Jei JOURNAL OF ECONOMIC ISSUES
Vol. XXXIX No. 3 September 2005

Dynamic Analysis of an Institutional Conflict: Copyright Owners against Online File Sharing

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Online music-sharing networks have been used by millions of people since they first appeared in 1999 (Leuf 2002; Associated Press 2004). The popularity of peer-to-peer (P2P) technology and the low-cost music distribution channel it created threaten the dominant position of a small number of large firms in the commercial music industry (Alexander 2002). Threatened by the possible restructuring of the entire industry in five to ten years (BBC 2002; Mann 2003), the dominant players responded with a fierce campaign against online copying. They oppose music-sharing networks on the grounds that the networks facilitate mass copyright infringement and erode industry's profits. This type of institutional response orchestrated by the incumbent economic players has precedents. Eighteenth century publishers in Great Britain resisted the emergence of public circulating libraries (Roehl and Varian 2000), and Hollywood studios perceived video technology when it first appeared in the late 1970s as a threat to their movie revenues (Roehl and Varian 2000; Alexander 2002).

According to the Recording Industry Association of America (RIAA), which represents music copyright owners, online file sharing causes a significant decline in CD sales and erodes the financial incentives for the production of new material (RIAA 2003). Several research studies, however, suggest that online file sharing may not have a negative effect on the music market (Alexander 2002). In a widely publicized study, Felix Oberholzer and Koleman Strumpf (2004) compared directly observed data on CD sales and downloading. They concluded that "downloads have an effect on sales which is sta-

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tistically indistinguishable from zero." The authors explained the result by noting that "most [P2P] users . . . would not have bought the album even in the absence of file sharing." Contrary to the RIAA claims, file-sharing networks may have also increased the supply of music—the networks brought visibility to many "non-marketable" artists that could not use distribution channels controlled by the profit-seeking commercial music establishment (Gallaway and Kinnear 2001).

The commercial music industry pursues an offensive strategy comprising litigation, lobbying, and self-help (Yu 2003). Often testing the boundaries of legal and regulatory systems, the war against file swapping set off sharp and sagacious debates on the nature of intellectual property, the role of the copyright law, and fundamental notions of citizenry such as freedom of speech (Lessig 2001; Goldstein 2003; Green 2003; Amy Harmon and John Schwartz, "Music File Sharers Keep Sharing," *The New York Times*, September 19, 2003). Since institutions invariably affect the economy (North 1992), the outcomes of the polemics in courts will have considerable pecuniary consequences for the recording industry and the entire economy. New laws and new interpretations of old laws may cause new industries that are attempting to grow on the platform of peer-to-peer technology to flourish or decline (for examples see Non 2000 and Elkin 2002). But it is still not clear to what extent the recording industry can control the recalcitrant music networks (France and Grover 2003). Some analysts predict that peer-to-peer networks will ebb under pressure from the music industry, while other experts prophesize a continuous rise in popularity (BBC 2002). There also have been warnings that the true danger to the existence of file-sharing networks is not the belligerence of the music industry but the prevalence of free riding on P2P networks (Adar and Huberman 2000; Alexander 2002).

With this article I hope to add to the understanding of the institutional conflict within the commercial music industry. The framework for our analysis is rooted in the descriptive pattern modeling approach of institutional economics (Wilber and Harrison 1978). However, acting on a proposition that the traditionally narrative analysis of institutional economics may be buttressed by formal methods (North 1992; Hodgson 1998), I use the approach of institutional dynamics (Radzicki 1988, 1990a; Radzicki and Seville 1993) to build a resource-based model of a peer-to-peer community. Then in a series of computer experiments with the model I simulate actions applied by the copyright holders against file sharing. The experiments reveal that the internal feedback structure of a peer-to-peer system renders it extremely resilient to outside disturbances. Experiments also suggest that institutional measures are likely to differ in their effectiveness.

I proceed by describing the institution of the commercial music industry. Then I explain actions that copyright owners have tried or may undertake against online file sharing. Subsequently, I develop a formal model of a representative peer-to-peer network that is then tested against a reference year. I devote one section to a series of experiments that examine the consequences of four policies inspired by litigation and self-help approaches. I offer a brief summary of findings and conclusions in the last section.

The Institution of the Commercial Music Industry

An institution is operationally characterized by the presence of (1) participants, (2) rules that govern activities within the institution, and (3) folk views that explain and justify actions within the institution (Neale 1987). Rules and folk views are constraints that define an institution, and they may be formal, such as copyright law, common law, and government regulations, and informal, such as conventions and socially accepted or self-imposed norms of behavior (North 1992). The commercial music industry has all the characteristics of an institution, as I describe in this section.

Participants

Participants of the commercial music industry are legion and, among others, include artists, recording studios, agents, customers, trade publications, disk jockeys, and many more (Dolfsma 2002; France and Grover 2003). Since an organization is a particular form of an institution created for a purposeful coordination of activities (Hodgson 1998, 180), some of these players are institutions in their own right. New participants emerge and old ones wane as the importance of players changes over time. Dolfsma 2002 offers an account of an institutional transformation that led to the disappearance of a music "presenter" and its replacement by a "disk jockey." Players also merge as the recording industry undergoes consolidations. Unlike in the early days when there were no national music conglomerates (Gallaway and Kinnear 2001), the industry is currently dominated by five major international corporations, commonly referred to as "The Big Five": Vivendi's Universal Music Group, AOL Time Warner's Warner Music Group, Sony Music Entertainment, Bertelsman's BMG, and EMI Group. In a recent account these companies controlled 75 percent of worldwide music sales (Anna Wilde Mathews, "Record Labels Send Messages to Warn Music File Sharers," *The Wall Street Journal*, April 30, 2003, B.6).

Players may appear and gain prominence due to novel technologies. For example, the introduction of the point-of-sale retail information systems in the 1980s led to the invention of a new music popularity chart. Adoption of the chart in 1991 by the leading trade publication *Billboard* transformed the industry by boosting positions of a small number of record companies, allowing greater segmentation of the music market, giving prominence to country music, and negatively impacting albums from some independent labels (Anand and Peterson 2000). Similarly, music-sharing communities owe their existence to the novel peer-to-peer technology.

Rules

Observing that institutions do not exist in isolation (Neale 1987), institutional economists have long recognized the inseparable amalgamation of legal and economic activity in the market world (e.g., Medema 1992); the alliance has been dubbed a legal-economic nexus (Samuels 1989). Soon after its formation in the 1880s, the music industry secured the extension of the copyright law to music (Anand and Peterson 2000). By constituting what is property and establishing ownership rights, the legal system since then has defined the structure of the music industry (Samuels 1989; Coase 1992, 717) and protected copyright owners against piracy (Lister 1998).

Folk Views

People use folk views to "justify the activities or explain why they are going on, how they are related, what is thought important and what unimportant in the patterns of regularity" (Neale 1987). The wide adoption of music-swapping technology showed that the public at large does not see music sharing as a criminal act, even though the recording industry believes that using peer-to-peer networks is akin to stealing (Amy Harmon and John Schwartz, "Music File Sharers Keep Sharing," *The New York Times*, September 19, 2003). This perception of legitimacy of music sharing comes from the underlying socio-cultural values of a society (Dolfsma 2002)—a great number of Internet users perceive online music as a free public good. The origins of this view may come from two facts: (1) music has been available as a free public good for years through the radio media (Gallaway and Kinnear 2001; Amy Harmon and John Schwartz, "Music File Sharers Keep Sharing," *The New York Times*, September 19, 2003), and (2) content on the Internet for the most part is free (Gallaway and Kinnear 2001). Moreover, "institutions constitute the arenas in which people try to accomplish their aims" (Neale 1987). Thus when faced with a choice of distribution channels they choose the least costly and most convenient one. As Gallaway and Kinnear succinctly put it, talking about P2P networks: "In the commercial milieu, one does not expect rational individuals to reject the option which offers lower prices, lower transactions costs, and better variety" (2002).

Attitudes toward the new technology among artists are less uniform. Many of them disapprove of peer-to-peer music distribution (*Economist* 2003; Roberts 2003). Besides the pure revenue considerations, a strong incentive for artists to resist P2P is that it undercuts the current sales-based performance charts (Chris Nelson, "At Sea with Mp3's, Boomers Buoy Struggling Record Industry," *The New York Times* [online edition], November 2, 2003), which are the most important signaling tool in the industry (Anand and Peterson 2000). However, many "non-marketable" artists welcomed the P2P revolution because it gives them visibility and allows them to reach a wider audience (Gallaway and Kinnear 2001).

Interaction between Incumbent Structures and File-Sharing Networks

Institutions exhibit inertia in terms of habit, persistence, and institutional lock-in (Hodgson 1998). SoundScan, Inc. waited five years before its new music popularity chart was adopted by *Billboard* in 1991 (Anand and Peterson 2000). Following the same behavioral trend, the constituent members of the RIAA do not welcome changes brought by the peer-to-peer technology. In an attempt to control the development and adoption of the technology, the RIAA has applied litigation and considered using potent self-help measures against file swappers (Yu 2003). I review these antipiracy tactics below.

Litigation

The first sortie launched by the copyright owners against the new file-sharing movement concerned Napster, Inc. After lengthy proceedings and many expert witness testimonies by prominent economists and legal scholars on the merits and downfalls of the novel technology, a federal judge in California ruled that Napster was a contributory and vicarious copyright violator (Hilden 2002; "Federal Appeals Court Affirms Earlier Ruling That Reined in Napster," *The Wall Street Journal,* June 26, 2001, B.6). Unable to comply with all the requirements imposed by the court, Napster shut down its servers in July 2001, two years after the service started in 1999. Combating peer-to-peer technology, however, proved to be not unlike fighting the mythical Greek serpent Hydra who, for every cut-off head, grew two new heads in its place. Napster was succeeded by dozens of imitators that are more resilient to attempts to shut them down for a number of reasons (Yu 2003; Woody 2003). First, while Napster utilized a central database of all shared files, the new networks do not have central servers. Second, some software companies resorted to legal and ownership maneuvering that made it difficult to track and prosecute them. A prominent example of the latter defense strategy has been Sharman Networks, Inc., which distributes software for the popular KaZaA network (see, e.g., Yu 2003; Woody 2003; CNN 2003). Third, U.S. courts do not seem to be willing to hold distributed networks responsible for copyright violations, which is a dramatic departure from the Napster ruling. In April 2003, a U.S. District Court ruled in favor of Grokster Ltd. and StreamCast Networks Inc.—two companies involved in the development of file-sharing software—citing that the companies do not control the traded material (Anna Wilde Mathews and Nick Wingfield, "Entertainment Industry Loses File-Sharing Case—Two Companies Are Cleared to Distribute Software Used to Copy Music and Movies," *The Wall Street Journal*, April 28, 2003, A.3; CNN 2003).

After the April 2003 setback, the RIAA and its movie industry counterpart, the Motion Picture Association of America (MPAA), revised their antipiracy tactics by announcing that they would go after individual users. The RIAA threatened hundreds of lawsuits against sharers (Lynette Holloway, "Recording Industry to Sue Internet Music Swappers," *The New York Times*, June 26, 2003). To prepare the battleground, copyright owners sued and won a case against Verizon, in which a federal judge ordered the telecommunications company to reveal the names of two of its Internet subscribers who shared copyrighted material (*Economist* 2003). Until that ruling, P2P participants were protected by the right to anonymity (Yen 2001). At the time of this article, the music industry has sued 2,947 P2P users in the U.S. and filed more than 230 copyright infringement cases in Europe and Canada (Reuters, "Music Industry Readies Fresh Wave of Net Lawsuits," *The New York Times*, June 8, 2004).

Self-help

Another line of offense considered by copyright owners is self-help. After a federal judge ruled in favor of StreamCast Networks Inc. and Grokster, the RIAA began spamming KaZaA and Grokster hosts with instant messages warning of legal penalties (Anna Wilde Mathews, "Record Labels Send Messages to Warn Music File Sharers," *The Wall Street Journal*, April 30, 2003, B.6). Madonna posted bogus music files to P2P networks that posed as songs from her new album; they contained nothing but profanity (*Economist* 2003). Record companies have also been known to post song files with random sounds inserted in them, such as, for example, the Gettysburg Address and car horns—all aimed at frustrating the copiers (Roberts 2003).

More potent self-help weapons against peer-to-peer networks will be available if the effort to pass the Peer-to-Peer Piracy Prevention Act succeeds in Congress. This piece of legislation is an example of future-binding encapsulation, that is, the legitimization of innovations that will perpetuate the ceremonially warranted power structure (Bush 1987, 1094). U.S. Representative Howard L. Berman, who sponsors the bill, has explained that the new law would protect record labels from liability if they resort to using "limited self-help measures" (2003). The Berman bill would legalize actions that are currently prohibited under various federal and state laws (Hilden 2002). It may override, for example, the Massachusetts Computer Crime Law, enacted in 1995, which makes unauthorized access to a computer system illegal. All large record labels are readying for the self-help phase of copyright warfare by investing in companies that develop programs for attacking the computers of digital music traders. The programs will either freeze offending computers or redirect peer network users to legitimate sites for music purchase (Russell 2003).

Model Development

Actions by copyright owners affect peer-to-peer networks in ways that are complex and multidimensional in nature. In this section I develop a computer model of a music-sharing network that will help us to understand system responses to measures against it. After reviewing the workings of a typical peer-to-peer network I proceed to define the boundary and overall structure of the model. The model is implemented using the computer tools of system dynamics. Before I describe individual sectors of the model, I offer a brief introduction to system dynamics.

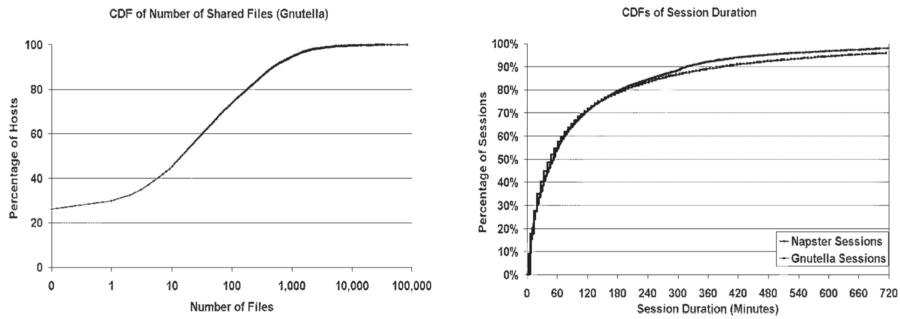
A Representative Peer-to-Peer Network

The peer grid of a system such as Gnutella or KaZaA is a virtual network formed at the application level that is distinct from the underlying physical network (Ripeanu et al. 2002). A person can participate in a peer network by either downloading a piece of software commonly referred to as a "servent" or by logging onto a dedicated Web site (Bolcer 2000). A Gnutella node forwards the search query to other nodes that it is connected to until the message travels the maximum allowed number of hops determined by the time to live (TTL) parameter. Hosts that contain the material in the query respond with a message that traverses along the path on which it arrived. The original Gnutella protocol treated all nodes equally, irrespective of their network connection speed, memory, or clock speed (Bolcer 2000); currently, more advanced algorithms for peer communities are being developed (e.g., Lv et al. 2002).

Peer-to-peer systems have been compared to an Internet potluck: nodes contribute to the network by offering files and by routing network traffic (Kan 2001). Users, however, clearly have incentives to free ride with respect to content and bandwidth, which means "taking their share of it and keeping their own resources for themselves" (Marwell and Ames 1979). Providing content to other peers is costly not only because acquiring the content may impose fixed costs on the altruistic peer in terms of purchasing a CD but also because each additional upload slows down the serving computer and its own downloads (Adar and Huberman 2000; Yang and Garcia-Molina 2002). Peers may also choose not to stay connected to the network for long periods in order to avoid exposure to computer worms and hacker attacks (Rincon 2002).

Free riding may be accomplished in a variety of ways. By default most of the peer-to-peer software shares all downloaded files (Golle et al. 2001; http://www.limewhier.com). However, Eytan Adar and Bernardo Huberman found by analyzing P2P traffic data that only about 30 percent of users shared files on Gnutella and 20 percent of hosts shared 98 percent of all the files available on the network (2000). A number of other studies confirmed the existence of significant free-riding tendencies on music networks. Figure 1a shows file-sharing statistics that typify the situation. Providing undesirable content is also a form of freeloading. Adar and Huberman reported that 1 percent of hosts provided 47 percent of answers to file requests and 25 percent provided 98 percent of the responses. Bandwidth and processing capacity offered to the network can be controlled through the number of allowed connections and by misstating the connection speed. Extreme cases of free riding are browser-based search Web sites, for example, asiayeah.com and gnute.com, that allow users to enter a peer network and search the shared database without contributing any content or routing the network data traffic.

Figure 1. Resource Sharing in Peer Networks



(a) (b)

Source: Saroiuet al. (July 2001).

(a) A cumulative distribution function (CDF) for the number of files shared on Gnutella.

(b) Session duration on Napster and Gnutella.

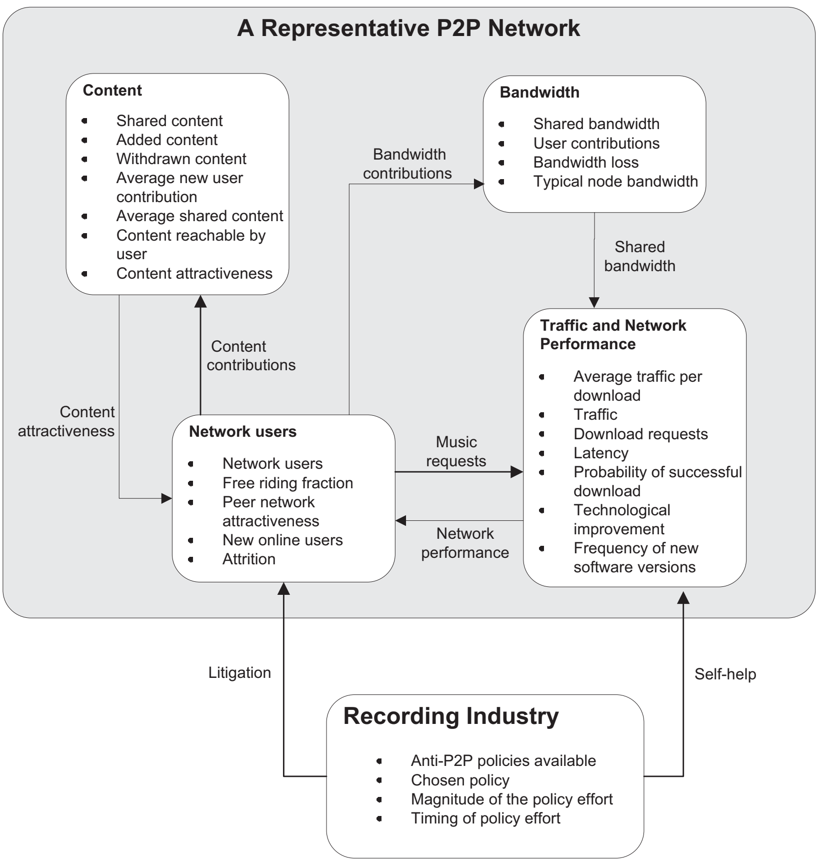
A person may also shirk by simply turning the computer off. There is a special term used in the peer-to-peer community to describe this type of behavior—*fishing*: a user logs into the network, downloads what he needs, and promptly leaves the system. Withdrawal of a host results in lost queries and failed uploads. Data presented in figure 1b show that about half of the connections are sixty minutes or shorter and only 20 percent of hosts remain continuously in the network for longer than three hours.

It has been suggested (Adar and Huberman 2000) that rampant free riding can be the reason behind variations in network performance, which may be measured in terms of search response latency and the probability of successful downloads—as more users join the network without adequately contributing to the common pool, public resources of a file-trading network become depleted, leading to poor performance. Economic literature on the private provision of public goods suggests that typically the free-riding problem worsens with the group size (see, for example, Isaac and Walker 1988 and Gaube 2001). Group size has been also found to be important for online communities, just as for physical groups (Butler 2001). Statistical analysis of P2P network traffic by Atip Asvanund et al. (2002) confirmed the declining marginal value, and increasing marginal cost, of each additional peer.

Model Structure

I model a representative network while holding influences from copyright owners external to the model. The model boundary and its structure are shown in figure 2 within the grayed area. The model has four endogenous sectors (subsystems): network users, content, bandwidth, and traffic and network performance. The network users sector tracks the daily network usage and models users' response to changes in network performance. The content dynamics are simulated within the content sector. The network users subsystem affects the content sector because users make content contributions. Increasing content raises content attractiveness, which encourages usage. The second resource, the bandwidth, is tracked in the bandwidth sector. The stock of bandwidth is increased when users make more bandwidth contributions. By submitting music requests, the network users create network traffic. The availability of the shared bandwidth and its adequacy for the traffic load determine network performance. The relationship between technical and performance characteristics of a network, such as traffic and latency, are simulated within the traffic and network performance subsystem. The recording industry represents a collection of copyright owners, artists, record labels, the RIAA, and lawyers. The two arrows entering the representative P2P network symbol-

Figure 2. Model Structure



ically show litigation and self-help efforts by the recording industry. Notice that the commercial impact of the peer network on the traditional recording industry is not part of this analysis and thus there are no connections from the network to the recording industry.

The model has been implemented numerically using the integral equation methodology of system dynamics. Michael Radzicki (1988, 1990b) has examined the many similarities between the approach of institutional economics and the computer modeling approach of system dynamics and proposed a formal institutional dynamics synthesis between the two disciplines. Resembling the analysis of institutional economics, system dynamics analysis is interdisciplinary, begins with a review of various facts pertinent to the case, uses extensively historic information about institutions, and is not tied to the idea of *homo economicus* but rather recognizes the bounded nature of human decisions. The only essential difference between the methods is that a system dynamics analysis concludes with a formal computer model. This journal has published a series of papers that utilize the system dynamics methodology. Radzicki and Donald Seville (1993) have successfully used numerical simulations to support their institutional analysis of a township in Massachusetts. John Harvey studied the Keynes' trade cycle model using its system dynamics implementation (2002). Harvey and Kristin Klopfenstein simulated Mexican development (2001). Khalid Saeed applied the methodology of system dynamics to the analysis of institution building for the case of mitigation banking (2004). An authoritative primer on system dynamics is an encyclopedic book by John Sterman (2000); the reader may also consult a volume by Kim Warren that contains a collection of models designed for resource-based analysis of various economic and business cases (2002).

Sectors

In this section I describe the four sectors that comprise the model. The model was implemented using the specialized software package Vensim DSS. The software partitions the model into separate views, each corresponding to a subsystem in figure 2. Sector renditions, which I provide below, follow typical system dynamics–diagramming practices (Lane 2000):

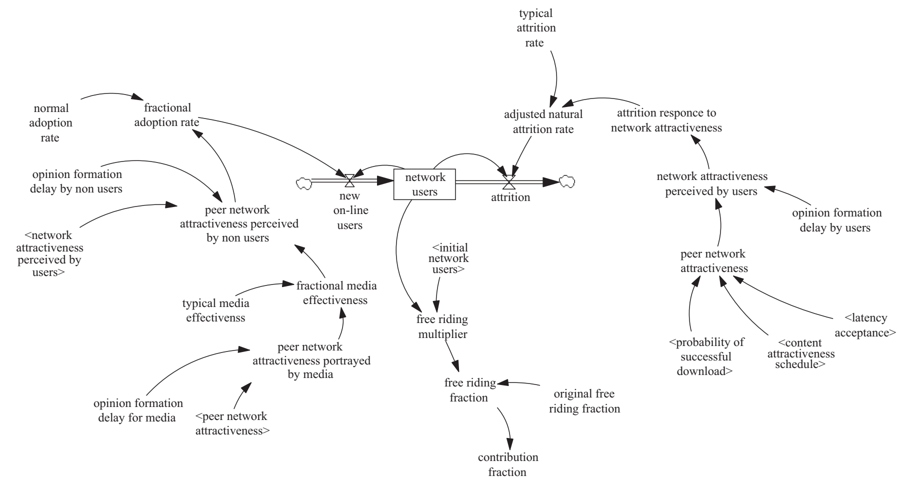
- Rectangles represent state variables, called stocks.
- Stocks increase due to inflows and decrease due to outflows. Flows are shown as "pipes" connected to the rectangle.
- Flows are controlled by valves, which look like small inverted bow ties.
- Clouds designate flow sources and sinks, which are outside the model boundary.
- Arrows between variables show causality.

- To increase the clarity of a sketch, a duplicate instance of a variable may be introduced. Secondary instances are called shadow variables. Shadow variables are distinguished by surrounding angular brackets < >.

The appendix contains the mathematical formulation of the model. Complete computer code and model documentation are available from the author upon request.

Network Users Sector. A stock-and-flow representation (Lane 2000) of the network users sector is shown in figure 3. The sector captures the daily average number of peers logged into the system. The state variable is the stock of network users. Ordinary variables affect other variables, including rates, flows, and stocks, as shown by the arrows. For example, the new online users and attrition flows are affected by the fractional adoption rate and by the adjusted natural attrition rate, respectively. To prevent the stock network users from going negative, the flows are also dependent on the stock value—when the stock becomes zero, the flows also become zero. The rates are in turn determined by some normal adoption rate and typical attrition rate; then, if the system is useful for current users and attractive in the view of potential users, the network use will increase. Word of mouth and media exposure are two typical mechanisms that stimulate such a growth. Since the introduction of Napster, the technology has drawn a lot of attention from the media, which contributes to the formation of public perception of the network's usefulness. Changes in the peer network attractiveness modify the typical growth rates of the system: lower attractiveness increases churn and leads to a reduction in the new user arrival rate; greater attractiveness has the opposite effect. Normally users respond with some delay to changes in the network's performance. Since media, including online news groups, are quick to report and discuss any performance glitches of a popular network, the shortest delay among the three delays in the model is the opinion formation delay for the media. The value of network attractiveness is determined by the content attractiveness (which in turn depends on available content), latency of responses to requests, and average probability of completing a successful download. There are first-hand and second-hand reputation effects (Warren 2003): new customers join based on second-hand reputation information, and customers leave based on their first-hand information. The diagram in figure 3 shows this relationship as an edge from the variable network attractiveness perceived by users to the variable peer network attractiveness perceived by nonusers. Brackets around the variable named "network attractiveness perceived by users" indicate that this is a duplicate instance of a variable defined elsewhere in the model—the main definition of the variable is embedded within the causal chain leading to the variable attrition (see the right section of the diagram). The variable free-riding multiplier moderates the effect of network size on the magnitude of the free-loading problem. The contribution fraction measures the average share of individual content and bandwidth that is being made available by each peer to the rest of the network; the share is equal to 1 – free-riding fraction.

Figure 3. Network Users Sector



Content Sector. Figure 4 presents a rendition of the content sector. This sector keeps track of the number of files available through the network. The maximum content a new peer can bring to the group is the number of music files on his or her hard drive, which I code as "maximum new user contribution." It is achieved when the contribution fraction is equal to one; otherwise, the average new user contribution is a fraction of the maximum user contribution. I use a coflow formulation (Sterman 2000) to determine the increase in the common pool of files: added content is proportional to the new online users, which is defined in the network users sector. I assume that the possibility that a node drops out of a network does not depend on its level of altruism. Thus, withdrawn content is proportional to the attrition and average shared content.

A common feature of peer networks is that due to the limited connectivity and the finite TTL parameter, the potential reach of each node is significantly smaller than that for the entire network (Leuf 2002, 199). For data collected for a seven-month period starting in November 2000, Ripeanu et al. found that the average number of hosts visible to a node is independent of the network size (2002). Jordan Ritter estimated that for a network in which each node has on average three edges and TTL is set to 7 (a typical number in Gnutella), at best 381 nodes are visible from each peer (2001). The variable content of interest reachable by a user captures this fact. I assume that there is some average collection of music owned by a typical user; I call it *typical collection.* The relative richness of the network, which is inversely proportional to the typical collection, determines content attractiveness through a diminishing returns schedule.

Bandwidth Sector. The bandwidth sector is shown in figure 5. Similar to the shared content, the network capacity, measured in terms of the shared bandwidth, increases with

Figure 4. Content Sector

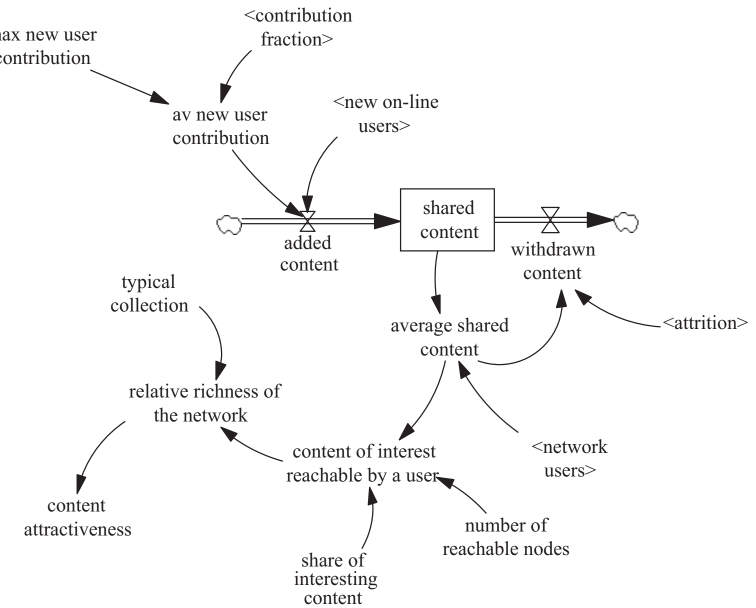
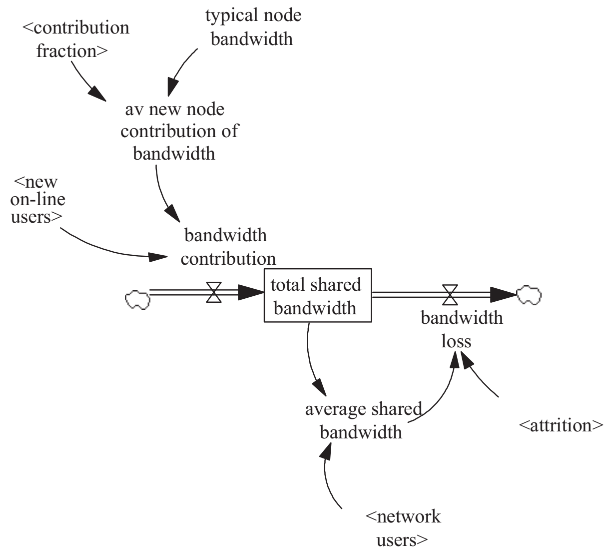


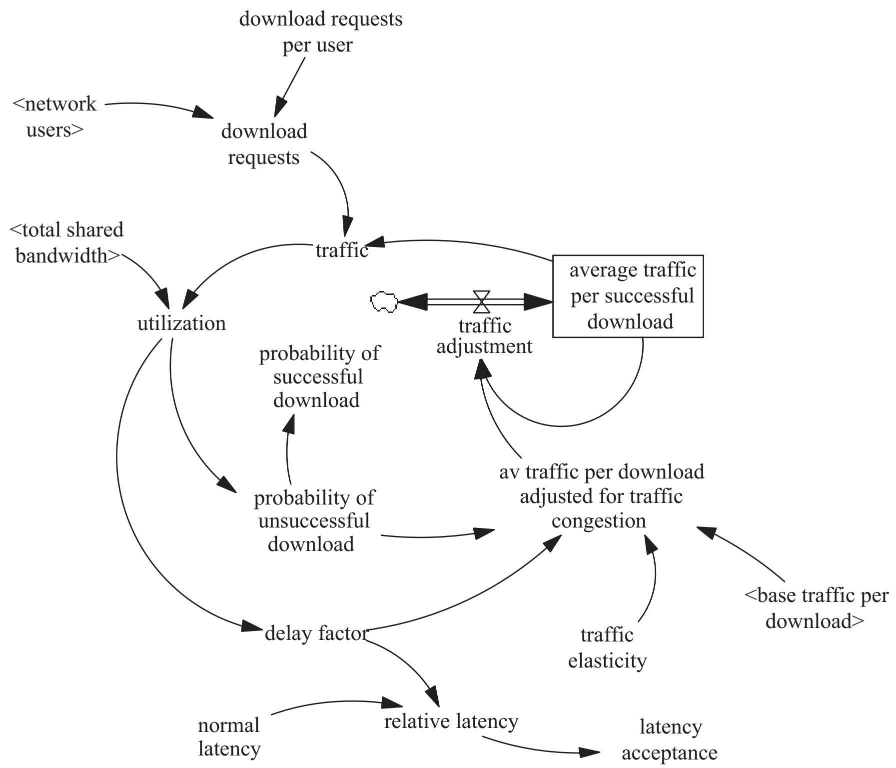
Figure 5. Bandwidth Sector



each additional new peer and diminishes when peers leave the network. At best, each peer contributes its entire available bandwidth, which is the typical node bandwidth. However, in most situations the contribution is below this maximum value and is controlled by the contribution fraction.

Traffic and Network Performance Sector. The sector shown in figure 6 models traffic and network performance. Following Ritter 2001, I assume a linear relationship between the number of queries and the size of a peer network, that is, peers submit some average number of requests per node to the system. Additionally, I assume, following Yang and Garcia-Molina 2002, that some average aggregate bandwidth (in bytes) is generated by a representative query, response to the query, and the following download—all summed as the base traffic per download. The variable traffic is an aggregate measure for the entire file-sharing network.

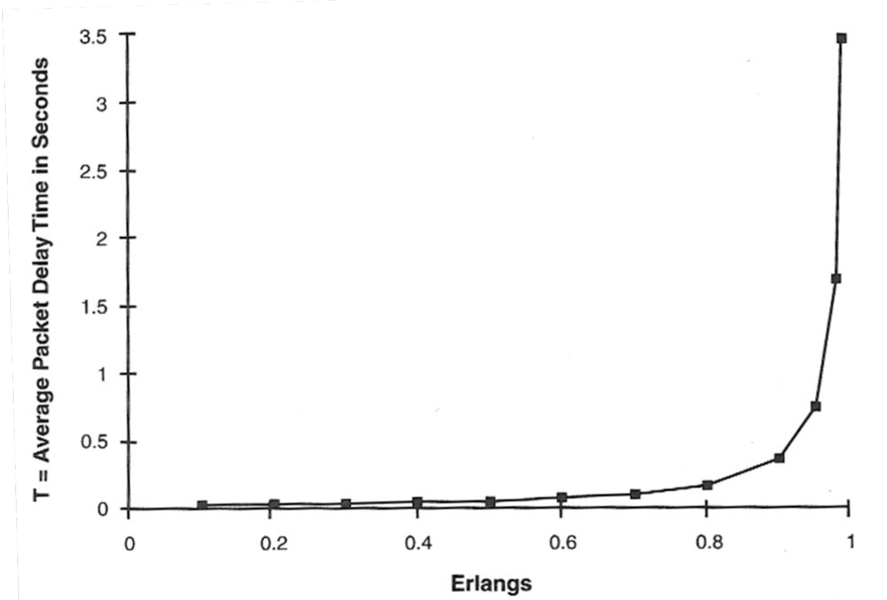
Figure 6. Traffic and Network Performance Sector



Utilization is the ratio of traffic to the connection capacity. In general, once a node's bandwidth is saturated a number of things may happen (Leuf 2002, 121). First, a connection might be dropped. This would lead to lost return paths, unfulfilled requests, and repeat of request broadcasts. Second, the node may simply ignore some of the request traffic. Thirdly, the node can buffer some messages and wait till bandwidth frees up, but this would slow down computer performance and also contribute to the latency along the path. Network theory suggests that delay (latency) and network traffic for a given capacity are related as shown in figure 7. This relationship is included as a delay factor. In a busy network, relative latency will increase beyond the benchmark value of normal latency. Consumers expect short response times to their searches. It has been suggested (e.g., Leuf 2002, 130) that Napster was able to achieve explosive popularity in its heyday because it provided quick responses to queries for music files. I represent the consumer reaction to delays with the latency acceptance variable. Latency acceptance is declining with increasing marginal dissatisfaction in relative latency.

Users tend to resubmit song queries if the reply has not arrived within some short time interval. Users will also resubmit a query if the download is interrupted. Additionally, the peer software itself will resend query packets if it does not receive confirmations of its messages from other nodes. This forms a reinforcing loop: more traffic slows down the system, which, in turn, gradually stimulates more traffic. The loop is balanced by the

Figure 7. Average Packet Delay as a Function of Traffic Load



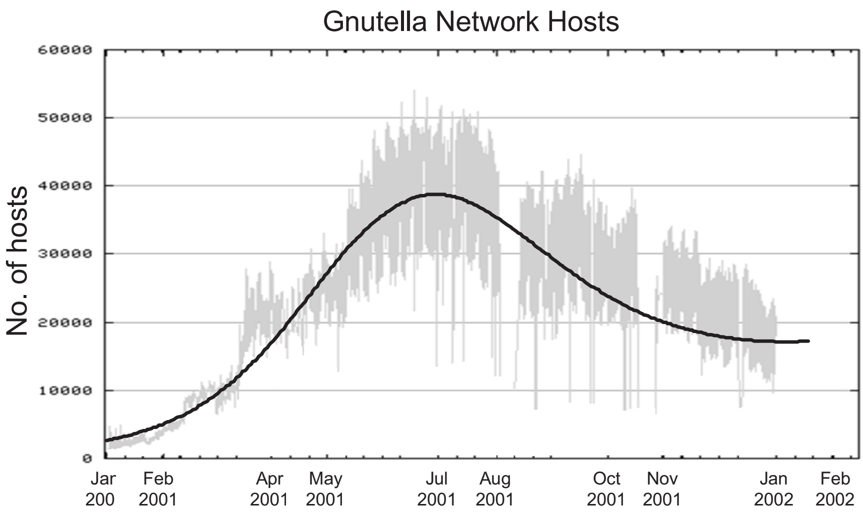
Source: Pecar and Garbin 2000, 429.

decline in traffic as users disconnect from the network because of the poor mesh performance.

Base Case Simulation

Figure 8 shows a fairly good fit between data on the actual number of connected hosts in a peer-to-peer network for one reference year and the simulated time series. Model parameter values, which are our best judgments rather than precise statistical estimates, are summarized in the appendix. The pattern exhibited in the figure is an outcome of a complex interaction between the private provision of public resources (bandwidth and content), private demand for music exchange, and the performance properties of a computer network. The fast oscillations in the actual data are due to the hourly variations in online usage—more people are on the Internet around midnight than at six o'clock in the morning (Kitz and Essien 2002). I do not replicate hourly variations in order to avoid the potential problem of stiffness that arises when time constants of significantly different magnitudes are employed in a model (see, for example, Maron and Lopez 1991 for discussion). Also, I was only able to obtain the plot, rather than the

Figure 8. Simulated Trajectory (Smooth Curve) and Actual Data (Jiggered Time Series)



Source: http://www.limewire.com.

Note: Actual data are the number of Gnutella network hosts during one year between January 1, 2001, and February 1, 2002.

actual numerical data, and therefore I do not smooth the data using the running average.

The graph in figure 9 is a causal loop diagram (Radzicki 1988) of a peer-to-peer system; it consists of all important state and flow variables and cause-and-effect links between them. As the initial small group of network users grows, so does the amount of shared content (the "user-contributed content" loop R1 in figure 9) and so does the bandwidth available to route the network traffic (the "user-contributed bandwidth" loop R2). The network's popularity is further enhanced by media attention (the "publicity loop" R5) and through word of mouth (the "word of mouth" Loop R4).

The growth in network resources is clearly visible in the data from the base simulation (figure 10a). The free-riding tendencies, however, become more prominent as the system scales up (the "content free riding" loop B3 and the "bandwidth free riding" loop B2). This leads to a gradual decline in the average membership contributions of content and bandwidth. Additionally, a larger network generates more traffic (the "traffic growth" loop B1). The exacerbating inadequacy of resources increases the network's search response latency and lowers the probability of a successful download (figure 10b). Increase in latency will induce some hosts to resubmit their requests (the "overload escalation" loop R3). A decline in network performance contributes to the growing overall dissatisfaction with the network, leading to a fall in the network usage starting around

Figure 9. Causal Structure of a Peer-to-Peer Network

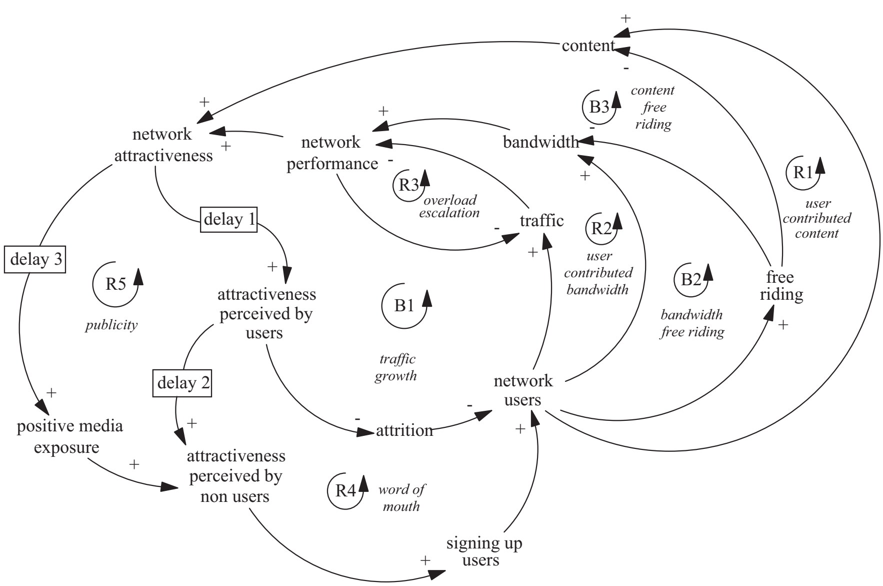
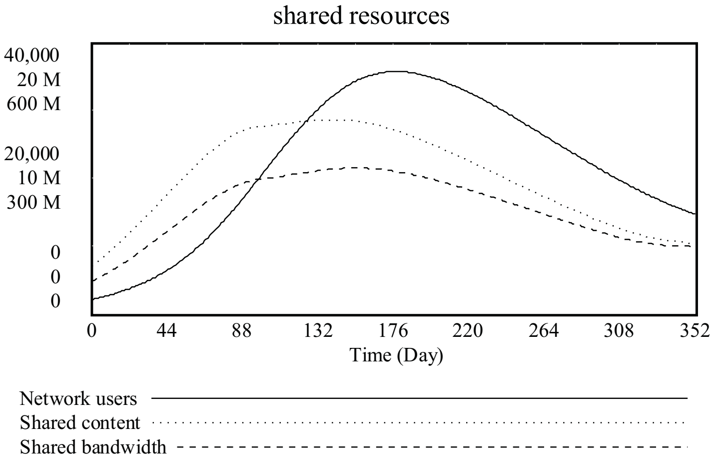
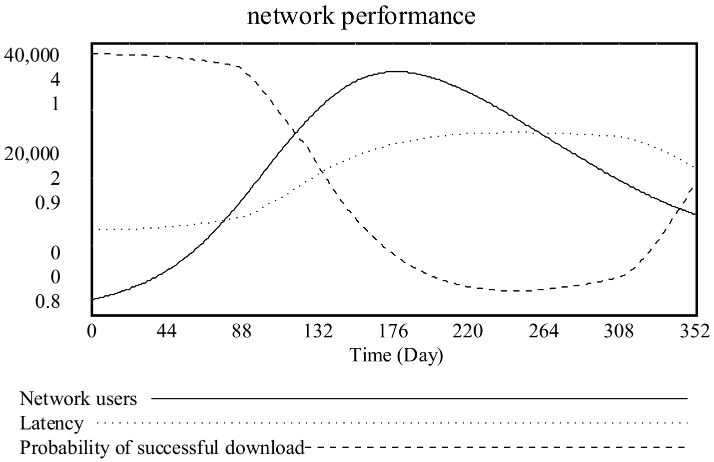


Figure 10. Simulated Network Dynamics



(a)



(b)

day 176 of the simulation (figure 10). This, however, reduces the traffic and network performance begins to improve (figure 10b and the "traffic growth" loop B1).

Policy Experiments

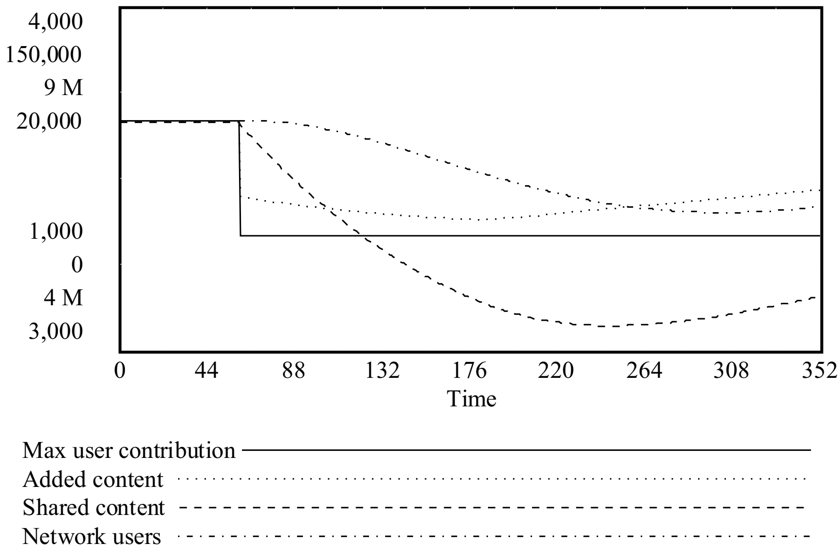
Copyright owners may obstruct the file-sharing activity within peer-to-peer networks by a number of means. Of the available options, in this section I review three alternative strategies: (1) using either litigation or self-help, copyright owners target large-scale contributors to the network, which are not necessarily its heavy users; (2) corporations attempt to limit file swapping by eliminating the most grievous copyright violators, that is, users who download significant amounts of files, by either suing them or by disabling such nodes online; and (3) recording companies opt to disrupt the infrastructure performance by generating bogus traffic that clogs the system, which is a variant of a self-help approach. I investigate how the system responds to these policies and then compare the effectiveness of the strategies against each other.

Targeting Large-Scale Contributors

Since the early stages of the battle against music sharing, the RIAA has been threatening to prosecute individual P2P network users. On September 8, 2003, it made good on the promise by filing suits against users in the United States who contributed significant music libraries to the network (Kirk Semple, "Record Industry Sues Hundreds of Internet Music Swappers," *The New York Times*, September 8, 2003). Information on file sharers was collected using automated Net crawlers (France and Grover 2003). The move prompted many users to scale back on their generous file offerings (Amy Harmon and John Schwartz, "Music File Sharers Keep Sharing," *The New York Times*, September 19, 2003; Associated Press 2004). Because only a very small percent of users contribute most of the shared files, the expectation is that such a reduction may negatively affect the common pool of free songs. However, there were still reports that the system continued to function and exchanges were still occurring. I would like to understand how the system responds to a policy against online contributions. I will refer to this policy as *policy 1.*

In highly uncertain situations people rely on rules of thumb (Hodgson 1998). After observing the trials, users may develop a rule of thumb similar to the following: "To avoid prosecution share only a limited amount of files." I simulate such a decline in maximum contributions by lowering the maximum new user contribution in the content sector, figure 4. In order to eliminate the transient adjustment effects and concentrate on the system's response to the policy, I begin our simulations in a steady state. The maximum new user contribution is reduced by 30 percent, from 3,000 to 2,000 files. The policy has an immediate impact on shared content (figure 11): users connecting to the network no longer bring the same amount of content as before, thus sharply reduc-

Figure 11. System Response to Policy 1 Implemented at Time 60

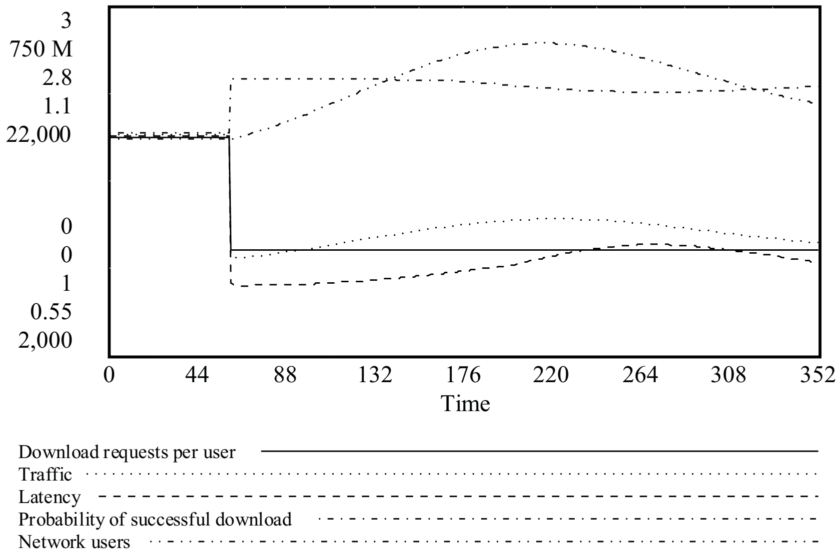


ing the inflow to the stock of content (figure 4). This is followed by a quick decline in the stock of shared content, which, in turn, reduces the attractiveness of the network and leads to the erosion of the user base (the "shared content" loop R1 in figure 9, exacerbated by the reinforcing effects due to the "word of mouth" loop R4 and the "publicity" loop R5). Smaller network size, however, eases the free-riding problem (the "content free riding" loop B3 and the "bandwidth free riding" loop B2), which improves the average new user contribution (figure 4). This slows down the erosion of network resources (shared content in figure 11), which, with some delay, encourages new growth in online membership (network users in figure 11).

Targeting Active Downloaders

The best way to change a complex system in a desired direction is to align goals of its participants (Radzicki 1988, 649). Accordingly, the ultimate goal of the lawsuits against online music sharers is to change the behavior of the online community (France and Grover 2003; Amy Harmon and John Schwartz, "Music File Sharers Keep Sharing," *The New York Times*, September 19, 2003). In this experiment I test a situation in which people respond to the RIAA's suing heavy network users (I call this *policy 2*) by adjusting their downloading habits—they download fewer songs, which is a realistic response according to the *Times* article just cited. Thus, for this experiment, I lower the typical

Figure 12. Network Response to Policy 2 Implemented at Time 60



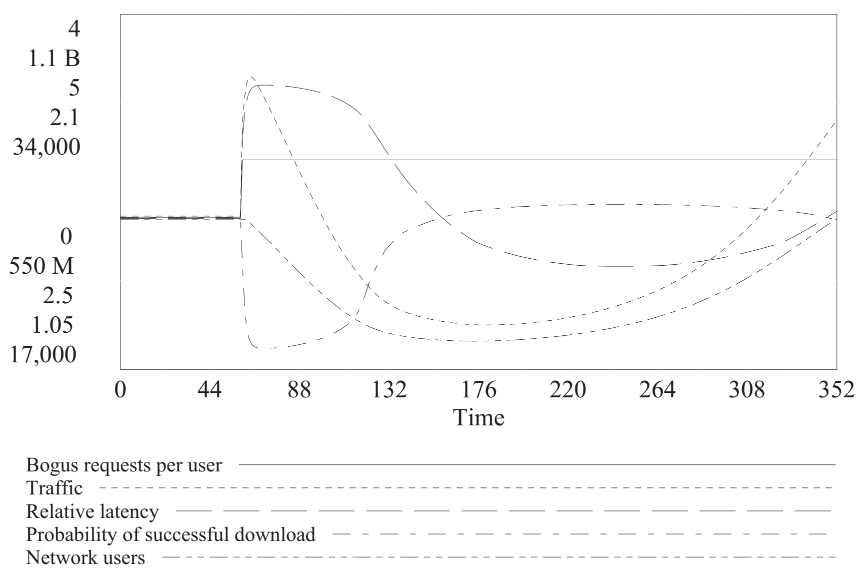
download request per user in the traffic and network performance sector (figure 6) to about one half of the original frequency: from 1.87 to 0.9 song requests per person per day (figure 12). The immediate consequence is a reduction in network traffic. But lighter traffic results in better performance (the "traffic growth" loop B1 and the "overload escalation" loop R3 in figure 9), that is, shorter latency and greater probability of a successful download (figure 12). This attracts a greater number of occasional users—that is, the network users trajectory in figure 12 is upward sloping immediately after the policy is implemented at time 60. Interestingly, a rise in users shortly after lawsuits began has been observed in real music networks, according to the *Times* article. The growth in the number of nodes gradually degrades network performance and attractiveness, which overturns the membership growth pattern (figure 12).

Targeting Infrastructure

Litigation of individual online network members is expensive and impractical (Yu 2003). The majority of individual copyright violators are not attractive legal targets because they are not rich enough to pay monetary judgments (Yen 2001). The RIAA may hope to recover only between $2,000 and $15,000 per each settled case (Aftab 2003). Therefore, music companies have strong incentives to search for more cost-effective methods to fight music swapping. For example, they may choose to introduce automated bogus peer-to-peer nodes that act as ultimate free riders (not unlike the existing network sites asiayeah.com and gnute.com). By generating numerous requests and not contributing any content or processing traffic from other peers, such nodes clog the peer network bandwidth, increase latency, and lower the probability of successful downloads for network users. If sufficient traffic is generated, then the system may collapse completely. The infrastructure strategy may be carried out in a number of ways. Here I consider two options: the policy effort is proportional to the file-trading activity (I call this *policy 3*), and the policy effort is constant over time (I call this *policy 4*).

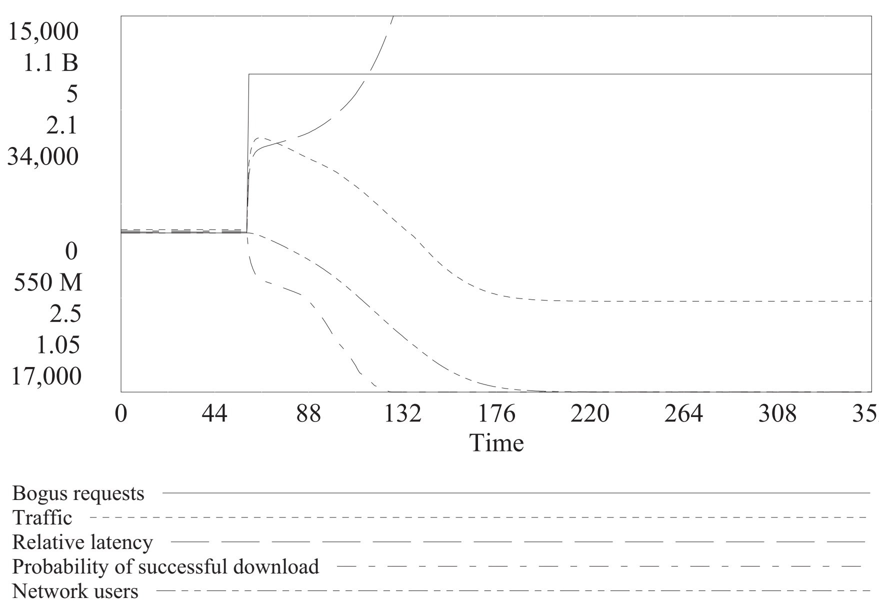
To simulate the implementation of a variable-effort policy (policy 3), I introduce a variable named "bogus requests per user," which is numerically added with the download requests per user in the traffic and network performance sector (figure 6). In effect, this is equivalent to artificially increasing the average number of file requests per each real connected user. I effectively increase the number of song requests per real user from the base 1.87 to 3 per user per day, which is about a 60 percent hike. As expected, traffic increases (figure 13), leading to a surge in latency and a drop in the probability of successful downloads. Accordingly, fewer users join and stay online—the network users trajectory falls. But this leads to less traffic (the "traffic growth" loop B1 in figure 9), which allows the system to recover in terms of the probability of successful download and latency (figure 13).

Figure 13. Network Response to Policy 3 Implemented at Time 60



To test a constant-effort implementation of the infrastructure strategy (policy 4), I increase network traffic by submitting an additional 10,979 bogus requests per day, which happens to be the average number of bogus requests during policy 3. Choosing this particular value assures that the average effort is the same in either implementation of the strategy. As soon as the policy is implemented at time 60 (figure 14), a decline in membership sets in (see network users in figure 14) due to the network's unusually poor performance (see the sharp increase in relative latency and the drop in the probability of successful download). The response mechanism is captured by the "traffic growth" loop B1 in figure 9. As users exit, they withdraw the two resources essential for the network operation: content and bandwidth. The decline in resources negatively affects network performance and attractiveness, which further worsens the situation. This is captured by the "user contributed content" loop R1 and "user contributed bandwidth" loop R2 (figure 9). Balancing forces of the "bandwidth free riding" loop B2 and "content free riding" loop B3 (figure 9) would typically reverse the decline in usage. In the case of policy 4, however, this does not happen—the performance and usage only get worse with time due to the time-invariant stream of exogenous bogus traffic and a continuous exodus of participants. The last network user leaves the system around the time 200.

Figure 14. Network Response to Policy 4 Implemented at Time 60



Policy Effectiveness

Policy effectiveness may be gauged using different criteria. From the legal and regulatory standpoints, the most potent strategy may be the one that allows the least number of copyright violators. On the other hand, evaluating the pecuniary effect of a policy may require information regarding the policy's impact on the amount of traded music. In this section, I compare the effectiveness of the four policies along two dimensions: the number of network users and exchanged content volume.

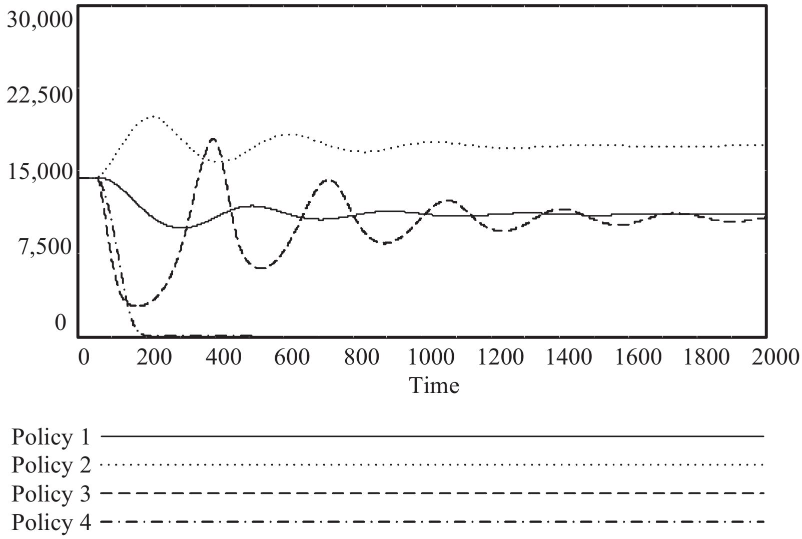
Measure: Number of Network Users. A network's response to the four policies with respect to the number of daily users is pictured in figure 15. Each simulation was run for the time sufficient for the transient behavior of the system to settle. Table 1 summarizes the simulation statistics. The effort chosen for policy 4 is sufficient for the network to collapse. Policy 2 is the least effective among the three remaining policies because it allows the greatest average number of users (table 1) and in the long run the network use upticks beyond the prepolicy level. Though our implementations of policy 1 and policy 3 are nearly equally effective in the long run—they reach about the same steady state membership numbers (figure 15)—the attack on infrastructure, policy 3, results in a highly unstable transient trajectory. Additionally, policy 3 is more effective on average than policy 1 at discouraging network use (table 1).

Measure: Exchanged Content Volume. Figure 16 presents daily figures for traded content, and summary statistics are presented in table 1. After a short period, there is no trading if policy 4 is implemented. Among the nonlethal policies, the response to policy 3 is, again, the most volatile. Policy 1 leads to the highest average and steady state volumes of traded content (see table 1). Interestingly, even though on average and in the long run policy 2 encourages participation (see figure 15), the policy achieves the lowest long-run traded content volume (figure 16).

Table 1. Policy Response Summary Statistics

	Measure 1: Online Nodes				Measure 2: Traded Content			
	Max	Min	Av.	St. Dev.	Max	Min	Av.	St. Dev.
Policy 1	14,374	9,799	11,236	896	24,169	17,519	19,873	1,259
Policy 2	19,861	14,374	17,197	927	24,169	12,751	15,482	1,673
Policy 3	17,834	2,705	10,147	2,891	25,819	2,484	15,112	4,666
Policy 4	14,374	0	1,692	4,241	24,169	0	1,995	6,154

Figure 15. Policies Compared with Respect to the Number of Online Nodes

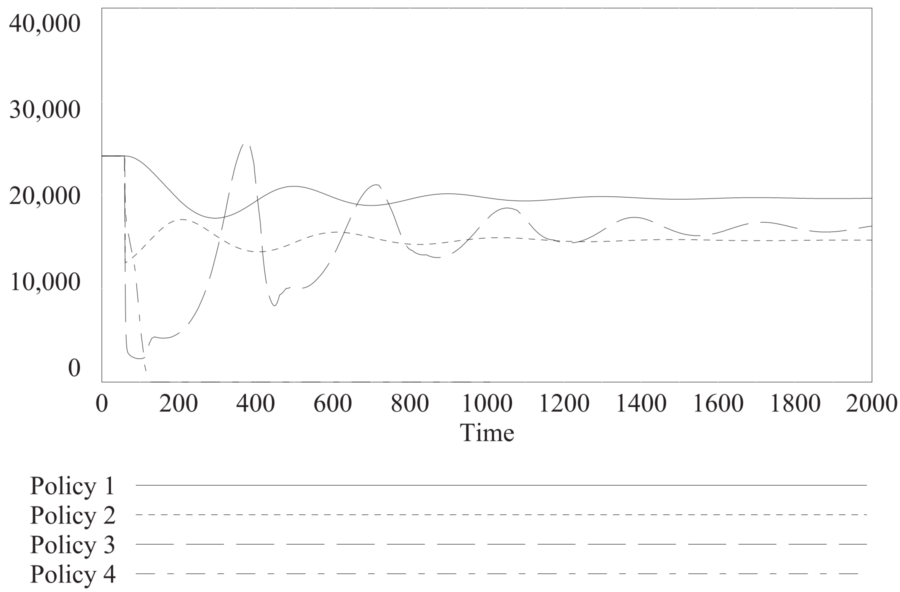


Conclusion

Peer-to-peer technology has transformed music into a widely available and easily copied public good by allowing consumers to obtain music without paying royalties to copyright owners. In this article I considered several actions that have been either implemented or reviewed by the recording industry as measures against online music networks. Starting with an institutional description of the commercial music industry, I amended the traditional methodology with a formal computer model. To build the model, I carefully reviewed a representative online music community, including technological and behavioral characteristics of such a system. A base run confirmed the model's ability to reproduce the behavior of the reference network.

After a satisfactory model was built, four policy experiments were performed. Policy 1 simulated a strategy that targeted large-scale file sharers. Policy 2 was based on an attempt to control downloading. Attacks against the peer-to-peer infrastructure were simulated by policy 3 and policy 4. Each of the strategies has a real-life counterpart. One of the most striking observations from the experiments was that some of the measures led not only to temporal but also to a long-term increase in network use. Such effects were created by the complex feedback nature of the popular networks, making the nets extremely resilient to any attempts to disrupt them. Network robustness suggests that the RIAA is not assured of gaining an upper hand in this copyright battle. Of the four policies, only policy 4 caused a complete collapse of the network. I also showed that, in

Figure 16. Policies Compared with Respect to the Traded Content



general, policy effectiveness may be judged differently depending on the chosen criterion: a policy using automated nodes that slowed down the system (policy 3) was the most potent among the nonlethal actions in terms of the decline in the number of connected nodes, but in the long run it lost to a policy that targeted heavy downloaders (policy 2) when compared by traded content. This suggests the importance of selecting an adequate yardstick when discussing policy alternatives and their potential impact on peer-to-peer systems.

Appendix

Below I present the mathematical formulation of the model.

Network users sector

Parameters

τ_n	Opinion formation delay by nonusers	100 days
τ_u	Opinion formation delay by users	25 days
τ_m	Opinion formation delay for media	1 days
u_a^t	Normal adoption rate	0.02 dimensionless

u_d^t	Typical attrition rate	0.001 dimensionless
f^{or}	Original free-riding fraction	0.09 dimensionless
Variables		
U	Network users	$(d/dt)U =$ new online users – attrition
u_a	Fractional adoption rate	$u_a = u_a^t r_n$
$g_d(r_u)$	Attrition response to network attractiveness	$g_d(r_u) > 0 \;\; g_d'(r_u) < 0 \;\; g_d''(r_u) < 0$
u_d	Adjusted natural attrition rate	$u_d = u_d^t(1 + g_d(r_u))$
	New online users	$u_a U$
	Attrition	$u_d U$
a	Peer network attractiveness	$a = a_c \cdot a_l \cdot p_{sd}$
r_n	Peer network attractiveness perceived by nonusers	$(d/dt)r_n =$ fractional media effectiveness $\cdot(a - r_n)/\tau_n$
r_u	Network attractiveness perceived by users	$(d/dt)r_u = (a - r_u)/\tau_u$
	Fractional media effectiveness	Typical media effectiveness $\cdot a_m$
a_m	Peer network attractiveness portrayed by media	$(d/dt)a_m = (a - a_m)/\tau_m$
$f(U)$	Free-riding multiplier	$f(U) \geq 1 \;\; f(U^{initial}) = 1 \;\; f'(U) > 0$
f	Free-riding fraction	$f^{or} \cdot f(U) \;\; f^{or} \leq f \leq 1$
κ	Contribution fraction	$1 - f$

Content sector

Parameters		
n_v	Number of reachable nodes	381 nodes
c_p	Typical collection	500 files
α	Share of interesting content	0.0025 dimensionless
c^{max}	Max new user contribution	3000 files

Variables

C	Shared content	$(d/dt)C =$ added content – withdrawn content
c^{av}	Average new user contribution	$c^{av} = c^{\max} \cdot \kappa$
	Added content	c^{av} ·new online users
s^{av}	Average shared content	$s^{av} = C/U$
	Withdrawn content	$s^{av} \cdot$ attrition
c_r	Content of interest reachable by a user	$c_r = \alpha \cdot n_v \cdot s^{av}$
s	Relative richness of the network	c_r / c_p
a_c	Content attractiveness	$a_c = f_c(s)$
		$0 \le f_c(s) \le 1$ $f_c(0) = 0$ $f_c'(s) > 0$ $f_c''(s) < 0$

Bandwidth sector

Parameters

b_t	Typical node bandwidth	60000 bps

Variables

	Bandwidth contribution	New online users $\cdot b_{av}$
b^{av}	Average shared bandwidth	B/U
	Bandwidth loss	$b^{av} \cdot$ attrition
B	Total shared bandwidth	$(d/dt)B =$ bandwidth contribution – bandwidth loss
b_{av}	Av. new node contribution of bandwidth	$b_t \cdot \kappa$

Traffic and network performance sector

Parameters

d_u	Download requests per user	1.87 files/day
l_n	Normal latency	1 dimensionless
α	Traffic elasticity	0.192 dimensionless

Variables

d	Download requests	$d_u \cdot U$
T	Traffic	$d \cdot t^{av}$
λ	Utilization	$\lambda = T / B$
l	Relative latency	$l = \left(1 + l_{df}\right) \cdot l_n$
l_{df}	Delay factor	$l_{df} = l(\lambda)\ \ l'(\lambda) > 0\ \ 1''(\lambda) > 0$ $l(0) = 0$
a_l	Latency acceptance	$a_l = f_l(1)\ \ 0 \leq f_l \leq 1,\ \ f_l' < 0,\ \ f_l'' > 0$
p_{ud}	Probability of an unsuccessful download	$p_{ud} = p_{ud}(\lambda)\ \ p'_{ud}(\lambda) > 0$ $\lim_{\lambda \to 0} p'_{ud}(\lambda) = 0\ \ \lim_{\lambda \to 1} p'_{ud}(\lambda) = 0$
p_{sd}	Probability of a successful download	$p_{sd} = 1 - p_{ud}$
t^{av}	Average traffic per successful download	$(d / dt)t^{av} = \text{traffic adjustment}$ $\text{traffic adjustment} = t^* - t^{av}$
t^*	Traffic per download adjusted for traffic congestion	$t^* = \left(1 + p_{ud}\right)^{\alpha} \cdot \left(1 + l_{df}\right)^{\alpha} \cdot t_b$ $0 \leq \alpha \leq 1$

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