replication of the same cooperation patterns as in "physical" communities in which members are constrained in their movements (switching costs due to location, social pressure, etc.). In these *offline* communities, long term reputation and reciprocity are generally strong drivers for cooperative behaviour (Axelrod, 1982). By contrast, Internet sharing communities appear to be loose-knitted and cannot easily self-enforce cooperation by long term reputation mechanisms.

To explain the vitality of online cooperative behaviour in virtual communities, we propose a model closely related to Krishnan *et al*. (2004). The latter constructed a model of

[2] Source IDATE.

content sharing in a P2P network where the users are heterogeneous in the content they own. They showed that both free-riding (consuming without contributing content) and sharing (consuming and contributing) can be observed at the equilibrium. They underlined that sharing can occur in the absence of altruism, motivated by self-interest because sharing content serves to offload traffic in the P2P network and increases the likelihood of accessing desired content. They also showed that under symmetric costs of sharing, high value contents are shared before lower value contents, this result being reinforced in a dynamic context where contents are replicated and propagated within the network.

Our model differs slightly from that of Krishnan *et al.* (2004). Here we consider an online community in which peers have the opportunity to send requests or queries to other peers (for example a request to download a given audio-file, a request for assistance or advice, etc…). In such a community, contributing involves sending requests but also treating requests from other peers, whereas free-riding involves refusing to answer queries from the other members. The originality of our model comes from the heterogeneity in the costs of contribution (some peers are more competent or efficient in treating the requests) and from the presence of a delay cost when the requests are not immediately treated.

Like Krishnan et al. (2004), we highlight that online cooperation is characterised at the equilibrium by the coexistence of heavy contributors and free-riders when users are heterogeneous in their cost of contribution. Thus the presence of intense free-riding is not always a sign of cooperation breakdown and can durably persist in sharing communities. However the level of free riding is higher than the socially optimal level. We also consider the impact of external incentives on free-riding behaviours, examining monetary incentives and priority mechanisms. These external incentives can be a remedy to the excess of free-riding since online communities generally have no means to filter entry or exclude members from the services.

The remainder of the paper is organised as follows. In the next section, we give more evidence about cooperative behaviour on the Internet and review the possible explanations. Section 2 develops a theoretical model of P2P community. Propositions and implications are discussed in section 3. Conclusions are given in section 4.

Section 1 Theory and Evidence

Evidence of free riding in online communities

In a community, individuals always have a common interest and are collectively better when all members decide to cooperate or coordinate their efforts. Curien et al. (2004) distinguish different types of communities: *epistemic communities* where members produce knowledge like in a community of open source software developers; *communities of practice* where members exchange expertise or information like in a technical support forum; and finally *content-sharing communities* where members directly share resources like in a P2P network. Beyond this classification, all these communities share a commonality: their output is a public good, subject to potential *free riding* or opportunistic behaviour. Each member of a community has a temptation to cheat, by consuming without contributing, letting the other members incur the cost of providing the public good. In these conditions how do members of online communities overcome free-riding and sustain stable cooperation? What are the motivations to contribute?

There can be different answers to these questions, depending on the type of online community. Epistemic communities are characterised by high barriers to entry and exit and by a high cost to contribute (requiring rare specific competencies or skills). As their size is rather limited, they can efficiently rely on more classical mechanisms of cooperation, based on bilateral or multilateral reputation. In these communities, members realise that they are repeatedly interacting with the same partners and can suffer from retaliation in case of cheating. Indeed it is difficult or costly to escape punishment, since leaving an epistemic community involves losing one's reputation and the benefits connected to it. Moreover, the small number of partners enables the community to quickly determine who has "cheated", and to personalise punishments (for example by using "tit for tat" (Axelrod, 1984) or a stick and carrot punishment (Abreu, 1982)). The possibility of "retaliation" is a strong incentive for maintaining cooperation, and largely explains the stability of epistemic communities. The relationships between Internet operators, also called ISPs (Internet Service Providers) illustrates this logic of cooperation. These operators form a club where each member decides with whom it accepts to interconnect at exchange nodes. Cooperation is materialised by peering agreements where each ISP agrees to convey all the traffic addressed to its network for free, and gets revenues only from the fees paid by its own subscribers[3]. These agreements

[3] It is a "sender keeps all" scheme. The network originating the traffic keeps all the money paid by its customers to access other networks (see Bailey, 1997)

are often not formalised (not written) and rely on mutual trust. Open source communities provide other examples of cooperation based on a direct multilateral reputation mechanism. In many open source projects, the number of members is limited (members are coopted) and each developer has a strong incentive to contribute honestly to encourage the others to contribute on the ongoing and future projects but also to signal her ability to future employers (Lerner and Tirole, 200) (for a further analysis of open source cooperation, see the chapter of Foray and Zimmermann in this book) [4].

In the remainder of the chapter, we will focus on the other two communities, i.e. practice and sharing communities, in which members exchange advice, expertise, information or other resources. These virtual communities are characterised by low barriers to entry and to exit, a huge number of members and an affordable cost to contribute. In these large communities, multilateral retaliation mechanism cannot be applied easily or are less efficient. Some of these communities can include millions of people from everywhere who agree to share certain resources (information, content, advice, etc…) even if they do not physically know their partners. Since the ease of entering and leaving a community gives *prima facie* strong incentives to "cheat", the existence and stability of these large internet communities represent a theoretical puzzle. However, these communities actually seem to manage the large presence of free riding well. For example, Adar and Huberman (2000) observed in August 2000 that on the Gnutella (0.6) P2P network, two-thirds of users did not contribute at all (namely by refusing to have their files downloaded by other peers) whereas the top 1% of users provided 50% of contents. Similarly, Asvanund *et al*. (2004) found in September 2002 that 42% of Gnutella peers were free riders. Moreover peers are less likely to contribute resources to the network as the network size increases. Asvanund *et al.* (2004) provided evidence of congestion effects that can counterbalance positive network externality resulting from a larger P2P community. Peers would have a higher propensity to free-ride as the size of the group rises, confirming the intuition of Olson (1965).

Similarly, Resnick and Zeckhauser (2002) found that on eBay, the Internet auction leader, 40% of buyers refuse to release an evaluation about their partners (positive or negative). This attitude can be assimilated to free-riding since the evaluation of the dealing partner is a public good that helps other buyers in the eBay community in their future transactions *e.g*. these evaluations enable buyers to build a reputation for each eBay seller (Houser and Wooders, 2001, Friedman and Resnick, 2001). Likewise, Dellarocas *et al* (2004)

[4] See Johnson (2000) on the impact of community size on the efficiency of open source projects.

observed rare coin auctions on eBay and found that 23% of sellers and 33% of the buyers did not leave feedback.

In all these examples, free riding seems to be a common dominant norm, but apparently without threatening or ruining the existence and the stability of Internet communities. In these circumstances, why do some members accept to contribute intensively to the functioning of these communities and to the provision of public goods such as distributing information?

The motivations for contributing

One reason often put forward is linked to the origins of the Internet: cooperation is supposedly rooted in the "academic" origin of the Internet. The essence of academic life is publication (publish or perish), making one's own discoveries available to the whole community of scientists. This tradition of releasing and sharing freely one's own production of information has been progressively adopted by non academic newcomers on the Internet: the latter seem to have been contaminated and converted to the academic spirit of free sharing. Hence the stability of cooperative behaviour within Internet communities online could be analysed as an *evolutionary stable strategy* that has the property to resist the invasion of mutant strategies, in particular strategies of free-riding (Maynard-Smith, 1982).

Altruism can also be a driver for sharing and contributing in a virtual community. For example, Gu and Jarvenpaa (2003) empirically showed that members of technical support forums are largely motivated by a "warm glow" effect (a pure utility derived from contributing and helping the other members[5]). In the context of eBay, the feedback provided by buyers may similarly be motivated by a feeling of belonging to a community that promotes courtesy, fairness and truthfulness, exemplified by the large proportion of positive evaluation (only 1% of non positive evaluation !)[6]. Dellarocas et al. (2004) found that self-interest is an important motivating force behind the high level of evaluations. Indeed many traders first send a feedback to elicit a reciprocal response (selfish motivation)[7]. But they also demonstrate some altruistic motivations, when eBay members agree to unconditionally evaluate their partner (a "warm glow" effect). Dellarocas et al. (2004) concluded that the motivation to

[5] Warm-glow effects have largely been evidenced in real communities, in particular through donation (see Andreoni, 1989).

[6] However, for Gross and Acquisti (2003), this hides a fear of retaliation and some unbalances among eBay "peers". See also Miller, Resnick and Zeckhauser (2002).

[7] They find that the probability of contributing decreases if the partner has yet released his evaluation.

contribute eBay's review system is multifaceted (ranging from self-interest and reciprocity to altruism).

Online cooperation can also be explained by the nature of contributions that involves providing informational content. It is often more expensive to protect one's own information or to keep it secret, than to share it freely. An Internet user needs to exert a costly effort if she does not want to participate in the public provision of information. This contrasts with a classical public good setting where the user supports a cost only if she contributes. The relative cost of contributing or not is indeed an important element in explaining the extent of cooperation within online communities: contributors are generally characterised by a higher personal cost when they refuse to contribute than when they agree to contribute. This happens in open source communities or technical forums where many members find it more profitable to make their information available, because this fosters technical improvements and innovation.

Cooperation can also be explained by the technical architecture or design of online communities. For example, in many P2P networks, each peer (client) is a server/contributor by default. When a peer downloads a file on a PC, this file becomes automatically available for uploading by other peers except if she explicitly forbids this. Hence being a free-rider (retrieving and hiding the downloaded files) requires certain technical competencies and can be time consuming.

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To summarise our discussion so far, cooperation tends to emerge and persist in large and loose-knit communities in which individuals are anonymous and do not have bilateral repeated relations, despite high levels of free-riding. In the following section, we propose a game-theoretic model to analyse more rigorously the dynamics of online cooperation.

Section 2 A Model of Peer-to-Peer Cooperation

The model considers a community of Internet users or peers who are loosely linked by a common interest: for example, it can be a peer-to-peer community exchanging music files (Kazaa), or a community of software users exchanging programs and assistance or a thematic community exchanging ideas and opinions. Belonging to a community allows members to send requests or queries to the other members, expecting that some of them will respond. This can be a request for a music file, for assistance, or for advice. In this model, the online community is narrowly defined as an electronic network permitting the exchange of requests. An Internet user belongs to the community as long as she continues sending requests.

Technically, the transmission of a query or request can be either decentralised or centralised. In the latter case, all requests are sent to a server or a coordinator in charge of soliciting the different peers and finding those who will agree to treat the request. In a decentralised design, the sender solicits community members directly, either simultaneously or sequentially. The main advantage of a centralised network is efficiency in the processing of requests but the main drawback is vulnerability (in case of the shutdown of the central server, *e.g*. Napster). Thus a decentralised network (e.g.; Kazaa, Morpheus, Gnutella 0.6) is more suited to large size communities and can be a response to threats of prosecution, even if it demands much more of the community members (Gu and Jarvenpaa, 2003, Asvanund, Clay, Krishnan and Smith, 2003)[8].

Here we consider a decentralised community without making explicit the mechanism of request transmission. When members are solicited, they can either agree or refuse to process a request. Thus two types of members can emerge in a community: the contributors who send requests but also respond to some requests and non-contributors who content themselves with sending requests without treating the requests of other members.

Can the presence of many free-riders destabilise cooperation inside a virtual community? Our model makes it possible to understand how online cooperation can be sustainable when a large proportion of members never want to contribute to the provision of community services (by releasing and transmitting contents or files, or by answering requests). Let us now detail the assumptions of the model.

Assumptions

We assume that members incur a cost when they decide to contribute. This cost can correspond to the efforts and time required to treat requests or to transmit the answer (files, information) to the other members of the community[9]. A key assumption is that peers face different costs. In other terms, they are heterogeneous in competencies or ability to treat

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[8] For example, in recent P2P networks, the catalogue of contents is distributed among several peers who agree to be local servers. The users log in to one of these ultra-peers to submit their requests. Then the ultra-peers collect the list of contents of all connected peers who accept to share part of their resources. On the base of this catalogue, the ultra-peer may answer or satisfy the request. If not, the latter transmits the requests to the other ultra-peers with whom she is connected. This is a hybrid solution between full centralisation and full decentralisation, relatively efficient and secure, which is assumed to reduce free riding and improve performance. See Krishnan *et al*. (2003) for a more detailed presentation of P2P architectures with their advantages and weaknesses.

[9] The decision to contribute is binary. See Curien et al. (2004) for a model where peers can select the intensity of

requests. For example, if they experience a different quality of Internet access, it is likely that those who have a broadband access will face lower costs in responding to requests[10]. We can also expect the more educated members to have better skills (and lower cost) to treat requests.

Let assume that the individual costs are distributed between $[\underline{c},\overline{c}]$, according to a density function *f* and a cumulative function *F*. A peer's decision to contribute or free-ride will straightforwardly depend on her cost. Indeed the peer faces the following trade-off. Free-riding allows one to save the cost of participation, but it degrades the quality of community services by increasing the likelihood of congestion in the treatment of requests. So contributing can be a better strategy if the cost of participating is more than counterbalanced by the increasing quality of services provided by the community. By agreeing to treat requests, a peer knows that she is contributing to reducing congestion and augmenting the probability for her own requests being treated rapidly.

If all members having a cost lower than $\hat{c} \in [\underline{c},\overline{c}]$ agree to contribute, then the proportion of contributors will be $F(\hat{c}) = \int_{\underline{c}}^{\hat{c}} f(c)dc = \int_{\underline{c}}^{\hat{c}} dF(c)$ *).*

We assume that peers send the same number of requests, this number being normalised to one by convenience. Moreover *N* is the volume of requests sent simultaneously per period. We can interpret *N* as the intensity of community activity or the capacity of request transmission in the network. Obviously, *N* is positively linked with the size of the community (the number of peers).

Let $\alpha(\hat{c},N)$ denote the probability that a request is instantaneously treated. We make the following assumptions on $\alpha(\hat{c},N)$: *i)* $\alpha_{\hat{c}}(\hat{c},N) > 0$*, ii)* $\alpha_{\hat{c}\hat{c}}(\hat{c},N) < 0$*, iii)* $\alpha_N(\hat{c},N) < 0$*, iv)* $\alpha_{NN}(\hat{c},N) > 0$*, v)* $\alpha_{\hat{c}N}(\hat{c},N) < 0$. The probability of request treatment is an increasing and concave function of $\hat{c}$. The higher the proportion of contributors inside the community, the more rapid the treatment of requests. But the positive effect of an additional contributor tends to diminish with the number of contributors and with the volume of requests (or the size of the community). Moreover, $\alpha(\hat{c},N)$ is decreasing and convex in N: a larger community contributes to degrading the quality of request treatment, by reinforcing the risk of congestion. When the number of peers increases as well as the volume of requests, contributors are much

their contribution.

[10] Indeed treating the requests implies a reduction of resources for other activities, and in particular a reduction of the contributor's bandwidth for other applications. Feldman, Lai, Chuang and Stoica (2003a) underlined the actual disincentive effects due the symmetric treatment of uploading and downloading in P2P networks because the download latency is dominated by the sender's outgoing bandwidth: his or her computer link is often burdened by the provision of service to peers at the expense of the fulfilment of his or her own requests.

more solicited and cannot satisfy all requests; consequently the treatment is more likely to be delayed. Finally, let us assume that $\alpha(\underline{c},N)$=0 (in the absence of contribution, the online community is fully congested),

We also denote u as the utility for a member to send a request and to obtain immediately an answer or an assistance. Facing a delay in the treatment of her request induces a disutility for the sender. Indeed the utility of a request treated t periods after its transmission is $\delta^t u$, where δ is the discount factor (common to all members of the community).

When a request fails to be treated in the initial period, this request is resubmitted until it receives an answer. Thus sending a request yields an expected utility G defined by:

$$G=\alpha(\hat{c},N)u+(1-\alpha(\hat{c},N))\delta G$$

After rearrangement, we obtain:

$$G=\frac{\alpha(\hat{c},N)u}{1-\delta+\delta\alpha(\hat{c},N)}$$

G represents the expected benefit of belonging to a community (and of sending a volume of requests normalised to one) where a proportion $F(\hat{c})$ of peers actively contributes. G is increasing and concave in $\hat{c}$ (*i.e.* in the number of contributors)[11]. This benefit also rises with the discount factor of the peer (her preference for the future). In the following proposition, we characterise the peers' equilibrium strategies in this virtual community.

PROPOSITION 1. EQUILIBRIUM CONDITIONS FOR ONLINE COOPERATION

If $\underline{c}>\frac{(1-\delta)\alpha_{\hat{c}}(\underline{c},N)u}{(1-\delta+\delta\alpha)^2}$, *then all peers refuse to cooperate (no community)*

If $\bar{c}<\frac{(1-\delta)\alpha_{\hat{c}}(\bar{c},N)u}{(1-\delta+\delta\alpha(\bar{c},N))^2}$, *then all peers contributes (no free-riding)*

Otherwise it exists a $\hat{c}\in[\underline{c},\bar{c}]$ *defined by* $\hat{c}=\frac{(1-\delta)\alpha_{\hat{c}}(\hat{c},N)u}{(1-\delta+\delta\alpha(\hat{c},N))^2}$ *such that a proportion F(*$\hat{c}$*) of contributors and a proportion (1-F(*$\hat{c}$*)) of free-riders coexist in the same community.*

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[11] We have $G_{\hat{c}}=\frac{(1-\delta)\alpha_{\hat{c}}u}{(1-\delta+\delta\alpha)^2}$>0 and $G_{\hat{c}\hat{c}}=\frac{(1-\delta)\left[\alpha_{\hat{c}\hat{c}}(1-\delta+\delta\alpha)u-2\delta(\alpha_{\hat{c}})^2\right]}{(1-\delta+\delta\alpha)^3}$<0.

Proof : A peer will agree to contribute if her cost of effort is inferior to her marginal gain. If $\underline{c} > \frac{(1-\delta)\alpha_{\hat{c}}(\underline{c}, N)u}{(1-\delta+\delta\alpha)^2}$, then the most competent peer has no incentive to contribute and consequently this is the case for all the other less competent peers.

Now let us consider that $\underline{c} \leq \frac{(1-\delta)\alpha_{\hat{c}}(\underline{c}, N)u}{(1-\delta+\delta\alpha)^2}$. Thus there exists at least one peer who agrees to contribute. Consider that there exists a peer with a cost $\hat{c}$ such that she is perfectly indifferent between accepting and refusing to treat requests, given that all the more competent peers than her are contributors. For this marginal peer, her additional gain from contributing $\frac{(1-\delta)\alpha_{\hat{c}}(\hat{c}, N)u}{(1-\delta+\delta\alpha(\hat{c}, N))^2}$ should be perfectly equal to her additional cost ($\hat{c}$). Then it can be recursively shown that any peer having a lower cost than $\hat{c}$ also has an incentive to contribute (because she knows that by refusing she will encourage all peers having a higher cost than herself to refuse). However, if $\bar{c} < \frac{(1-\delta)\alpha_{\hat{c}}(\bar{c}, N)u}{(1-\delta+\delta\alpha(\bar{c}, N))^2}$, even the less competent peer wants to contribute and there is no free-riding inside the community. ■

Proposition 1 underlines that inside the community the contributors are always the more competent or efficient peers. This result is similar to that of Krishnan et al. (2004), who showed that the contributors are the owners of the highest value contents. Hence; if members are widely heterogeneous ($\underline{c}$ sufficiently low and $\bar{c}$ sufficiently high), the community will be characterised by partial cooperation. The more competent members (those who have a cost below $\hat{c}$) will agree to contribute whereas the other members are mere consumers of community services. So the presence of free-riders is not incompatible with a cooperative community. It may be in the interest of highly skilled members to continue contributing and maintaining the community activity because they are aware that they will be indirectly penalised if they stop treating the requests of their peers (meeting more congestion for their own requests). However if the members of the community have a strong preference for the present ($\delta < 1 - \frac{\alpha_{\hat{c}}(\underline{c}, N)}{\underline{c}}$), then no one will agree to contribute: in this case, no sustainable cooperation will emerge from this community. Online cooperation will be feasible only if members are sufficiently patient (high preference for the future).

The impact of community size

The world-wide expansion of the Internet has deeply impacted the functioning and activities of online communities. Most of them have welcomed many newcomers from all over the world and have dramatically grown (some Internet communities can bring together several million users). Does the boom in Internet communities represent a threat or an opportunity for them? We can expect that new members will be more free-riders due to their lack of competence or expertise. But it is also possible that the arrival of new members may incite some current free-riding members to contribute and counterbalance the negative effect of increasing request activity generated by newcomers. So it is debatable whether a larger community size may destabilise or reinforce cooperation.

By differentiating $\hat{c} = \frac{(1-\delta)\alpha_{\hat{c}}(\hat{c},N)u}{(1-\delta+\delta\alpha(\hat{c},N))^2}$, we obtain:

$$\frac{d\hat{c}}{dN} = \frac{-2(1-\delta+\delta\alpha)\delta\hat{c}\alpha_N + (1-\delta)\alpha_{\hat{c}N}u}{(1-\delta+\delta\alpha)^2 + 2(1-\delta+\delta\alpha)\delta\hat{c}\alpha_{\hat{c}} - (1-\delta)\alpha_{\hat{c}\hat{c}}u}$$

The sign of the denominator is always positive, but the sign of the numerator is undetermined. A larger community can create new incentives to contribute and may increase the proportion of contributors if $2(1-\delta+\delta\alpha)\delta\hat{c}\alpha_N < (1-\delta)\alpha_{\hat{c}N}u$. This condition is likely to be satisfied if the risk of congestion is high (α_N high in absolute value) or if members have a strong preference for the future (δ high[12]).

Proposition 2. *An enlargement of the online community may reinforce cooperation if peers are sufficiently patient.*

An increase in the size of the community (or in its activity) does not systematically threaten the stability of the community. As the risk of congestion becomes higher, some free riders may realise that their efforts could be determinant to maintain cooperation and may decide to join the club of contributors.

The optimal level of cooperation

Does a decentralised online cooperation lead to an optimal level of contribution and request treatment? Are there too many or too few contributors? To address this question, we

[12] For δ =1, the condition becomes $2\alpha\hat{c}\alpha_N < 0$ and is always true.

have to find the level of cooperation that maximises the collective surplus of the online community. This optimal level $\tilde{c}$ is given by:

$$Max_{\{\tilde{c}\}}\left(\frac{\alpha(\tilde{c},N)u}{1-\delta+\alpha(\tilde{c},N))\delta}\int_{\underline{c}}^{\bar{c}} f(c)dc-\int_{\underline{c}}^{\tilde{c}} cf(c)dc\right)$$

We notice that costs are only supported by the contributors $[\underline{c},\tilde{c}]$ whereas gains $G(\tilde{c})$ are equally shared among all peers $[\underline{c},\bar{c}]$. Thus $\tilde{c}$ is defined by:

$$\tilde{c}f(\tilde{c})=\frac{(1-\delta)\alpha_{\tilde{c}}(\tilde{c},N)u}{(1-\delta+\delta\alpha_{\tilde{c}}(\tilde{c},N))^2}\int_{\underline{c}}^{\bar{c}} f(c)dc$$

The right-hand side stands for the marginal collective benefit if peers having a cost $\tilde{c}$ decide to actively contribute to the functioning of the activity, and the left-hand side shows the collective cost the type $\tilde{c}$ incurs.

PROPOSITION 3: *Decentralised online cooperation always induces an excess of free riding when the community is heterogeneous.*

Proof: Since $\frac{f(\tilde{c})}{\int_{\underline{c}}^{\bar{c}} f(c)dc}<1$, then $\tilde{c}\frac{f(\tilde{c})}{\int_{\underline{c}}^{\bar{c}} f(c)dc}=\frac{(1-\delta)\alpha_{\tilde{c}}(\tilde{c},N)u}{(1-\delta+\delta\alpha_{\tilde{c}}(\tilde{c},N))^2}<\tilde{c}$ (i.e. $G_c(\tilde{c})<\tilde{c}$). Since $G_c(\hat{c})=\hat{c}$ et $G_{cc}<0$, then $\tilde{c}>\hat{c}$. ■

Note that optimal online cooperation does not imply a full participation (except if $\bar{c}\frac{f(\bar{c})}{\int_{\underline{c}}^{\bar{c}} f(c)dc}<\frac{(1-\delta)\alpha_{\tilde{c}}(\bar{c},N)u}{(1-\delta+\delta\alpha_{\tilde{c}}(\bar{c},N))^2}$) but the coexistence of contributors and free-riders. It may be sub-optimal to force all peers to contribute, especially the less competent (since the quality of their contribution is low).

The stake for an online community is to maintain and if possible strengthen cooperation in a context of membership growth, where screening of newcomers is difficult to implement. In the next section, we will consider different incentive designs that have already been experimented in online communities or have been debated.

Section 3 How to stimulate online cooperation ?

There exists recent interdisciplinary literature that examines the means to reduce free-riding in P2P networks and online communities. What kind of incentives should members receive to be incited to provide resources, content or efforts? Some authors have proposed micro-payment mechanisms (Golle et al. 2001), reputation systems (Lai et al. 2003), admission control systems (Kung and Wu 2003) or priority systems (Krishnan et al. 2004). However these systems generally rely on centralised administration and cannot be easily implemented in most online communities (based on a decentralised architecture). Nevertheless, it is worthwhile trying to understand how such systems could improve cooperation in our setting of a decentralised community.

We examine two cooperation-fostering mechanisms: first the introduction of monetary incentives and second, the use of priorities for request treatment. Can these two mechanisms improve the performance of the community, enhance the matching and routing or requests and reduce the level of free-riding?

Monetary incentives

Let consider that each non contributor has to pay p to participate in the community and that the collected monetary sum is equally shared amongst contributors. Then each contributor receives $\left(\frac{1-F(\hat{c})}{F(\hat{c})}\right)p$ where $F(\hat{c})$ is the proportion of a contributor.

Monetary incentives impact the trade-off between free-riding and cooperating. The level of cooperation is now determined by the following condition:

$$\hat{c}_p = \frac{(1-\delta)\alpha_{\hat{c}}(\hat{c}_p, N)u}{(1-\delta+\delta\alpha(\hat{c}_p, N))^2} + \left(\frac{1-F(\hat{c}_p)}{F(\hat{c}_p)}\right)p$$

where $\hat{c}_p$ is the peer indifferent between contributing and free-riding.

A higher payment p leads to a larger proportion of contributors in the online community. However monetary incentives have decreasing returns. Indeed, when p increases, then the proportion of contributors rises and tends to 100%, reducing the share claimed by each contributor.

Therefore there exists fees $\overline{p}$ such that $\hat{c}_{\overline{p}} = \overline{c}$. Hence fees rising above $\overline{p}$ create no more incentives inside the community[13].

[13] In other terms, the differential in the marginal benefits of contributing with and without monetary incentives decreases and tend to zero as p becomes larger.

It is important to bear in mind that most online communities are decentralised and cannot technically or practically control access and exclude members. So membership fees are hard to enforce. Fees must be voluntary in an anonymous community. Obviously things would be different in a centralised community, sponsored and managed by either a non-profit or for-profit organisation (for example eBay, Amazon or Yahoo,etc.).

Let us consider the incentives of non contributors to voluntarily remunerate the contributors. The expected benefits of this voluntary transfer outweigh the cost when

$$\frac{\alpha(\hat{c}_p, N)u}{1-\delta+\delta\alpha(\hat{c}_p, N)} - \frac{\alpha(\hat{c}_0, N)u}{1-\delta+\delta\alpha(\hat{c}_0, N)} > p$$

PROPOSITION 4: *If* $\hat{c}_0 \geq 1 \Big/ \frac{d\hat{c}_p}{dp}$*, then a voluntary payment mechanism can be feasible even in a decentralised community*

Proof : The problem can be reformulated as follows. The net benefit for a free-rider is defined by:

$$B(p) = \frac{\alpha(\hat{c}_p, N)u}{1-\delta+\delta\alpha(\hat{c}_p, N)} - p$$

By differentiating with respect to *p*, we have:

$$\frac{\partial B(p)}{\partial p} = \left(\frac{(1-\delta)\alpha_{\hat{c}}(\hat{c}_p, N)u}{\left(1-\delta+\delta\alpha(\hat{c}_p, N)\right)^2} \right) \frac{d\hat{c}_p}{dp} - 1$$

As $\hat{c}_p = \frac{(1-\delta)\alpha_{\hat{c}}(\hat{c}_p, N)u}{\left(1-\delta+\delta\alpha(\hat{c}_p, N)\right)^2} + \left(\frac{1-F(\hat{c}_p)}{F(\hat{c}_p)} \right) p$, then

$$\frac{\partial B(p)}{\partial p} = \frac{d\hat{c}_p}{dp} \left(\hat{c}_p - \frac{1-F(\hat{c}_p)}{F(\hat{c}_p)} p \right) - 1$$

At the neighbourhood of p=0,

$$\left. \frac{\partial B(p)}{\partial p} \right|_{p=0} = \hat{c}_0 \frac{d\hat{c}_p}{dp} - 1$$

If $\hat{c}_0 < 1 \Big/ \frac{d\hat{c}_p}{dp}$, then $\left. \frac{\partial B(p)}{\partial p} \right|_{p=0} < 0$ and non contributors will refuse to voluntarily pay to send their requests. ■

A voluntary payment is more likely to exist if the proportion of free riders is sufficiently low (if 1-$F(\hat{c}_0)$ is low or equivalently if $\hat{c}_0$ is high): but if there are too many free-riders, then the net benefit of monetary incentives does not counterbalance the cost.

Note that this proposition is useful to help understand why many communities are based on free interactions, without monetary compensation. For example, the community of Internet carriers is characterised by a predominance of peering agreements where each carrier keeps all the revenues from its customers and exchanges traffic with its peers without monetary compensation.

A priority system

Another mechanism to promote cooperation is to put priorities on the requests of contributors to encourage participation. Such a mechanism is examined by Krishnan *et al.* (2004). According to them, differentiating the quality of services provided to contributors and non contributors could improve P2P network performance and can be easily implemented even in a decentralised environment. Indeed Kazaa has developed priority-like system where depending on the past behaviour of the peer, her requests will be treated as a priority or be delayed. Each peer has a kind of score related to the number of files she is currently offering to other peers and the number of files (requests) that have been downloaded on her own computer.

Let $q\alpha$ denote the probability of being served when the peer is a contributor (q>1), and α the probability of obtaining a response when she is a free-rider. Here we implicitly assume that peers can distinguish between requests sent by a contributor and from a free-rider. Then the expected utility of a request sent by a contributor in an online community is defined by:

$$G = q\alpha(\hat{c},N)u + (1 - q\alpha(\hat{c},N))\delta G$$

meaning that for a contributor the expected utility is

$$G^c = \frac{q\alpha(\hat{c},N)u}{1-\delta+\delta q\alpha(\hat{c},N)}$$

whereas for the non contributor it is $G^{nc} = \dfrac{\alpha(\hat{c},N)u}{1-\delta+\delta\alpha(\hat{c},N)}$.

The marginal contributor is now determined by:

$$\hat{c}_q = \frac{(1-\delta)q\alpha_{\hat{c}}u}{(1-\delta+\delta q\alpha)^2} + \left(\frac{q\alpha u}{(1-\delta+\delta q\alpha)} - \frac{\alpha u}{(1-\delta+\delta\alpha)}\right)$$

The first term on the right hand side corresponds to the marginal benefit of decreasing congestion and the second term the benefit with a right of priority.

The equilibrium level of contribution is higher with a priority system, as the incentives to contribute are reinforced: direct incentives through the priority label and indirect incentives through the reduction of congestion. We can observe that $\hat{c}_q$ is an increasing function in q (that measures the extent of priority).

However, in reality this system can have a limited efficiency if free-riders can easily modify their profile and take on the appearance of a contributor. A network like Kazaa has faced this problem where some users have managed to replace their free rider profile or score by a contributors' profile.

Taxation as a means to destabilise online communities

The taxation of upload flows on the Internet is strongly supported by music companies like Universal Music that are complaining about piracy and P2P networks that may be responsible for the drop in record sales. Several empirical studies have attempted to measure the impact of P2P on music sales. Most of them conclude to the existence of a significant negative effect, but that only partially explains the CD sales decline these last few years (Peitz and Waelbrock, 2004 ; Molteni and Ordanini, 2003 ; Boorstin 2004, Hui and Png 2003 ; Leibowitz 2003 ; Oberholzer and Strumpf 2004). Nevertheless music companies see taxation as a means to destabilise P2P communities by making active contribution more costly. Indeed a tax would penalise those who agree to let their files downloadable. Our framework enables us to understand the rationale of this taxation for record companies. Now the level of cooperation is defined by $\hat{c}_t$ where t stands for the tax applied to contributors :

$$\hat{c}_t + t = \frac{(1-\delta)\alpha_{\hat{c}}(\hat{c}_t, N)u}{(1-\delta+\delta\alpha(\hat{c}_t, N))^2}$$

We can note that the threshold level of participation is decreasing in the tax *t*. If the goal of the record companies is to fully deter online cooperation on P2P networks, they should plead for a minimum tax $\underline{t}$ such that $\underline{c} + \underline{t} > \frac{(1-\delta)\alpha_{\hat{c}}(\underline{c}, N)u}{(1-\delta)^2}$. With a sufficiently large tax, all members of the community will refuse to contribute or to release content, files, information, etc.

Conclusion

This chapter has provided a survey of the recent economic literature on P2P systems, as well as a theoretical framework which has enabled us to give insights into issues which have been discussed in the literature. While many authors stress the point that the persistence of communities is a puzzle, given the large amount of free riding which permeates them, we claim that a selfish attitude is perfectly consistent with cooperation because in such communities there exist heavy contributors. The large amount of free riding is explained in our model by heterogeneity among community members. The main results provided are that monetary incentives may not be the proper way to reduce free riding in these P2P networks, while prioritisation may be better suited in some cases. Thus integrating the user's self interest to cooperate in the design of computer networks is crucial. In Internet communities, free-riding problems can be more easily tackled by a technical response than in real communities (Schneidman and Parkes 2003).

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