THE ECONOMICS OF PEER-TO-PEER NETWORKS

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ABSTRACT

Peer-to-Peer (P2P) networks have emerged as a significant social phenomenon for the distribution of information goods and may become an important alternative to traditional client-server network architectures for knowledge sharing within enterprises. This paper reviews and synthesizes the relevant computer science and economics literatures as they relate to P2P networks, and raises important questions for researchers interested in studying the behavior of these networks from the perspective of the economics of information technology.

With regard to the economic characteristics of these networks, we show that while the characteristics of services provided over P2P networks are similar to public goods and club goods, they have many important differences and hence there is a need for new theoretical models as well as empirical and experimental analysis to understand P2P user behavior. We then identify several important areas for study with regard to the economics of P2P networks and review recent academic papers in each area.

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INTRODUCTION

Peer-to-peer (P2P) networks allow a distributed community of users to share resources in the form of information, digital content, storage space, or processing capacity. The novel aspect of these networks is that, in contrast to client-server networks where all network content is located in a central location, P2P resources are located in and provided by computers at the edge of the network (a.k.a. “peers”).

It is interesting to note that while they are perceived to be a recent phenomenon, P2P networks have their origins in many of the early Internet applications and architectures. Internet Relay Chat (IRC), which was developed in the late 1980s, was one of the first P2P services on the Internet. IRC allowed for the transmission of text messages, and later digital content, directly between groups of network users. Likewise, the Domain Name System, and Usenet bulletin boards exhibit elements of P2P design. Thus, it can be argued that the P2P design concept is embedded in many of the original Internet protocols and applications (Minar and Hedlund 2001).

Still, the widespread popularization of P2P at the consumer level can be traced to the release of the Napster file-sharing program in May 1999. Napster was developed in a matter of months by Shawn Fanning, then a Northeastern University student. Initially distributed to 30 friends, the program grew to 25 million users worldwide within its first 12 months of operation (Strahilevitz 2002).

In all P2P file-sharing networks, the content resides with the network users. The only difference between the architecture of these networks is the nature of the catalog of this content. In Napster and OpenNap (an open source version of the Napster protocol) the catalog of content is centralized in a single server or a set of mirrored servers to accomplish load balancing (Asvanund, Clay, Krishnan, and Smith 2003). Users who logged into the Napster network would automatically upload a list of the content they were sharing to a mirrored set of central content databases owned by Napster.

Users who wanted to access content on the network would issue a query against this

CONTRIBUTION

This paper contributes to IS research in several ways. First, we discuss prominent P2P architectures and applications. Second, we highlight several significant economic characteristics of these networks and compare these characteristics to similar characteristics in the economics literature. Third, we review the nascent literature integrating economics into the study of the performance and design of P2P networks with a focus on the recent 2003 Workshop on the Economics of Peer-to-Peer networks at the University of California at Berkeley. Fourth, we identify and discuss important areas for future research in this domain.

central database that would then point them to a list of peers who had the content on their computer. The Napster program at the peer initiating the search would then automatically issue a ping message to each of the peers in the list of search results to determine the level of congestion on the network and at the peer. The Napster client would then display the search results in a tabular format with the names of the files returned by the search along with the file size and length, bitrate and encoding frequency, and the name of the user along with the user’s self-reported connection speed and ping time (Figure 1).

The searching peer could then decide which of these search results they were interested in accessing, and initiate a file download directly from the peer who provided the content. This architecture gave users a high degree of visibility to content on the network and thus improved the ease of user search. However, it also introduced a vulnerability to the network: The network ceased to function if the central servers were shutdown, as a judge ordered Napster to do following a lawsuit filed by the Recording Industry Association of American (RIAA).

Many networks that have emerged following Napster’s demise have adopted a decentralized or hybrid catalog of content to reduce both legal and technical risks from the loss of the central server and to reduce the monetary investment required to operate the network by distributing database management

Figure 1: Napster Search Results

Filename	Filesize	Bitrate	Freq	Length	User	Connection	Ping
Music\Sting-The Police_01_Message In A Bottle.mp3	4,663,296	128	44100	4:50	anniesara	T3	0
Sting & The Police - Every breath you take.mp3	4,049,606	128	44100	4:13	kellyt...	T3	0
Music\Pras f. Puff Daddy & Sting - Roxanne (Rugees remix).mp3	711,598	128	44100	0:49	herbyb3	T3	0
Music\Eric Clapton with Sting & Billy Joel - Change the World.mp3	3,774,464	128	44100	3:56	CaK&K	T3	0
Music\01 - Windmills of Your Mind - Sting - Thomas Crown Affair Soundtrack.mp3	5,143,115	160	44100	4:17	jdibic	T3	0
Music\Toby Keith (with Sting) - Im so Happy I Cant Stop Crying.mp3	1,383,236	128	44100	1:30	jdibic	T3	0
Bryan Adams\Bryan Adams, Sting, Rod Stewart - All For Love.mp3	4,532,224	128	44100	4:42	sudhris...	T3	0
My Files\Sting - Desert Rose.mp3	6,650,752	132	44100	4:44	wade05	T3	0
Music\Sting & the Police - If I ever lose my faith in you.mp3	3,260,416	96	44100	4:31	bowna...	T3	0
Music\Sting and Toby Keith- I'm So Happy I Can't Stop Crying.mp3	4,835,328	160	44100	4:02	eliseno...	T3	0
Music\Toby Keith and Sting - I'm So Happy That I Can't Stop Crying.mp3	3,884,855	128	44100	4:03	eliseno...	T3	0
Music\Sting - Fields of Gold.mp3	3,555,706	128	44100	3:43	eliseno...	T3	0
Music\Sting - I Was Brought To My Senses.mp3	5,609,472	128	44100	5:48	eliseno...	T3	0
Music\Police - Every Little Thing She Does Is Magic (Sting live).mp3	4,115,446	128	44100	4:17	eliseno...	T3	0
Music\Bruce_SpringSting_Secret Garden.mp3	4,286,464	128	44100	4:27	eliseno...	T3	0
Music\Police - Message in a Bottle (Sting Acoustic Solo).mp3	4,595,316	128	44100	4:46	eliseno...	T3	0
Music\Sting and The Police - Every Breath You Take.mp3	3,038,586	96	44100	4:13	eliseno...	T3	0
Music\Sting - They Dance Alone (Cueca Solo).mp3	6,897,664	128	44100	7:06	eliseno...	T3	0
Music\Sting - Brand New Day.mp3	3,839,093	128	44100	4:00	eliseno...	T3	0
Music\Sting - Dream of the Blue Turtles - 03 - Russians.mp3	3,812,751	128	44100	3:58	eliseno...	T3	0
Music\Sting - Windmills of Your Mind (Thomas Crown Affair).mp3	2,831,776	128	44100	2:58	eliseno...	T3	0
Music\Sting - If I Ever Lose My Faith in You.mp3	4,335,200	128	44100	4:30	eliseno...	T3	0
Music\Sting - When We Dance.mp3	5,738,496	128	44100	5:56	eliseno...	T3	0
Music\Sting - Every Little Thing She Does Is Magic.mp3	4,177,320	128	44100	4:21	eliseno...	T3	0
Music\Sting - Desert Rose (I Dream of Rain).mp3	5,714,010	160	44100	4:44	eliseno...	T3	0
Music\Sting & The Police - Every Breath You Take.mp3	6,072,528	132	44100	4:13	eliseno...	T3	0
Music\Peter Gabriel, Sinead O'Conner & Sting - Don't Give Up (live - unreleased).mp3	7,763,287	128	44100	7:59	eliseno...	T3	0
Music\Sting - Desert Rose.mp3	4,564,901	128	44100	4:44	meL1213	T3	0
Music\Sting - Desert Rose Dance Remix.mp3	8,956,893	128	44100	9:12	meL1213	T3	0
Sting - Brand New Day - 03 - Fill Her Up.mp3	5,415,040	128	44100	5:36	joewaz	T3	0
Sting - Brand New Day - 06 - tomorrow we'll see.mp3	3,175,700	128	44100	3:19	joewaz	T3	0
Music\Sting - If I Ever Lose My Faith In You.mp3	4,331,520	128	44100	4:30	GT@T	T3	0
Sting & The Police - Every Breath You Take.mp3	4,083,156	128	44100	4:15	johnao	T3	0
Sting - Desert Rose.mp3	5,708,676	160	44100	4:44	johnao	T3	0
Music\Sting & The Police - Every Breath You Take.mp3	4,050,844	128	44100	4:13	KMARL...	T3	0
Music\Sting - Desert Rose.mp3	4,854,901	128	44100	4:44	herbyb3	T3	0
Napster\Sting - Fields of gold.mp3	5,333,664	132	44100	3:43	Clay421	T3	0

Returned 100 results.

Get Selected Files Add Selected User to Hot List

Online (rkt02093): Sharing 0 files. Currently 7,258 users sharing 1,516,132 files (6,548 gigs)

responsibilities to the individual peers (Asvanund, Clay, Krishnan, and Smith 2003). Gnutella 0.4, Gnutella 0.6, and Kazaa are notable examples of such networks.

The Gnutella 0.4 protocol features a distributed catalog of files. To connect to the network, a Gnutella peer would establish simultaneous connections to approximately 3 other peers on the network. These peers would also maintain simultaneous connections to other peers. In this mesh architecture, peers maintain a list of their own files. A peer can issue a search to its neighbors with a time-to-live (TTL) definition. This search will be forwarded up to the number of times defined by the TTL field (typically 7). If a peer receiving the search message has the requested content, they will send a reply back through the chain to the originating peer. The advantage of this architecture is that Gnutella 0.4 networks do not have a central point of vulnerability.

However, a disadvantage of this architecture is that the finite TTL field on query packets limits the size of the network that a peer is able to access. The Gnutella 0.4 protocol limits the number of peers that can be

reached by a query to 10,000 regardless of the size of the network (Kirk 2003). This problem is exacerbated by the fact that queries are passed among peers who may have significantly limited bandwidth (for example, modem users). These bandwidth limits result in large numbers of dropped packets and in practice limit the effective reach of a Gnutella 0.4 query to between 5,000 and 8,000 peers.

The Gnutella 0.6 and Kazaa protocols adopt a hybrid architectural design that relaxes some of these scalability problems. In each of these networks a small set of computers are selected to maintain local content databases. In Gnutella 0.6 these are called ultrapeers and in Kazaa they are called supernodes. In both cases peers on the network indicate their willingness to serve as local content databases and are selected for this task by the network protocol. Ultrapeers and supernodes are selected from the pool of available peers based on their available bandwidth resources and tenure on the network (a proxy for stability). Other peers connect directly to these ultrapeers and upload their list of content as in the Napster protocol. The ultrapeers are then interconnected in much the same way as peers on a Gnutella 0.4 network. Searches for

content are first issued to the ultrapeer and then these queries propagate to other interconnected ultrapeers using the same TTL field discussed above. Compared to Gnutella 0.4's decentralized architecture, these networks have the advantage of increased content visibility and enable more efficient search. Still it is important to note that inter-ultrapeer connections are limited by the TTL field in Gnutella 0.6 and thus the effective size of a user's local network is still limited versus a centralized architecture. Compared to Napster's centralized architecture, shutdown risks are minimized because new ultrapeers can be selected if some existing ultrapeers are disabled. More details on both the Gnutella 0.4 and Gnutella 0.6 protocols are available in Kirk (2003).

File sharing using these and similar networks has been called the "killer app" of P2P, and rightly so. The Yankee group estimates that consumers swapped over 5 billion music files over P2P networks in 2001 (Dignan 2002). A recent study by Ipsos-Reid finds that 23% of the American population over age the age of 12 has downloaded MP3s over the Internet (Ipsos-Reid 2002). This proportion is likely to be much higher among the 12-21 year-old demographic critical to the music and movie industries. In 2000, a Gartner study found that Napster accounted for up to 75% of the traffic on some university LANs (Shuchman 2000). More recently, the March 2002 shutdown of the Morpheus P2P network resulted in a 50% drop in the number of packets sent on Carnegie Mellon's wireless network (Sirbu 2002).

However, while P2P file sharing networks are among the most popular applications of P2P technology, P2P technology is also gaining adoption in a variety of other arenas. For example, P2P networks are being used for distributed computing (e.g., SETI@Home), enterprise knowledge sharing (e.g., Bad Blue), and user collaboration (e.g., Groove Networks). Further, while most of the previous examples of consumer P2P networks have a high proportion of copyrighted content, there is no reason that Digital Rights Management (DRM) cannot be incorporated into such P2P networks. For example, the subscription-based Napster service launched in early 2002 used

DRM technology within its P2P architecture to protect copyright holders. Subsequently, Altnet has proposed a similar scheme as an overlay to the Kazaa network.

A great deal of research has analyzed the technical features of these networks, particularly on improving the efficiency of P2P indexing schemes (e.g., Ratnasamy, Francis, Handley, Karp, and Shenker 2001; Stoica, Morris, Karger, Kaashoek, and Balakrishnan 2001), content caching schemes (e.g., Druschel and Rowstron 2001; Bhattacharjee, Chawathe, Gopalakrishnan, Keleher, and Silaghi 2003), and architectural designs (e.g., Kirk 2003; Sripanidkulchai, Maggs, and Zhang 2003). Until recently little research has been conducted regarding the economic characteristics of P2P networks and how these economic characteristics might impact their design and operation. The remainder of this paper seeks to highlight this important area of P2P and proceeds as follows. In section 2, we analyze the economic characteristics of peer-to-peer networks focusing on comparing the services offered over peer-to-peer networks to traditional private, public, and club goods. In section 3, we identify important areas of research integrating an economic perspective into the analysis of P2P networks and review selected recent papers in each area. In section 4, we conclude and discuss fruitful areas for future economic research relating to peer-to-peer networks.

UNDERSTANDING THE ECONOMICS OF P2P NETWORKS

While P2P networks vary in their architectural design, files are always transferred directly between the computers of peers connected to the network. Further, once these files have been delivered the user downloading the file, by default, becomes a provider of that content. Thus, in an ideal case the provision of content on the network will scale to match the level of demand for the content. To the extent this holds, P2P networks share some of the characteristics of public goods and club goods (Asvanund, Clay, Krishnan, and Smith 2003).

Public goods are goods that have the characteristics of non-excludability in supply

and non-rivalry in demand (Hardin 1968). Non-excludability in supply means that individuals can't be excluded from consuming the product — if the product is provided to one person in a community it must be provided to everyone. Non-rivalry in demand means that one user's consumption of a product does not diminish another user's value of that product. Typical examples of public goods include clean air, national defense, and public radio and television broadcasts.

In contrast to public goods, club goods are goods that are excludable in supply but non-rival in demand. Thus, the number of people with access to the good can be limited, but contingent on having access to the good, the consumption of the good by one user does not reduce the utility of other users. Cable and satellite television broadcasts and private swimming pools are typical examples of club goods.

P2P networks share some of the economic properties of public and club goods. In the ideal case, P2P networks will approximate both non-excludability in supply and non-rivalry in demand. Non-excludability is accomplished because network resources are typically provided to all members of the network equally. Non-rivalry is accomplished because, given that a downloading user shares the content they download, the net number of opportunities to download will not decrease for other users on the network.

However, this non-rivalry property will not hold if some network users consume network resources but do not share their content in return. These users are commonly known as free-riders and free-riding is a common characteristic of P2P networks. For example, Adar and Huberman (2000) observe that 66% of Gnutella 0.4 users were free-riding in August 2000. Similarly, Asvanund, Krishnan, Smith, and Telang (2003) observe that 42% of Gnutella 0.6 users were free-riding in September 2002. In the presence of free-riding, P2P networks will exhibit levels of rivalry — the consumption of network resources by a free-riding user will diminish the level of utility offered by the network to other users. This level of rivalry, combined with the non-excludability of network resources discussed above distinguishes

resources provided by P2P networks from either public goods or club goods.

Asvanund, Clay, Krishnan, and Smith (2003) identify several other differences between resources provided over P2P networks and other typical public and club goods. First, they note that the size of the offering of a public or club good is typically discrete and fixed. A swimming pool, for example, has a fixed size. In contrast, the size of the offering of P2P goods is typically relatively continuous and variable because it is a function of the type of content shared by network users and the number of users who share. A second difference noted by the authors is that in public or club goods settings the default choice of users is typically non-contribution, whereas in most P2P client programs contribution is enabled by default. Strahilevitz (2002) notes that this is an important factor in establishing community norms around sharing. A third difference is that contribution in P2P networks is linked to consumption and is in the form of network resources whereas in typical public and club goods environments contribution is separate from consumption and is in the form of a monetary payment. This linkage between the consumption and provision of P2P network resources has implications for the formation and sustainability of P2P networks as shown by Krishnan, Smith, Tang, and Telang (2003).

In spite of these differences between public and club goods and P2P network resources, there are important similarities between the provision of these goods. For example, an important observation from the public goods literature that seems to extrapolate to P2P networks is the inability of individually rational behavior to bring about socially optimal outcomes. In typical economic models, individual economic actors will only consider their private utility when making consumption and provision decisions — they will not consider the impact (a.k.a. the externality) this decision will impose on other community members. Because of this, in the absence of outside incentives, the self-interested consumption of public goods may deplete the overall public utility. This is popularity known as the “tragedy of the commons” (Hardin 1968). Common examples of such “tragedies” include over-grazing by

farmers using public lands and over-fishing of public waters.

In the context of P2P networks similar situations are observed relating to both over-consumption and under-provision of community resources. Over-consumption of network resources might occur because, when deciding whether to initiate a download from the network, P2P users may only consider their private utility of initiating that download and not the congestion this download will impose on other network users. Likewise, under-provision might occur because, when deciding whether to share, users may only consider their private costs of sharing (e.g., reduced bandwidth) and not the benefits their sharing provides to other network users. This will lead to levels of free-riding above the optimal level for the community.¹ Indeed, as noted above, most P2P networks exhibit high levels of free-riding. These high levels of free-riding led Adar and Huberman (2000) to observe “free-riding leads to degradation of the system performance...if this trend continues copyright issues might become moot compared to the possible collapse of such systems.”

Will the economic characteristics of resource provision on P2P networks lead to the ultimate collapse of such systems? Can user incentives be designed into such systems to forestall such a collapse? How can trust be enhanced among a set of distributed self-interested peers? What are the implications of P2P systems on the balance between the rights of copyright holders, network entrepreneurs, and users? We raise these and related areas for research in the next section. We also review selected recent papers in each area with a focus on selected papers presented at the 2003 Workshop on the Economics of P2P Networks at the University of California at Berkeley.²

¹ In the case of downloads that involve copyrighted material, one could also argue that the provider or downloader of the content might only consider their private utility from provision or consumption and not the externality this action would impose on content producers.

² More information is available on this conference at the conference website:
<http://www.sims.berkeley.edu/research/conferences/p2pecon/>

ANALYZING THE ECONOMICS OF P2P NETWORKS

Incentives

One obvious question raised by the previous section is how user behavior will respond to the economic characteristics of P2P networks and how can network designers influence this behavior through incentive mechanisms. This question is particularly important in light of recent observations of the importance of incentive alignment for Information Technology design (Ba, Stallaert, and Whinston 2001). One obvious area where economic incentives find application in P2P networks is controlling free-riding behavior on the part of users.

As noted above, free-riding behavior occurs when a user consumes network resources without providing any resources in return, and this situation may deteriorate in larger P2P networks where social norms are likely to be weakened (Olson 1968). A variety of solutions have been proposed to reduce the problem of free-riding on P2P networks. The most common proposal follows a pricing model, where incentive compatibility is achieved by pricing a scarce network resource (e.g., MacKie-Mason and Varian 1995; Wang, Peha, and Sirbu 1996). In the spirit of pricing network resources, Golle Leyton-Brown, and Moronov (2001) propose to charge for the use of P2P network capacity through a system of micro-payments. Similarly, Chandan and Hogenborn (2001) analyze the use of micro-payments in the context of wireless P2P networks and find that micro-payments may be able to provide an incentive compatible solution to the free-riding problem.

However, it is also interesting to note that direct payments between peers may be impractical in many common P2P implementations. For example, it is difficult to imagine transfer payments between users of a knowledge sharing P2P network with an enterprise. Likewise, in many consumer P2P networks direct micro-payments will be difficult to implement because of the anonymous nature of network usage. In these settings it will be particularly important to develop non-priced incentives to encourage efficient behavior on the part of P2P users.

Some examples of non-priced incentives could include delay times (e.g., providing priority queuing to users to share more content with the network), network membership (e.g., threatening to remove non-sharing members from the network), or peer ratings of content providers. Krishnan, Smith, Tang, and Telang (2003) provide an example of such an approach. Strikingly, their model finds that it may not be socially optimal for all users to share depending on the cost an individual user incurs when sharing and the value that their sharing would provide to the remainder of the peers on the network. They use quality-of-service as a tuning parameter to induce the optimal amount of sharing.

Several authors have proposed similar non-priced mechanisms for sharing based on implicit or explicit reciprocity among users. For example Vishnumurthy, Chandrakumar, and Sirer (2003) propose KARMA, a system for tracking both user's contribution to and consumption of network resources. Each user receives a particular "karma" score, increasing in contribution and decreasing in consumption of network resources, which governs their future consumption of network resources. Similarly, Kamvar, Yang, and Garcia-Molina (2003) propose a similar scheme based on the possibility that self-interested peers will not forward query requests from other peers. In their network, peers "buy and sell" the right to respond to queries from other network users. Ranganathan, Ripeanu, Sarin, and Foster (2003) argue that sharing in P2P networks is akin to the Prisoner's Dilemma problem such that non-sharing is the only dominant outcome. They then argue that if the game is extended to a multi person setting, mechanisms can be developed to improve the level of sharing in the network. In both these mechanisms, higher reputation leads to better quality of service, which in turn encourages sharing.

User Behavior and Motivation

A closely related area of inquiry concerns what motivates users to share on P2P networks. Is it individually rational behavior? Altruism? Some combination of the two? The analysis of user behavior is a fruitful area of research, particularly given the importance of incentive design for efficient network design.

Several recent papers seek to

understand and explain user motivations when contributing to P2P networks. Gu and Jarvenpaa (2003) provide an empirical study of sharing behavior among users on P2P technical support forums. They argue that sharing in these settings is most consistent with altruistic motivations. Feldman, Lai, Chuang, and Stoica (2003) on the other hand argue that sharing does not impose as much cost as users think in a broadband symmetric network. But in other cases when upload and download speeds are different (like ADSL), sharing can lead to some latency. They also show that prioritizing the TCP traffic could potentially lead to better network performance in some cases. Finally, Strahilevitz (2002) argues that sharing occurs in network due to "charismatic code" — the intentional perception given to network users that sharing is a common and normal practice in the network.

Reputation and Trust

The development of systems to track the reliability or consistency of a peer's contribution to other members of the network is also closely related to the development of incentive systems for P2P networks. Such systems build on the incentive schemes mentioned above which track a user's contribution in the present period (e.g., Krishnan, Smith, Tang, and Telang 2003), by tracking a user's contribution over a longer time period.

P2P reputation systems are closely related to the efforts of online communities, such as eBay, to develop incentive-compatible systems for rating the performance of a distributed set of users (see Dellarocas 2003 for a review of this literature). However, the design of reputation systems for P2P networks is complicated by two factors. First, the distributed and intermediated nature of P2P network interactions makes it easy for users to conceal or change their identity. Second, in some fully distributed applications, the administration of the rating system must also be distributed throughout the network, making it vulnerable to coordinated gaming strategies. Dutta, Goel, Govindan, and Zhang (2003) and Shneidman and Parkes (2003) discuss in more detail the difficulties associated with fully distributed reputation networks.

With regard to such systems, Lai, Feldman, Stoica, and Chuang (2003) study the evolutionary prisoner's dilemma (EPD). Since EPD characterizes cooperation that requires *repetition* and *reputation*, it needs to be modified in the context of P2P networks because of the lack of repeat interaction among the peers and the easy acquisition of pseudonyms. They introduce the concept of "private" history and "shared" history as a way to encourage sharing. Shared history is a centralized pool where peers' past behavior is noted and services are provided according to their reputation.

Other work in this domain includes Moreton and Twigg (2003) who compare reputation mechanisms with payment mechanisms and then argue that "stamp trading" mechanisms capture the essence of both mechanisms quite well. Cohen (2003) on the other hand argues that a "tit for tat" treatment leads to a significant improvement and robustness in a P2P network. He demonstrates the practical implementation of this mechanism in the context of the BitTorrent P2P network. Kung and Wu (2003) combine elements of incentive design with persistent trust ratings by proposing an admission control system that provides quality of service differentiation to users based on a distributed mechanism that tracks user reputations. Woodard and Parkes (2003) employ mechanism design techniques in the context of network formation. They analyze how a network of distributed, self-interested peers might be able to form.

Reputation and trust mechanisms can also help to protect against a coordinated attack by an outside adversary. For example, the RIAA and its member organizations have recently initiated several attacks against P2P networks by flooding the network with "fake" files labeled to appear as though it were real content (the economics of this strategy is discussed in more detail below). The first documented case of the strategic distribution of fake files on a P2P network was in September 2000 by the rock group Bare Naked Ladies (Wake 2000). This was a small effort and only targeted the Napster network. In May 2002, the practice was imitated on a larger scale for the release of Eminem's "The Eminem Show" album (Avery 2002).

Strahilevitz (2002) notes that this practice became widespread in June 2002 with three of the major record labels adopting the practice for many of their artists.

Such an attack is facilitated in a distributed network because it is difficult to tell whether an individual offering a file is a genuine sharer or an adversary posing as a legitimate sharer. Rosenthal, Roussopoulos, Maniatis, and Baker (2003) discuss mechanisms to protect against coordinated attacks in the context of protecting information goods for library services.

Intellectual Property

The strategy of the RIAA is motivated by their legitimate desire to protect their intellectual property from unauthorized sharing. However, this legitimate effort to protect intellectual property can, in some cases, collide with the interests and rights of entrepreneurs attempting to develop novel information sharing networks, individuals exercising fair use rights associated with legitimately purchased materials, and network operators seeking to protect the privacy of their users.

Thus, the issue of liability, privacy and intellectual property rights on these networks is a promising area of research that has academic, policy and commercial implications. From an academic perspective, a natural question is: how much of an impact do P2P networks have on sales of associated information goods? Liebowitz (2001) argued that early data suggested that the impact of P2P networks on record industry sales was minimal. Hui and Png (2002) have a similar finding, arguing that P2P networks had significant promotional value for record companies, which militated against losses. However, using more recent data, Liebowitz (2003) finds that the impact may be a significant cause of the recent downturn in record sales.

From a policy perspective, how should the interests of artists and copyright creators be balanced against the interests of network users and entrepreneurs designing new distribution mechanisms for information goods? From the perspective of commercial industries, is it possible to use P2P networks as a promotional

channel while simultaneously reducing commercial risk from piracy as argued by Hui and Png (2002) and what form would such a network take?

Another interesting commercial question concerns the optimal response of copyright holders to the threat of piracy. Recently, Varian (2003) studies the social cost of sharing and shows that when sharing is possible and a monopolist can observe it then generally it can price the product such that it leads to an inefficient outcome and low overall welfare.

It is also possible to consider legal and strategic options available to copyright holders to make participation in P2P network less attractive for users. In a typical scenario, a user's net utility from consuming a product is $U - p - sc$ where U is the utility of the product, p is the price of the product, and sc is the search cost associated with obtaining the product. In the case of MP3 file sharing for a record company's file sharing site to yield higher utility to a potential customer than using a copyright-infringing site the record company would need $U_r - p_r - sc_r > U_p - sc_p$ where the price to use the copyright-infringing site is assumed to be 0. What is interesting for the record companies is that, unlike in a typical situation where they can only control their own utility, price, and search cost, in the case of MP3 file sharing networks they can also influence the utility and search cost of the competing network. One way copyright holders can search costs is by flooding the network with fake files and thereby increasing user's search costs for their desired content (see Segal 2002 for example). In such a scenario, the record company would register numerous peers on the copyright-infringing site each with a set of MP3s that use the same naming structure as popular music content, but which contain no usable content.³ The end result should be to increase the number of files a user must download before they find the "real" content they were looking for. By lowering the utility and increasing the search costs of their competitors' file sharing networks, the record company's web sites will

have more flexibility in setting the utility level of their content (e.g., by restricting the legal uses of the files) and their prices. Copyright holders can also threaten users with fines or lawsuits for illegally sharing and downloading copyrighted content. This raises the implicit cost of users to share content, thereby increasing free-riding, and thus reducing the utility of the network by reducing network performance and scalability (Asvanund, Clay, Krishnan, Smith 2003). This strategy may have been responsible for a 15% drop in week-to-week file-sharing traffic for the week ending July 6, 2003 following well-publicized lawsuits against prominent file-sharers on the Kazaa network (Reuters 2003).

Another interesting commercial question concerns the interests of Internet service providers who provide benefit to their users through the provision of P2P network services, but who also incur significant costs through the consumption of scarce bandwidth by P2P traffic. Many colleges and universities have found that P2P traffic makes up more than 50% of traffic on their links to the Internet. Similarly, a report by Sandvine.com found that P2P packets made up 60% of the traffic on major Internet backbone connections. These problems are exacerbated by the fact that connections in many popular P2P networks are not optimized for either similarity in user interests or similarity in user locations with respect to the network topology. This can result in large transit fees being borne by the ISP seeking to provide access to P2P applications. A natural response to these high bandwidth requirements, and one adopted by several Universities, is to limit the quality of service provided to P2P packets passing through the organization's link to the Internet with the intention of getting users to limit their use of P2P. A more draconian approach is to block all packets to and from P2P network users. However, some alternate approaches are emerging. For example, Asvanund, Krishnan, Smith, and Telang (2003) propose economic models to encourage the dynamic formation of clubs in P2P networks based on common interests, similar provision of resources, and proximity with regard to network location. Similarly, Singh, Ramabhadran, Baboescu, and Snoren (2003) propose conditions under which Internet Service Providers would benefit

³ The companies MediaDefender and Vidius both advertise software product to make this process easier for the record companies.

from sponsoring their own ultrapeers for the provision of P2P network resources.

DISCUSSION

It is evident from the growth of P2P networks in last 2-3 years that they are becoming important tool for content sharing and distribution. While the popularity of these networks has been mainly from consumer P2P file sharing, many organizations have been using these networks for as knowledge management tools to share information across the enterprise.

A review of the recent literature on P2P networks suggests that while technical developments have kept pace with the growth of these networks, the economic and social analysis of these networks is still in a nascent stage. Understanding P2P network operation from the perspective of the economic characteristics of content provision and user behavior will be critical to developing protocols and systems to ensure the efficient operation of these networks.

Public and club goods provide a useful starting point for the economic analysis of P2P networks. P2P networks share many characteristics with public and club goods, but differ from these goods in important ways. Since the literature on public goods is quite extensive, it allows researchers to extrapolate some of the results from this literature. But we note that not all results are equally applicable. Since these goods are essentially a different class of product, we need to understand the mechanism of these networks carefully before

applying these results. In many cases, we need different models to understand user behavior.

Another important observation we have noted is the existence of extensive free-riding on these networks and its social and economic implication. Free-riding may significantly reduce the performance of P2P networks. A standard result in the economic literature is that larger groups lead to more free-riding. But at the same time, altruism could significantly mitigate these effects in the context of P2P networks. As these networks continue to grow, we need new theoretical models as well as experimental and empirical data to understand user behavior.

An emerging body of research seeks to integrate economics into the study of P2P networks. Significant questions addressed in this research include the role of incentives in improving network performance, the motivations of users who consume and provide resources in P2P networks, the application of trust and recommendation mechanisms to the unique environments present in P2P networks, and the balance between the rights of copyright holders, entrepreneurs, and consumers. It will be important for future researcher to pursue these and other relevant questions in the coming years.

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