THE ANALOG HOLE AND THE PRICE OF MUSIC: AN EMPIRICAL STUDY

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We present the results of surveys of music consumers exploring their willingness to pay for digital downloads of music and measuring the impact of the so-called analog hole. The analog hole refers to a perhaps-unavoidable vulnerability of most digital rights management systems. In short, because people cannot consume digital information directly, they must rely on devices to convert digital information into analog signals, which are very difficult to keep from being copied.

Although content providers decry the analog hole as a loophole of the technical measures they use to protect content, surprisingly little is known about its fundamental aspects. Can average users exploit the analog hole, or is this limited to sophisticated users? Does analog hole copying significantly degrade the quality of music or video? Will people pay for music that isn't a perfect digital copy? Intuitions and guesses abound, but until this article, no study has answered these questions. While the surveys' sample sizes were too small to form statistically significant conclusions, we discovered several interesting results including one tantalizingly specific result: what's the analog hole worth? Based on our survey, 24¢. That's how much less our survey respondents would pay for a music track when a perfect digital copy was replaced by an analog hole copy. Although our results must be replicated on a larger scale, they suggest many conclusions that have never before been proved: people are willing to pay for less-than-perfect analog hole copies of songs; people will pay much more than half the price of a typically-priced digital music file for its degraded alternative; and even self-avowed "pirates" show a willingness to pay for digital music, albeit at prices well below today's market standard of 99¢ per song.

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I. INTRODUCTION

The music industry has come to trust that digital rights management technology ("DRM"), backed by laws like the Digital Millennium Copyright Act ("DMCA"), will keep most people from making unauthorized, perfect digital copies of DRM-protected content. Its increased faith has led it to license its music to various online music stores, which has helped spawn a thriving market for pay-per-download music. Nevertheless, the music industry frets about what is known as the analog hole, which arises from the simple fact that digital music must be converted to an analog signal at some point if it is to be enjoyed. It is very difficult, if not impossible, to prevent people from capturing these analog signals, re-digitizing them, and distributing them on the Internet, stripped of DRM. To try to "plug" the analog hole, Congress has considered bills that would mandate strict controls over what device manufacturers can do with analog ports and information.[1] This approach seems premature because there is much we do not yet know about the analog hole.

An empirical study of the effect of the analog hole is warranted. For example, whether the analog hole poses the threat that some claim depends on how it impacts consumer preferences. It may be that analog hole copies, which tend to have a degraded signal quality, are so much less preferred by consumers than higher fidelity, digital versions, as not to act as a market substitute at all. It may also be the case that exploiting the analog hole is so prohibitively complex or costly that it is unlikely to occur with any regularity. We begin to answer these empirical questions.

In this paper, we describe a series of empirical studies we conducted that establish four important results. First, readily-available commercial technologies can be used to exploit the analog hole to obtain, copy, and distribute DRM-protected digital content. These technologies are not difficult to use and require no specific expertise or computer skill. Second, we conducted consumer surveys which demonstrate that consumers can perceive the difference between analog hole copies and digital originals. Third, we also used surveys to determine consumer willingness to pay. These surveys reveal that consumers are willing to accept degraded-quality analog hole copies at a discounted price despite diminished quality. Although this result may seem intuitive, as far as we know, we are the first to examine the question with rigor and to quantify the actual price-point where piracy might be avoided. Our econometric model suggests that people would be willing to pay 75¢ for an analog hole copy of a 99¢ digital track.

1. *See* Digital Transition Content Security Act of 2005, H.R. 4569, 109th Cong.; Consumer Broadband and Digital Television Promotion Act, S. 2048, 107th Cong. (2002).

Finally, we asked whether so-called "pirates" would be willing to pay *anything* for music. Against conventional wisdom, our results demonstrate that a large majority of pirates would be willing to pay something, granted far below market rate, to purchase music instead of illegally copy it.

Part II of this paper describes the analog hole with particular emphasis on the problem of signal degradation. Part III discusses the economics of music sales, focusing on the questions we sought to answer with our study. Part IV details our empirical research and results.

II. DRM AND THE ANALOG HOLE

A. Technical Overview

The analog hole is only meaningfully understood in the context of DRM. As the "D" in the acronym implies, DRM technologies operate exclusively on content in its digital form. DRM protects against unauthorized access, duplication, and distribution of digital content (e.g., audio and video), ensuring that such access to protected content is possible only under the conditions specified by the content owner.[2]

Although there are many disparate types of DRM, some generalizations will help motivate our discussion of the analog hole. Many DRM schemes rely on the introduction or injection by the content provider of extra data into the digital content stream or file, data that has nothing to do with the content itself.[3] For example, fingerprints[4] or watermarks[5] can be embedded into the digital copy of a song or movie, imperceptible to the end-user but detectable with DRM devices. These embedded codes can be used to authenticate a user's entitlement to play, reproduce, or distribute; to embed personal information to assist a future investigation; or to mark the data as free from tampering. After a DRM system identifies the fingerprint or watermark it can filter out or simply ignore the extraneous bits, thanks to the nature of digital data, leaving behind a perfect copy of the content. The listener or viewer will be unable in such a situation to detect any difference in the content.

2. *See* Eugene T. Lin et al., *Advances in Digital Video Content Protection,* 93 PROC. OF THE IEEE 171 (2005).

3. *See* Richard Owens & Rajen Akalu, *Legal Policy and Digital Rights Management*, 92 PROC. OF THE IEEE 997 (2004).

4. *See* Jürgen Herre, *Content Based Identification (Fingerprinting)*, *in* DIGITAL RIGHTS MANAGEMENT: TECHNOLOGICAL, ECONOMIC, LEGAL AND POLITICAL ASPECTS 93 (Erberhard Becker, Willms Buhse, Dirk Günnewig, & Niels Rump eds., 2003); Daniel Schonberg & Darko Kirovski, *Fingerprinting and Forensic Analysis of Multimedia*, 2004 PROC. OF THE 12TH ACM INT'L CONF. ON MULTIMEDIA 788.

5. *See* L. Jean Camp, *DRM: Doesn't Really Mean Digital Copyright Management*, 2002 PROC. OF THE 9TH ACM CONF. ON COMPUTER & COMM. SECURITY 78.

The analog hole (also known as analog reconversion)[6] refers to an inherent vulnerability in DRM systems that makes otherwise protected material copyable by allowing it to be recorded as it is consumed.[7] The analog hole arises as an inevitable byproduct of the interface between computer technology and human biology. In order to sense (hear, see, feel) content in a digital form, it must first be converted into an analog signal. Visual images are converted from binary digits into signals that can be shown on a piece of display hardware (which typically uses light, via a LCD, LED, or CRT, to propagate the image through space to the human retina); sounds are converted from bits into signals that can be played, typically, using some kind of speaker (which converts the signal into compression waves in the air that travel to the human tympanum). If we lived in a world of science fiction, and we could "jack in" directly to our computers, comprehending the bits themselves, there would be no analog hole.

The inevitable conversion from digital to analog (typically performed using a specialized microchip called a digital-to-analog converter ("DAC"))[8] has two deleterious effects on DRM. First, the conversion process tends to strip away non-signal related information such as the fingerprints or watermarks relied upon by DRM. In fact, often the simple act of converting to analog and back again (using an analog-to-digital converter ("ADC"), naturally) will defeat DRM schemes.[9] Second, it is quite difficult to cram extraneous information inside the waveforms of an analog signal without affecting the perceived image or sound, so it is difficult to create DRM-like schemes on the analog side.

6. Many blanch at the term, "analog hole" for different reasons. Critics of legislation designed to "plug" the analog hole have said, "'Analog hole' is an artfully chosen term, referring to the fact that audio and video can be readily converted back and forth between digital and analog formats. This is just a fact about the universe, but calling it a 'hole' makes it sound like a problem that might possibly be solved." Posting of Ed Felten to Freedom to Tinker Blog, http://www.freedom-to-tinker.com/?p=954 (Jan. 12, 2006). Meanwhile, industry proponents of such legislation, perhaps hoping to move away from some of this stigma, describe it as "analog reconversion." *See* Susan P. Crawford, *The Biology of the Broadcast Flag*, 25 HASTINGS COMM. & ENT. L.J. 603, 619 (2003) (describing the Analog Reconversion Discussion Group ("ARDG")).

7. *See* Ross J. Anderson, SECURITY ENGINEERING: A GUIDE TO BUILDING DEPENDABLE DISTRIBUTED SYSTEMS (2001).

8. This DAC is the device that takes the quantized digital signal and returns it to an analog signal for transmission. To do this, the digital signal is decoded and stored in a buffer waiting to be sent to the speakers or headphone outputs.

9. Typically, the analog hole is exploited in two steps. First, an analog copy is created using a DAC; sometimes, but not always, this "intermediate copy" is saved, for example on videotape or cassette. Second, the analog copy is usually (but not always) converted back to digital using an ADC, which provides for the many advantages of digitally formatted information. For purposes of this discussion, both the intermediate copy and the final, digital copy will be referred to as "analog hole copies."

In other words, every conversion from digital to analog and every physical port, CRT, LCD, speaker, or wire through which an analog signal travels represents an opportunity to circumvent DRM. If a cable can be attached to a port, a video camera pointed at a CRT, or a microphone aimed at a speaker, a recording of the supposedly-protected content can be made. If the other end of the cable, video camera, or microphone happens to be attached to a computer, the unauthorized copy will be digital, suitable for high-quality and inexpensive mass duplication and redistribution over the Internet. Furthermore, unlike the arcane tools and skills required to circumvent DRM on the digital side, average consumers tend to be experienced with exploiting the analog hole, even if they don't know that's what they're doing. Consumers have been making copies from analog sources for years. The *Sony* case involved the use of videocassette recorders which were connected by consumers to analog television signals to record shows for future viewing.[10] Likewise, even average consumers (at least those born before 1990) can operate cassette recorders to copy music stored on CDs and vinyl records.

However, there is a significant limit to the uses of analog copying—signal degradation. First, each trip through an ADC or DAC degrades the signal, as information is lost in the process. For example, loss of stereo information and bass can occur, making a song sound like it is coming from inside a tin can. Distortion can also occur if the digital to analog converter supplies too much gain. Copies made using speakers and microphones may include ambient noise or distortion from the pass through the air gap.

The amount of degradation varies with the sophistication of the equipment used. For example, sophisticated reproduction equipment can be used to create relatively high-quality analog copies; large music companies use expensive and elaborate production facilities to mass-produce analog tapes. Such an operation requires a master recording specifically designed for longevity without significant degradation and special equipment to produce the tapes; however, this kind of high-quality mastering equipment and media is not generally available to the public at consumer pricing levels. This is one reason why large scale piracy by consumers in the pre-digital content age was never successful or lucrative.

In some sense, the analog hole can never truly be "plugged."[11] Those who talk about "plugging" refer to technical and legislative measures intended to make it more difficult to access and reproduce

10. *See* Sony Corp. of Am. v. Universal City Studios, Inc., 464 U.S. 417, 419 (1984).

11. *See* Felten, *supra* note 6. In other words, for video, even if every analog port on every device is sealed shut and every new video camera recognizes and refuses to record protected content, legacy video cameras will still be able to record the image.

analog signals. Developers are working on technical solutions that will embed watermarks in an analog signal that newer devices can recognize and refuse to record, including two complementary solutions known as Video Encoded Invisible Light ("VEIL") and Copy Generation Management System – Analog ("CGMS-A"). Older, less sophisticated systems such as Macrovision work a bit more crudely, essentially confusing the automatic gain control of VCRs, causing unwatchable reproductions. In addition, Congress has proposed legislation designed to mandate technologies like VEIL and CGMS-A to make the analog hole harder to exploit.[12]

There are many ways to exploit the analog hole to allow the recording of protected digital audio or video. Analog hole exploits can be separated into approaches "inside the box," which involve acquiring the signal from an internal wire, bus, or computer chip and often require advanced programming or electronics skills, and "outside the box" techniques which use external hardware, for example connecting two devices with a cable. Inside the box, signals can be captured directly from device buffers where the content is unprotected, or captured on its way to either an audio or video output device using capture hardware such as a video capture card. Although these techniques require a fair amount of skill, some software packages allow for easy inside-the-box copying. Outside the box, the content can be recorded using various analog capture devices including microphones and VCRs. The bottom line is that with the right equipment, one can sidestep DRM and reproduce the protected material with relative ease and little technical knowledge.

In fact, most standard computers, even relatively old ones, already possess all that is needed to generate a quick-and-dirty analog hole, digital copy: an audio card (with both "out" and "in" jacks) and audio file creation software packages, (available with standard operating systems). Simply run a cable from the speaker jack to the audio-in jack, push "play" on one music program and "record" on another, and you are exploiting the analog hole. There is an even more low-tech alternative—simply play the music through speakers and use a microphone attached to a recording device to copy the music as it plays. In either case, one then has the ability to produce an unlimited number of digital copies from the initial digital copy, thanks to a quick conversion to analog and back, albeit with some signal degradation.

12. *See* Digital Transition Content Security Act of 2005, H.R. 4569, 109th Cong. § 101 (proposed bill mandating use of VEIL and CGMS-A in all digital devices with analog outputs).

B. Legal Scholarship

Legal scholars have given scant attention to the analog hole. What is most often noted is the relationship between the analog hole, the DMCA, and fair use. In advocating for strict DRM anti-circumvention provisions in laws like the DMCA, content industry leaders have pointed to the analog hole as a good thing, as the safety valve protecting expression and fair use in a world without free digital copying.[13] Courts have embraced this reasoning, ruling that the analog hole provides breathing room to the DMCA necessary to preserve fair use and First Amendment rights.[14]

Several scholars have criticized this reasoning along two primary lines of attack. First, and more self-evidently valid, these claims are completely inconsistent with other claims made by the same content industries, sometimes contemporaneously, maligning the analog hole as a loophole around the DMCA that must be closed through regulation.[15] The other commonly voiced critique is that exploiting the analog hole is an imperfect safety valve for fair use and freedom of expression, because it is too costly,[16] too complicated,[17] or because of signal degradation.[18] Those raising these arguments provide no empirical support for the

13. *See* Gigi Sohn, *Don't Mess With Success: Government Technology Mandates and the Marketplace for Online Content*, 5 J. ON TELECOMM. & HIGH TECH. L. 73, 83 (2006) ("The presence of the analog hole is a common justification for greater limitations on fair use imposed by the anti-circumvention provisions of Digital Millennium Copyright Act."); Tal Z. Zarsky, *Assessing Alternative Compensation Models for Online Content Consumption*, 84 DENV. U. L. REV. 645, 661 (2006) (citing "DRM advocates" who "argue that existing loopholes in the DRM system [such as the analog hole] . . . would in fact allow users to exercise their right to fair use").

14. *See* Universal City Studios, Inc. v. Corley, 273 F.3d 429, 459 (2d Cir. 2001) (noting that the DMCA continues to allow one "to make a variety of traditional fair uses of DVD movies, such as . . . recording portions of the video images and sounds on film or tape by pointing a camera, a camcorder, or a microphone at a monitor as it displays a DVD movie"); 321 Studios v. MGM Studios, Inc., 307 F. Supp. 2d 1085, 1102 (N.D. Cal. 2004) ("[U]sers can copy DVDs, including any of the material on them that is unavailable elsewhere, by non-digital means.").

15. *See* Crawford, *supra* note 6, at 618-21.

16. Zarsky, *supra* note 13, at 662 (suggesting that the analog hole is not a suitable substitute for fair use rights because "the tools for making digital copies of analog outputs are too costly").

17. *See* Alfred C. Yen, *What Federal Gun Control Can Teach Us About the DMCA's Anti-Trafficking Provisions*, 2003 WIS. L. REV. 649, 679 (noting that exploiting the video analog hole "requires the purchase of an appropriate camera and the effort of setting up the camera so that a serviceable image can be captured"); Zarsky, *supra* note 13, at 662 (suggesting that the tools that exploit the analog hole "require a high level of sophistication").

18. *See* R. Anthony Reese, *Will Merging Access Controls and Rights Controls Undermine the Structure of Anticircumvention Law?*, 18 BERKELEY TECH. L.J. 619, 653 (2003) (arguing that analog hole techniques seem "likely as a practical matter to substantially diminish the quality and availability of such use"); Zarsky, *supra* note 13, at 662 (suggesting that exploiting the analog hole "might provide the relevant content in low quality").

claims of excessive cost, complexity and signal degradation. Instead, they tend to rely on intuition. By studying these three empirical questions—cost, complexity, and degradation—our study will give us the facts to bolster or refute these arguments.

III. ECONOMICS OF DIGITAL MUSIC AND THE COSTS OF DEGRADATION

Despite recurring claims by the content industry that analog hole exploitation will burden the market for their works, many questions must be analyzed before these claims can be assessed. Most importantly, given inevitable signal degradation, are analog hole copies truly market replacements for other, higher fidelity versions of the works? For music specifically, do analog hole copies of songs—made directly by users or downloaded from peer-to-peer networks—substitute for good-enough digital originals, such as compact discs or downloaded tracks? There are two extreme possibilities, with the likely truth somewhere in between. First, analog hole copy degradation may be so detrimental to listener enjoyment that no listener would consider an analog hole copy to be an acceptable replacement. If this is true, then the vulnerability will have no impact on the potential market for the digital originals. At the other extreme, the degradation problem may be wildly exaggerated, and analog hole copies may be good enough as not to hurt listener appreciation at all, meaning consumers will accept an analog hole copy as a perfect substitute for the digital original.

Assuming we establish that the consumer reaction to an analog hole-degraded copy falls between these two extremes, the next step is to ascertain the cost-quality relationship of these copies. If consumers are willing to tolerate analog hole-degraded copies if they are sold at a lower cost than a perfect digital copy, content owners may be able to take advantage of this tendency to price discriminate. Recent developments in the way digital music is sold provide a perfect platform to implement such a price discrimination scheme.

For digital music, an emerging business model is the pay-per-unit download, offered by services like Napster and iTunes. The music industry sells songs through these services for the price of 99¢ per download.[19] Chris Sprigman, in an article appearing earlier in this volume, provides a detailed, careful analysis of the 99¢ price point.[20] In particular, he wonders why virtually all songs are priced at this uniform price and specifically why the music industry has failed to price discriminate in setting prices for music downloads.[21] He suggests

19. *See* Chris Sprigman, *The 99¢ Question*, 5 J. ON TELECOMM. & HIGH TECH. L. 87, 88 (2006).
20. *Id.* at 90-94.
21. *Id.* at 89-90.

multiple song characteristics about which music companies could price discriminate: hit songs versus non-hits, old versus new, heavily restricted versus lightly restricted DRM.[22] Of most immediate interest is the idea of variable pricing based on audio quality.

Professor Sprigman speculates that music companies could increase sales and profits, and recapture surplus away from consumers by offering multiple versions of songs, at varying levels of quality, for varying prices.[23] "The audiophile who listens to music on his $10,000 home stereo may be willing to pay considerably more for a high-resolution digital file (which could easily offer better-than-CD-quality sound) compared with the casual listener who experiences music mostly through the cheap headphones of an iPod."[24] Despite this obvious market opportunity, he finds almost no indication of firms exploiting this form of price discrimination.[25]

Ultimately, he advances several theories for why downloads are not priced variably. Of particular interest, he considers, and apparently rejects, theories about consumer behavior.[26] These theories suggest that consumers would react unfavorably to the prospect of variable prices for different songs. For example, perhaps consumers would view the price differences to be unfair or confusing. In other words, these theories posit consumer resistance to variable pricing or, in reverse, a preference for the simplicity of the 99¢ price. It would be much easier to assess these theories if we knew more about consumer reactions to variable pricing based on quality differences.

Finally, our survey also explores the motivation of putative "pirates" of digital content. The conventional story is that pirates—those who obtain music online without paying anything for it—have become conditioned by the availability of free music against ever being willing to pay for music. In a related manner, Professor Sprigman attempts to tie the reluctance to move to variable pricing to a fear in the music industry of piracy and, in particular, peer-to-peer ("p2p") networks.[27] He speculates that if the record companies "attempt to charge too high a

22. *Id.* at 91-92.

23. *Id.* at 103.

24. *Id.* at 104.

25. Sprigman, *supra* note 19, at 104 ("While product differentiation by varying the bitrate of audio files might be a promising price discrimination strategy, we see little evidence of it.").

26. After rejecting consumer behavioral explanations, he seems instead to favor theories that involve the complex interplay between the oligarchical "Big 4" record companies, who control over 85% of music sales in the U.S., *see id.* at 95 n.12 and accompanying text, and Apple, Inc., whose iTunes Music Store dominates the industry, with approximately 83% of the U.S. market, *id.* at 95.

27. *Id.* at 115-16 ("[R]aising prices for hits above the 99¢ threshold may drive some who would otherwise be paying customers to unauthorized peer-to-peer downloading.").

price for premium content, they risk re-invigorating the p2p threat."[28] Again, this conclusion invites empirical analysis, because the interplay between the motives of those who use p2p networks to pirate copies is not well understood in the literature.

Many of these economic theories and assumptions are tested in the empirical study we describe below.[29] Measuring consumer response to quality degradation can support or refute Professor Sprigman's theories about possible price discrimination strategies for content owners. Studying the willingness to pay of putative pirates can confirm or rebut the widely-held conventional wisdom about the motives behind piracy.

IV. THE PRICE OF DIGITAL MUSIC

Can consumers perceive a difference between an original and an analog hole copy? How much is higher quality worth? At what price discount, if any, will a consumer accept lower quality? Are individuals who actively partake in digital music piracy willing to pay anything for music? Our study glimpses into the mind of the music consumer, attempting to quantify internal utility calculations in the cost/quality tradeoff. We note from the outset that our two surveys included only 70 and 90 participants, respectively, and that larger surveys should be completed to verify or refute our findings.

A. Simple DRM Circumvention with the Analog Hole

Our first goal was to assess, qualitatively and anecdotally, how difficult it is to create analog hole copies to circumvent DRM. If the analog hole is something that can be exploited only by the technically savvy user, it should perhaps be of little concern to the music industry. On the other hand, if the analog hole is easy to exploit, it supports industry claims (and refutes the contrary claims of some scholars) that it provides a meaningful safety valve for fair use and free expression in light of the DMCA. For music, we came to the latter conclusion. At least with current technology, the analog hole is very easy to exploit.

Our experiment utilized readily available software and hardware to make a copy of a digitally protected file. We created copies using two test-bed configurations, which we call the analog hole copy ("AHC") and the professional consumer copy ("PCC"). Both are outside-the-box approaches. The AHC was created by connecting the headset jack on a laptop to the audio-in jack on a desktop PC. The PCC was created by playing music out of a high-quality speaker (a home studio monitor) and

28. *Id.* at 117.

29. Although this research was completed before we knew of Professor Sprigman's work, it is a happy coincidence that these two efforts were contemporaneous with one another.

recording through a microphone across an "air gap."

For the AHC approach, setup took less than 15 minutes. Specifically, it took a few seconds to connect the laptop to the PC via a cable, less than five minutes to download and install software (called GoldWave) onto the PC, and another five minutes to install the same software onto the laptop. The most time-consuming element of this method was recording itself because the clips were simultaneously played and recorded in real time (e.g., it took thirty seconds to record a thirty-second clip). Finally, a software-based noise-reduction algorithm was applied at various levels to the captured clips using GoldWave; this final step again took only a few seconds. In total, it took about 45 to 50 seconds to record, noise reduce, and store a 30 second analog hole copy of the original music clip.

The PCC copying experiments used an Apple Mac G4 laptop with an M-Audio Mobile-Pre USB interface.[30] We played the clips out of Behreninger Truth near-field monitors and used two small diaphragm, Audio-Technica condenser microphones to record the music onto the same computer. The software used was Apple's "Logic Pro 6." This process also required only a few minutes to setup and a few minutes to create the copy.

The experiment showed that exploiting the analog hole for digitally protected music using readily available hardware and software is relatively easy, but mildly time-consuming. An individual intent on copying a large number of songs would be constrained by the amount of time it would take to record each piece of music. However, the GoldWave software has features that can speed up the recording time considerably, including double-time playback and double-time recording. We tested these settings and perceived no obvious quality difference. GoldWave also provides a batch feature which could be used to cue up a large number of songs for playback and recording. The batch copy is fairly sophisticated and could be used not only to copy, but also to apply the post-processing filters and even to place the final clip in the proper directory on the computer.

B. The Stated Preferences Surveys

We used the outputs—the analog hole copies—from our qualitative study as specimens for our surveys. The first survey was an econometric survey designed to assess what an analog hole-degraded copy of a protected digital file is worth. Thirty-second sound clips were used for the econometric survey. These were produced using the AHC and PCC

30. Professor Michael Theodore from the University of Colorado Department of Music created the PCC copies using his own equipment.

methods described above, introducing whatever degradation occurred in the ordinary course of the analog re-conversion. In other words, we took no additional steps to increase or decrease the "ordinary" level of degradation. Each respondent listened to a subset of the sound clips based on their listening preference from four music genres: alternative, country, oldies, and rock.

Through the survey, we sought to answer two questions: (1) is there a noticeable difference between the original and the copies? and (2) what is the economic value of the copies? For the first question, there was a fairly simple way to find the answer: play two snippets of the same song—one the digital original and one the post-analog re-conversion copy—for the respondent and ask which sample they preferred. The second question was more difficult to answer as it was not econometrically accurate simply to ask the respondent to provide a numerical answer. Instead, we had to extract this data in other ways.

In creating a survey, it is very easy to determine answers to questions such as, "Which do you prefer?" and "Have you ever done this?" Alternatively, the answers to "What is the value of this over that?" and "How do these aspects interact?" are far more difficult to ascertain. To answer these questions, an econometric model known as *stated preferences* was employed.[31] The main idea behind stated preferences is to ask consumers to indicate their preferences in a utility maximizing setting, or more simply, to have them indicate their preference for one option over another. By asking respondents to indicate their preferences in a series of questions, it is possible statistically to extrapolate important inferences relating the variables.

When applying this econometric method, it is important that every comparison between variables is made. This ensures that the relationships between variables are fully explored. This survey attempted to find the relationship between two variables—cost and quality—by asking people to indicate which audio clip they would rather purchase. Cost is a continuous variable (that is, there can be any value associated with it); however, using this method produces a discrete cost by limiting the number of options to two.

For example, after listening to two sound clips, labeled "Clip A" and "Clip B," the survey respondent was asked: "If Clip A cost $0.55 and Clip B cost $0.25 which do you prefer?" The survey varied both the prices and the clips, and each respondent was asked to assess every possible quality comparison available.[32]

31. *See* IAN J. BATEMAN ET AL., ECONOMIC VALUATION WITH STATED PREFERENCE TECHNIQUES: A MANUAL (2002).

32. In other words, with files containing music at three levels of sound quality–original, PCC, and AHC—there were nine possible comparisons made, including "comparisons"

Our statistical model relied on a few key themes. People make decisions to maximize their utility (personal value). Relying on this basic economic rule, statistics can be used to create various models to assign a probability to a respondent's choice. These probabilities allow determination of the respondent's evaluation of the importance of the two variables.

The survey itself was conducted using Zoomerang,[33] an Internet survey application.[34] The survey collected responses from 70 participants. Of those, 66 completed the music portion of the survey. Demographically, the respondents were either current and former graduates of the University of Colorado's Interdisciplinary Telecommunications Program or engineers and computer scientists working for a local technology firm. The respondents varied in age from 18 to 63 years; the median age was 28 and the mean age was 30.

C. Results and Analysis of the Surveys

Our analysis centered on the following two questions: (1) do consumers perceive a difference between analog hole copies and originals? and (2) at what cost will the consumer be willing to sacrifice some quality?

With respect to the first question, based on the number of times the digital original was picked as preferable to the analog hole copy, it appears that respondents preferred the original clips to the analog hole copies, but not by as wide a margin as we had originally expected. Specifically, when respondents were asked whether the clips were of the same quality or if one was of superior quality, the original was picked approximately 52% more often than the AHC and 42% more often than the PCC copies.

To answer the second question, an econometric survey using the approach described above was conducted. As discussed earlier, the model was designed to ask consumers to indicate their preferences in a utility maximizing setting. In this case, a random utility model was applied. The trade-off between cost and quality was the change in utility with respect to quality divided by the change in utility with respect to price.[35]

between identical versions. During the survey, each respondent received each one of the nine possible permutations to compare, with randomly assigned prices for each song in the pair.

33. Zoomerang, http://info.zoomerang.com (last visited Mar. 22, 2007).

34. Zoomerang was created in 1999 by MarketTools to provide online survey services that are accurate and comprehensive for minimal cost and effort. Zoomerang, About Us, http://info.zoomerang.com/company.htm (last visited Mar. 22, 2007). This program allows flexibility and originality in survey creation. One is able to choose the type of question as well as provide answer choices and randomization.

35. While the details of this econometric study are beyond the scope of the paper,

The results of the study indicate that the survey respondents place a value of 24¢ on the difference in quality between an original and an analog hole copy. In other words, for this group of respondents, there was a perceived quality difference between the original and the copies, and the respondents were willing to pay 99¢ for the original and 75¢ for the copy.

These results support the claim that the music industry should attempt to capture new market segments by releasing different quality versions of their digital content.[36] Specifically, if these results are generalizable, the market for digital copies of music could be segmented with a standard quality song retailing for 75¢ per download.[37] This price point could encourage consumers who are unwilling to pay the current 99¢ price for "superior quality" copies to purchase cheaper, "standard quality" downloads instead.

D. Will Pirates Pay for Digital Music?

In a follow-up survey, we studied the willingness to pay of so-called "pirates," which we defined as people who obtained most of their music through illegal file-sharing.[38] The goal was to determine if there was a price point at which even a pirate would abandon piracy and begin to pay for music. We surveyed 90 users of pirated music. To focus on those least likely to pay anything for music, we also required that they had not paid for any online music in the last six months. Demographically, every respondent turned out to be undergraduate or graduate student at the University of Colorado between the ages of 18 and 25.

Among this sample population, we found a bimodal distribution. Twenty percent of these individuals were not willing to pay anything for the music. However, the remaining 80% were willing to pay from 20 to 40¢ for a legal download, instead of obtaining copies from non-paid sources.[39] This is a very interesting finding and suggests that alternative

interested readers should contact douglas.sicker@colorado.edu for the details.

36. *See supra* Part III. Professor Sprigman's suggestions, discussed *supra*, about varying price with quality focused in particular in varying the bitrate (roughly speaking, the higher the sampling bitrate, the higher the quality of the track) and file format (e.g., mp3, aac, and ogg). *See* Sprigman, *supra* note 19, at 103-04.

37. iTunes already produces a lesser-quality content download.

38. The exact question we used to screen respondents was: "Would you say that most of your digital music collection was obtained through illegal file sharing? If so, please answer the following questions."

39. Interestingly, this may be an economically feasible price range. eMusic, an online service that sells downloads from independent record labels, charges $10 for 40 songs, or 25¢ per song. *See* Sprigman, *supra* note 19, at 111. Professor Sprigman finds the difference between this price and the major labels' 99¢ price to be some evidence of the exercise of market power by the majors. *Id.* If he is correct, perhaps 20¢ to 40¢ is within the range of the competitive, market-clearing price that would exist absent this market power.

pricing models might be able to capture these individuals. We also gave the respondents space to comment on why they would prefer to purchase instead of pirate. Aggregating these answers, they appear generally motivated by three things: the desire to own content legally, the convenience of being able to more easily find desired content, and the guarantee of a high-quality product. We also asked the survey respondents for their thoughts about DRM. Eighty percent indicated that were they to purchase music, they would want the flexibility to move the music onto different media players or to control and access it in various other ways.

V. CONCLUSION

Our results suggest some untested pricing methods for minimizing the impact of digital piracy. We have shown that consumers are willing to price differentiate on quality and that would-be pirates are willing to pay for content, albeit at a significantly reduced price. These results all point to lost opportunities for the music industry. Price discrimination based on quality can increase sales, profits and seller surplus. The community of pirates may be "brought back into the fold" if the 80% who are willing to pay can find a market.

We have also filled in empirical gaps in the debate over the analog hole. The analog hole can be easy to circumvent, at least for music. Furthermore, although analog hole exploits tend to lead to detectably degraded copies, many ordinary consumers will not notice the difference. This also supports industry fears that analog hole copies may serve as a market substitute for DRM-protected digital copies.

The survey sample sizes we used were not large enough to reach external validity for applying these results to the general population. Looking forward, a next step would be to execute a similar survey to the one administered for this paper but on a much larger scale. Also, tailoring surveys specific to demographics such as socio-economic, age, ethnicity, and gender could yield insightful and perhaps unexpected results.[40] Although we focused on music, similar research in copying and distributing video should be examined as well.

40. It is likely that our sample of college-aged students at the University of Colorado represents a very stratified sample.