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ABSTRACT

This paper extends previous work by the authors in which they propose a dynamic distribution model based on modified economic growth theory to determine file distribution patterns in peer-to-peer networks. Although the theoretical model provides a good foundation for exploring different pricing mechanisms for peer-to-peer networks, there are several issues that remain unexplored because of computational difficulties. In this paper, we use the methods of experimental economics to create a sequence of experimental designs to explore some of these issues. The designs mimic the structure of the industry, the type of current and future property rights, some technical constraints, and the strategic interactions between the different actors.

Keywords

Peer-to-peer networks, experimental economics, digital content distribution, pricing digital goods, digital/electronic market design.

INTRODUCTION

As the media industry has begun shifting its operations from physical to digital distribution models to deliver its content products to consumer markets, it faces the question whether to adopt a centralized or a decentralized solution (Bockstedt, Kauffman, and Riggins, 2005). The former approach will typically be implemented as some kind of client-server system where content provision and customer relationships are managed centrally. Decentralized distribution, on the other hand, might be most effective when implemented over peer-to-peer (P2P) networks where consumers partake in the distribution process by trading information and content files (Parameswaran, Susarla and Whinston, 2001). For media companies, however, adopting P2P distribution means trading-off control over content supply and distribution channels for possibly increased distribution efficiencies and service levels (Kwok, Lang and Tam, 2002). Distributional efficiency becomes critical as file sizes become large, as they routinely do for digital movies, for example. Meanwhile post-Napster P2P download systems like Kazaa, Grokster, BitTorrent, and others are have gained and maintained immense popularity (Thompson, 2005) despite legal disputes and are challenging the control position of traditional distributors.

In previous research (Lang and Vragov, 2005) we have used modified economic growth theory to develop a basic theoretical file distribution model that shows the advantages of P2P networks as an efficient distribution tool. The analytic model involves a setting in which a monopolist producer of a file offers a specific price schedule to all consumers willing to buy the file based on the timing of the consumers' buy requests and their willingness to share the file with other users. There are two prices determined by the monopolist seller: a download price, which is constant over all generations of consumers and an upload price, which changes in every generation. The pricing scheme eliminates free-riding within the P2P network and can be implemented in practice in several different ways. We show that, irrespective of implementation, decentralized file distribution based on our model occurs much faster than in an equivalent client-server setting while at the same time it still earns the monopolist the same amount of revenue. Because of the complex nature of P2P file exchange systems purely analytical approaches fail short of addressing several important issues. In this paper we turn our attention to possible experimental approaches.

Experimental economics methods have already been applied to a variety of network settings including but not limited to transportation networks, electricity networks and gas networks (Backerman, Rassenti and Smith, 2000; Cox, Offerman,

Olson and Schram, 2002; McCabe, Rassenti and Smith, 1991). In this paper, we advance our earlier results by way of using methods from experimental economics to further explore issues related to P2P networks that are difficult to examine theoretically because of computational complexities. These involve, for example, exploring the effects of introducing network service providers as strategic players in file distribution, introducing a variable cost of computer resources, and various producer and consumer bandwidths. We also recognize that in a P2P setting, time-related preferences are another important source of variation that needs to be investigated. The main purpose of this paper is to establish a common experimental design framework that can help compare different P2P pricing mechanisms that have been suggested in the literature and propose a possible format for a pilot study.

GENERAL EXPERIMENTAL ENVIRONMENT

We specify a general description of the experimental environment that can establish the design foundation for future experiments. The experimental environment consists of N peer users / consumers. We consider a heterogeneous multi-product market with F digital content files. Each consumer is characterized by a valuation for each file, a time preference, an opportunity cost for her computer resources, and a bandwidth. There are M file producers, who are characterized by the fixed cost of their product, the time-dependent maintenance and security cost, their server capacity and network bandwidth. There are also Q network service providers who supply the P2P system software and hardware platforms if such are necessary. They are also responsible for network security and monitoring and incur costs for these services. Given this generalized environment we can explore a variety of issues related to digital content distribution over a P2P network.

PILOT PARAMETERS

In the first series of experiments, we investigate consumer behavior under a pricing mechanism that allows peers to view or distribute content (viewing and distribution pricing). This mechanism necessitates two different licensing rights; a viewing and a distribution right. A consumer who obtains a distribution right for a digital file is permitted to share the file with other consumers connected to the P2P network. The viewing right permits only using (viewing or listening to) the file, but does not allow sharing. Under the rules of this mechanism the producer (record companies, movie studios, independent companies, individual artists, etc.) of a file issues distribution rights at the time when the product is ready for release and distribution. After this initial "IPO" every buyer of a distribution right can sell the right to another consumer at a mutually advantageous price at a *Digital Rights Exchange*, which is designed as part of the P2P network. The viewing right can be purchased only from the original producer of the file any time throughout the file distribution process. We will explore a lab setting in which the number of tradable files $F = 3$, and we will focus our attention on consumer behavior keeping in mind that the purpose of this pilot is to see if consumers are comfortable using the pricing mechanism and if they are able to adjust their behavior according to the prevailing market conditions.

Consumer characteristics

Consumer Bandwidth

The current experimental design models differences in bandwidth using an implicit bandwidth limit by increasing the cost of the download speed. Subjects in the experiment can manipulate the downloading speed for any file. High speed is more expensive than low speed. However, there is a point, when the implicitly set bandwidth limit is reached, at which increasing the price that the subject is willing to pay for an increase in the speed is no longer effective.

Opportunity cost of sharing resources

Clearly when consumers make a decision about sharing bandwidth for P2P services they have to consider the opportunity costs associated with all alternative uses of the bandwidth and processing time. In our scenario, we chose to ignore those costs. This is done only to reduce the computational burden on the part of the subjects. These costs are hard to estimate in reality and we are not aware of any studies that attempt to do that. It might be an interesting exercise from a practical point of view to determine what the level of these costs are for different types of computers and computer users. We will leave this task to a later study.

Time -variant content valuation

In a P2P setting, files are distributed sequentially from one or several users to the downloading user. In the theoretical model mentioned earlier we kept the generation size fixed and the value for the content file time-invariant to ensure that the model is analytically tractable. We relax these assumptions in this experimental setting. Time is a very important dimension for

consumer utility, especially in the current digital economy. The usage value for all files in our experiment is changing according to figure 1.

Producer Information and Decision Spaces

The producer's behavior in the pilot is fixed. In our initial experiment, we assume that the producer has decided to sell files *A* and *B* using time-based price discrimination – i.e. the price of the viewing right for files *A* and *B* is decreasing over time. The price for file *C* on the other hand remains fixed throughout the experiment.
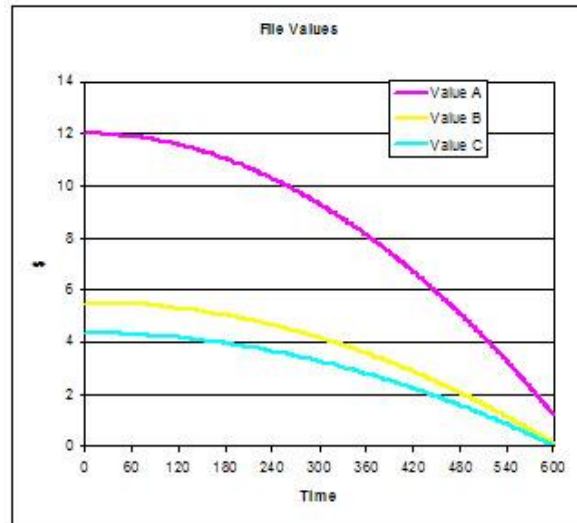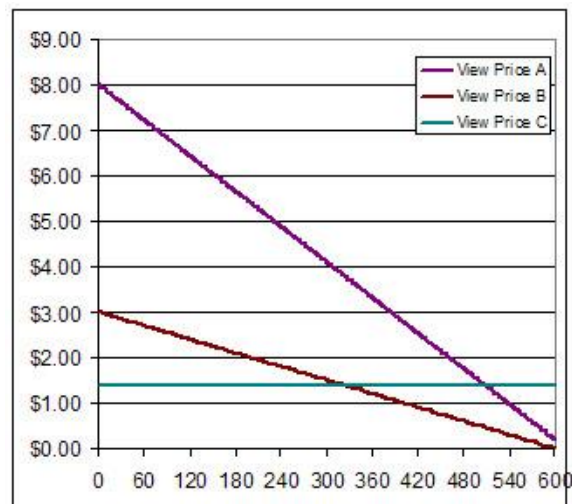
Figure 1.

Figure 2.

We assume that the producer has estimated the expected sales volume for each file and has accordingly chosen the number of distribution rights for the "IPO" as well as their price. The price for a distribution right is equal to the expected income from owning the right throughout the rest of the distribution process. In this sense, the distribution rights for the three files in the experiment are priced in a different way. We assume that the distribution market size is large, so that no individual consumer can influence the price in the market. We want to introduce some variety in terms of how accurate the producer's expectations are on average. This is why we deliberately set, as shown in figure 3, the distribution right for file *A* to be

undervalued; the distribution right for file *B* to be overvalued, and the distribution right for file *C* to be priced approximately fairly.

Figure 3.

Consumer Information and Decision Spaces

We assume that all consumers know their value for viewing a file. Consumers in this experiment are allowed to control the file download speed, which is expressed in percentages per second. As soon as a subject buys the viewing right for a file, the file starts downloading at the minimum possible speed (0.187%/s), and the subject is charged 0.01c/s. The supply conditions that the subjects face are shown in figure 4. Subjects are also allowed to control the speed at which they are sharing the file with other users. As soon as a subject buys a distribution right, s/he starts sharing the file and charging the minimum price of 0.01 c/s. The subject is facing file download demand conditions as shown in figure 5.
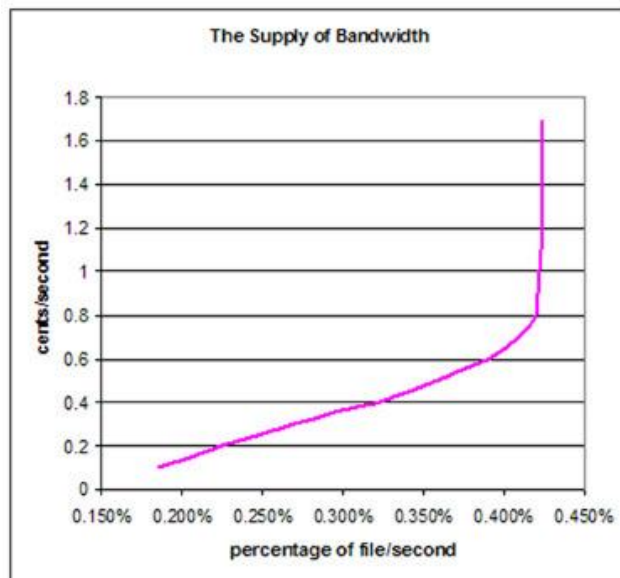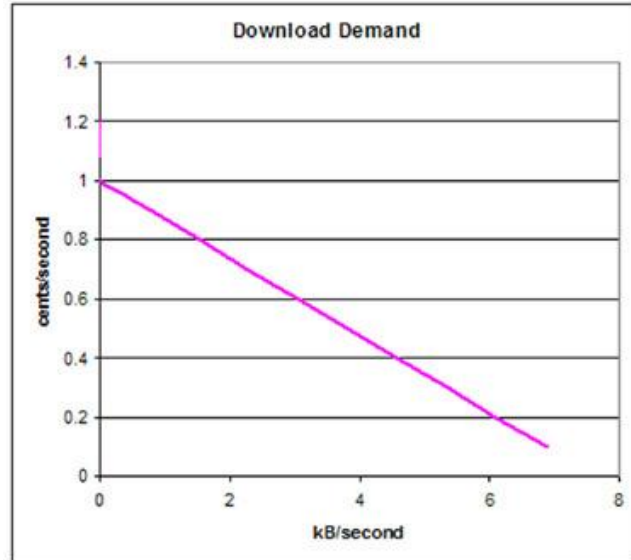

Figure 4.

Figure 5.

DESIGN ISSUES

There are many electronic market design issues that come up during the process of creating and implementing the mechanism. In this section, we would like to discuss the two that we consider most important. The first one concerns the pricing of download speed. We consider two possibilities: (1) pricing based on bytes/second and (2) pricing based on downloaded percentage of a file per second. The first one should be more familiar to computer users because most popular P2P downloading software uses it to show download progress. The second one, however, represents better the temporal variation in customers' willingness to pay for a file. A customer's willingness to pay for a file might be directly related to file size but the decrease in willingness to pay due to time delays in downloading is not necessarily related to file size. This approach also simplifies the calculation of the initial price of the distribution right for a file. It will be easier for the file creator to find out what the IPO price should be only based on the estimated demand without paying attention to the actual file size.

Allowing the content provider to charge different prices for a file depending on how long after its initial release a customer decides to download the file was another issue that we explore in this design. From an economic theory point of view price discrimination increases efficiency and volume traded while decreasing consumer surplus and the deadweight loss related to the monopolistic market setting. In practice, however, businesses have discovered that complicated price-discriminating schedules could be confusing for customers and create perceptions of unfairness that might deter them from participating in the exchange. To explore this issue in our setting we use temporal price-discrimination for files *A* and *B*, and a fixed price for file *C*.

OPTIMAL STRATEGIES

Using our parameter settings and some linear optimization techniques we can calculate the optimal strategies in the market for viewing rights. In that market, a subject should buy file *A* at the beginning of the session and then pay 0.7 c/s to download it at 0.41%/s. A subject should buy file *C* at the beginning of the session and then pay 0.5 c/s to download it at 0.36%/s. File *B*, on the other hand, can never be profitably downloaded. The optimal strategies in the market for distribution rights are much harder to determine. Once the right for any of the available files is acquired, the optimal charge is 0.5 c/s. The optimal timing of buying and selling is not easy to estimate. The prices of the distribution rights in the beginning of the session are based on estimated demand. The prices start going down every second based on the actual number of downloads that happened during the previous second. Because of this fact buying and selling a distribution right many times during the session should result in zero profits on average. In addition, the distribution right for file *B* is over-valued throughout the session, so if a subject wants to make some profit out of it s/he has to sell it before the end of the session. The distribution right for file *A* is undervalued, so buying it around the 500th second and holding it until the end should maximize a subject's

profit from owning it. The distribution right for File *C* is priced fairly, so the timing of buying and selling decisions should not matter on average.

CONCLUSION

Designing a functioning and efficient electronic market for exchange and distribution of digital files is challenging. There are a host of issues that need serious experimental treatment. This paper establishes a common experimental framework that could be used to test different GUIs, other pricing mechanisms, and different tradable digital rights structures. The current experimental environment could be used to probe a variety of other important questions including optimal industry structure when many actors are involved and also competition between different pricing mechanisms. We expect to present some pilot results at the AMCIS '05 conference.

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