Sidestepping DRM: A Look into the Analog Hole

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Abstract

When digital content is consumed, it must be transformed into an analog form; light from a video display for movies, images, and text, and sound waves for audio content. When the content is in this form it is no longer protected by digital protection schemes, such as Digital Rights Management (DRM), and can be recorded using an analog copy device such as a camera, audio recorder or media capture hardware (sound card or video capture card on a PC). If this recording is then digitized, it becomes an unprotected copy of the original digital content. This is known as the analog hole. Through this experiment, we will take an in depth look at the issue of exploiting the analog hole. We will create audio forms of the analog hole processed (AHP) unprotected analog/digital media. We will then use econometrics to ascertain the consumer value of the AHP unprotected media versus the original copyrighted content. Through this experiment, we hope to demonstrate ease of creating this unprotected media, explore the value of this material to consumers, and quantify the threat of unprotected media to various forms of DRM.

Introduction

Using the analog hole is an obscure, yet realistic way to copy DRM protected material. The analog hole is a method in which one can obtain originally protected material by recording the content as it is consumed [1]. When digital material is consumed, it must be converted into an analog form, where it loses any encryption or protection, such as Digital Rights Management (DRM) [1]. Consumers have been using this method for years: two of the earliest uses of analog hole were watching television and recording it for future viewing on a video cassette recorder (VCR) and converting a record to a cassette on a stereo. These methods successfully enabled a consumer to create material for personal use; however, due to the fast degradation of quality from repeated analog copying, it was difficult to distribute these copies on a large scale.

In today's digital environment, however, the copy degradation problem does not exist, as digital copies create exact duplicates of the original. Once an individual makes a copy using the analog hole, they can then produce an unlimited number of digital copies without losing additional quality. The current methods of exploiting the analog hole are largely done through a computer. For instance, one can easily copy music using line in/line-out, by retrieving the data from the audio card, or by using a microphone and speakers. The extension to copying video is also relatively simple. Both the ease of creating and copying unprotected media make it a very real and quantifiable threat to DRM.

Background

Today's digital media environment, while ripe in new technology, includes massive amounts of illegal file-sharing—the burning and illegal copying of DVDs, CDs and MP3s [4]. This has led to an uproar amongst various media producing groups. Enter: Digital Rights Management (DRM). DRM is frequently touted as a solution to this issue, as it incorporates encryption, conditional access, copy control mechanisms and media tracing and identification mechanisms to protect copyrighted content owned by businesses and corporations [5]. According to Pam Samuelson, DRM also enables electronic markets to become more efficient and maximizes the utility of digital works for the electronic community [6]. This mechanism was originally designed to inhibit hacking.

According to Haber et al., “The goal of a DRM system is to enforce licenses between a content provider and consumer that define rules about authorized use of managed content.” [12] In order to accomplish this, three types of technology are required. First, one needs hardware or software to evaluate the license. Next there must be authentication to identify the license. Finally, the license must be associated to the content [12]. The building of a DRM system is the first step. The method of protection that DRM actually uses must then be chosen. There have been many papers written on DRM systems [14], [15], [16], on the future effect of stronger DRM [12], [17], and fair use of content [18], [19], [20].

One approach to DRM involves watermarking, which is the process of embedding information or data into a different object. Researchers associated with the Watermarking World suggest that upon the completion of watermarking, three ideas must coincide in order for the mechanism to be successful. First, the watermarked content must be imperceptible, meaning that it must model the original by looking and sounding almost like it. Second, the work must be robust, in that, the watermark itself should have the ability to survive plausible forms of processing on the work that is being protected. Lastly, the watermarked content must be secure, meaning that it should not show any signs or clues that a watermark exists through un-authorized detection [8]. Watermarking does represent a defense against copying that otherwise defeats digital rights management, but with two drawbacks: first, it is difficult to design watermarks that can meet all the above requirements and survive successive digital to analog and analog to digital conversion and second, watermark must be used reactively (to attempt to identify copies and copiers after the fact) rather than proactively (to prevent copying in the first place).

Another method for digital rights management is fingerprinting. Fingerprinting is a method in which content owner information is imbedded in the file [10]. This can be used to trace the origin of content. This method was used to trace movies sent to a voting member of the Academy of Motion Pictures Arts and Sciences that ended up on the internet. This method is also reactive and not proactive.

A significant motivation of our research involves the legal and social ramifications of DRM and the analog hole. Both of these issues have frequently appeared in legal matters. One noteworthy case is the Sony Betamax Case. In the Sony Betamax case, the Universal City Studios filed suit against Sony out of fear that its new video recording technology would unlock the door for widespread copyright infringement of film productions. Although a lower court found Sony guilty of copyright infringement, the U.S. Supreme Court overturned the decision, stating that a new technology "does not constitute contributory infringement if the product is widely used for legitimate, unobjectionable purposes. Indeed, it need merely be capable of substantial non-infringing uses" [2] to be protected by law. More recently, Napster was involved in a similar case dealing with its file-sharing methods. Because Napster's MP3 technology has legitimate uses, Napster argued that it should have the same protections as Sony [2]. However, copyright infringement can occur when individuals share MP3 versions of copyrighted content over Napster's file-sharing program. In June, the US Supreme Court decided that sometimes the creators of software used to share peer-to-peer files can be held liable for copyright infringement. In the case of MGM Studios v. Grokster Ltd the Supreme Court held:

> "One who distributes a device with the object of promoting its use to infringe copyright, as shown by clear expression or other affirmative steps taken to foster infringement, going beyond mere distribution with knowledge of third-party action, is liable for the resulting acts of infringement by third parties using the device, regardless of the device's lawful uses" [3]

It was clear that Grokster gave away its software and encouraged the recipients to use the software to download copyrighted materials. This network of machines using peer-to-peer sharing software has been dubbed "the Darknet" [7] by Peter Biddle and his associates at Microsoft.

Biddle et al. use the term object when referring to content copied in circumvention of copyright and hold that the idea of the Darknet is based on the assumption that widely distributed objects will be available to users in a form that permits copying, that users copy objects if it is possible and interesting, and that users are connected by high bandwidth channels [7]. The Darknet offers a place to share content created using the analog hole.

The Darknet is the sea in which digital piracy takes place. Piracy is the unauthorized use or reproduction of content protected by copyright [12]. Copyright protection gives the content owner exclusive rights to do certain things with their content or authorize others to do so. Part of copyright law includes the idea of "fair use". Fair use is the idea that certain reasons for copying or reproducing various purposes for which the reproduction of a particular work may be considered "fair," such as criticism, comment, news reporting, teaching, scholarship, and research [13]. For the purposes of this research, we will not distinguish whether the copy actions constitute piracy, only that if an individual were intent on using the content illegally, it is not difficult to gain unauthorized control over digital content.

There are various problems with DRM that occur when the media is consumed. In order to play the content, it must go through a buffer that both decrypts the material, and converts it to an analog signal [9]. At this point, the analog media can be captured in various ways. It can be captured directly from the device buffer where the content is unprotected. The media can also be captured on its way to either an audio or video output device using capture hardware. Finally, the content can be recorded using various analog capture devices (a microphone or video recorder). Therefore, if one is capable, one can sidestep DRM and reproduce the protected material. This is where the analog hole can be exploited. One can simply produce an unprotected copy of the DRM protected audio or video by accessing and recording the media in its unprotected analog state [9].

Research Goals

For this research project we used materials which are strictly available to the average consumer such as standard PCs, and easily obtainable software.

1) *Create audio files using the analog hole.*

   We obtained protected audio examples. We then captured the media in analog form using various methods. Examples of this include recording through the line-in/line-out of an audio or video device or traditional analog recording devices.

2) *Assess the quality of the AHP.*

We conducted a comparative analysis of the original and pirated media, using a subjective test of human experience via an online survey. For this paper, only a pilot survey was conducted with 30 respondents. A new survey is forthcoming to collect more data for analysis.

3) *Determine economic value of AHP using consumer preference-based econometric experiment.*

After collection of survey data, we will conduct an analysis of the results using the stated preference model to evaluate the economic value of piracy.

Copy Methodology

We began our copying experiments by connecting the headset output from a laptop to the audio input of a PC soundcard using a 1/8" mini stereo male to male cable. We downloaded a music program called GoldWave from the internet (http://www.goldwave.com/). The shareware version of the software is free and is limited to 150 commands every time it is run and a maximum of 3000 commands total. A software license can be purchased for about $45.00 that will remove the command limitation and allow full usage of the package. The software allows easy recording from the audio in on the soundcard.

In this experiment, we used hardware and software readily available to us. If we had spent some time and money, we could have obtained higher quality sound cards, video capture cards, and more sophisticated software packages for recording and post copy processing. We recognize that the unprotected copies could be made even better by using higher end hardware and software. We chose not to use higher quality products to see what the quality of the unprotected copies would be and see what effect that would have on the survey responses from a process requiring minimal technical sophistication and cost and so within the capabilities of a large segment of the general population.

Once we had our physical connection and a software package to use, we began to record content via the analog hole. We had to adjust the output volume on the laptop and the input recording volume to achieve a copy that closely matched the original waveform as seen in the GoldWave software. Once we recorded the wave file, we then applied a light noise reduction algorithm (one of many filters included in the GoldWave software) to the file to reduce noise caused during recording. This noise, when present, is likely the result of the quality of the soundcard used, an electrically noisy environment, and the use of unshielded cable connecting laptop to PC. After capture and noise reduction we stored the Analog Hole copy in MP3 format.

The setup time for this experiment was a few seconds for connecting the laptop to the PC. It took less than 5 minutes to download and install the GoldWave software on the PC (the laptop had already been loaded with the program). The real time consuming element of this methodology is in the recording itself. Our experiment recorded thirty-second audio clips in real time. Finally applying the noise reduction algorithm takes only a few seconds and saving the file to MP3 format also takes a few seconds. In all it takes about 45 to 50 seconds to record, noise reduce, and store a thirty-second Analog Hole copy of original material. GoldWave also has a speed increase/decrease function, and it is possible to increase the speed of the recording two-fold without major quality reduction.

For our econometric survey we recorded 48 thirty-second sound clips for the survey respondents to listen to. Each respondent will listen to a subset of the sound clips based on their listening preference. The creation of the 30 second clips from the original mp3's took about 3 hours using GoldWave and generally had to restart GoldWave after 8-10 clips. Recording the analog hole sound clips took approximately 1 hour and 45 minutes in the lab. This was the actual record time plus listening and re-recording if there was any problems with the copy. During the recording process, the GoldWave software had to be restarted once because of the 150 command limitation.

Our lab experiment shows that exploiting the Analog Hole using readily available hardware and software is relatively easy, but time consuming. An individual who was intent on copying a large number of songs would be limited by the time consumption of using this method. However, the GoldWave software does have the capability of double time playback, and double time recording capability. The software also has a batch feature which could be used to cue up a large number of songs for playback. With some clever scripting on the receiving computer, this could be used to automate at least part of the copy functions.

Survey Implementation

We decided to create an econometric survey to ascertain values of unprotected audio clips and compare them to the original. The survey was done with the assistance of an already existing internet survey application entitled Zoomerang [10]. The program consists of many unique features that allow flexibility and originality in the survey one creates. We were able to choose the kind of question we wished to ask as well as provide our own answer choices and randomize them if we wished.

Using simple HTML code, we were also able to create tables within a question so that the consumer would be able to easily access the audio files. We also discovered how to use skip logic to lead the respondent to various parts of the survey that related to the answers they chose. In order to access the audio to download and listen to it, we used a secure shell file transfer client to place the sound clips on a department server (drachm.colorado.edu) and used hyperlinks in the survey to access the media. The respondents would now be able to access the audio files, play them back using their choice of programs, and complete the survey.

Some of the survey questions became complicated when dealing with issues of legality. We chose to use the terms “with permission” and “without permission” to reduce the legality bias on survey respondents. By using this wording, we hope to reduce bias induced by emotional reactions to the terms “legal” and “illegal.” Our original pilot survey contained some errors so we created a second version of the survey to improve the wording and get most of the links running correctly. The survey still needs some improvements. Future work on the survey may include increasing the number of genres available in the survey framework, increasing the number of choices available for certain questions, and increasing the number of discrete dollar fraction values available to choose for the stated preference sections. See Appendix A for a sample of the survey questions.

Econometric Analysis Methodology

The crux of the project began as three main questions dealing with our research into the analog hole.

1. *Is there a noticeable difference between the original sound clip and the analog hole copy?*
2. *What is the economic value of the analog hole copy of the sound clip?*

3. *Does the economic value of the analog hole copy change if the song is not legally obtained?*

To obtain these answers we began creating a survey. While building the survey, we realized only asked what and how much, but not why. Because of this, we added another question to answer:

4. *What is the perceived relative legality of obtaining/possessing music illegally?*

With the thesis questions defined, we looked for ways to answer these questions through the survey.

For the first question, there is a fairly simple way to find the answer: give the respondent both samples, and ask which sample they prefer. To better answer the last question, it was broken into a few different issues:

a) the relative legality of illegal music.

b) other related behaviors demonstrated by the respondent.

c) other related behaviors demonstrated by both the respondent's parents and cohorts.

With these issues in mind, we asked two types of questions: yes or no questions about their own, their parents' and their cohorts' previous, related behaviors; and questions to determine if a specific music collection is more or less legal than various other crimes. The second and third questions are more difficult to answer, as it is not econometrically accurate to simply ask the respondent to provide a numerical answer. Instead, one must extract this data in other ways.

Stated Preference Model

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 does these aspects interact?” are far more difficult to find.

To answer these questions, we employed an econometric model known as stated preferences. The main idea behind stated preferences is to ask consumers to indicate their preferences in a utility maximizing setting (more simply, to indicate their preference of one option over another). By asking respondents to indicate their preferences in a series of questions, it is possible to statistically extrapolate important inferences about the variables we seek.

In this method, there are two integral parts: the questions and the statistical model. When trying to apply this econometric method, it is important that every comparison between variables is made. This ensures that the relationships between variables are fully explored. In our survey, we attempted to find the relationship between three variables—cost, quality, and legality—by asking people to indicate which audio clip they would rather purchase. Cost is generally a continuous variable (that is, there can be any value associated with it); however, in this method we create a discrete cost by limiting the number of options to three. Additionally, both quality (analog hole processed (AHP) or original) and legality (legal or not legal) are discrete as well. To compare each of these possibilities, there are a minimum of 3*2*2 = 12 comparisons that must be made for the questions to be valid. (See appendix A for more details.)

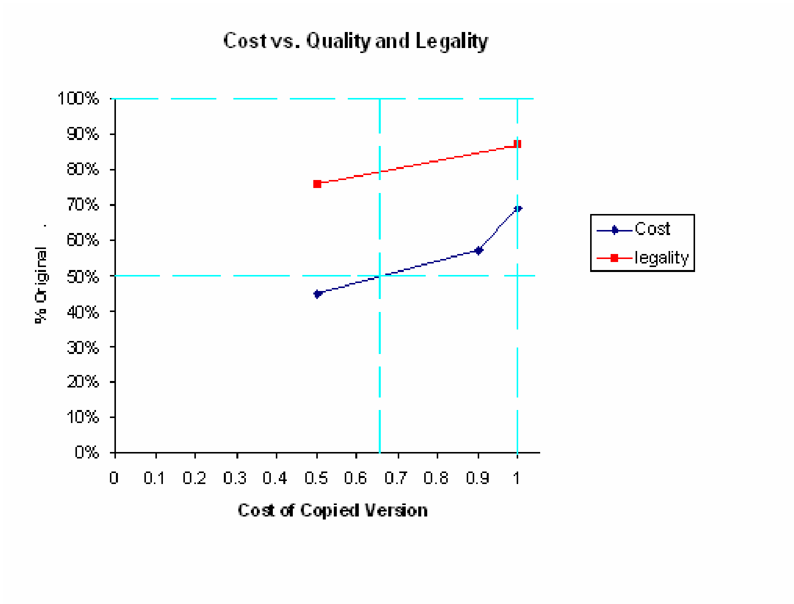
The other main aspect is the statistical model, which relies on a few key themes. First and foremost, people make decisions to maximize their utility (personal value). This rule of economics allows us to create this type of model. Given that every respondent makes decisions to maximize their utility, statistics can be used to create various models to assign a probability to a respondent's choice. These probabilities will then allow us to determine the respondent's evaluation of the importance of the three variables. With this known, we can finally determine the two questions that we set out to discover: "What is the value of the analog hole copy?" and "Does the value of the analog hole copy change if the song is not legally obtained?" (For a more mathematical description of this process, see Appendix B).

RESULTS

In our study, we set out to examine the value of AHP music, with special emphasis on the impact of legality on that valuation. Based on the results from the survey pilot, we are able to conclude a few things. Prior to the survey, we felt that it was very difficult to distinguish the AHP clips from the original clips. However, basic hypothesis testing on our data shows that people are 69 $\pm$ 13% likely to choose the original media over the analog hole processed (with 95% confidence rating). Additionally, we found that the consumer is indifferent between purchasing the AHP clip at 65 cents and the original clip at $1. Both of these findings go against our original hypothesis that people would be indifferent to the two samples at equal pricing. However, our findings still give substantial value to analog hole processed media.

It is interesting to note, that those respondents who indicated that they "had a good ear," were less likely to select the original sample over the AHP clip, than those who did not "have a good ear."

Additionally, we found that the respondents place a very high value on legality. Respondents were anywhere from 18% to 30% more likely to choose the original, "with permission" clip when it was compared to the AHP "without permission clip," then when it was compared to the AHP "with permission" clip.

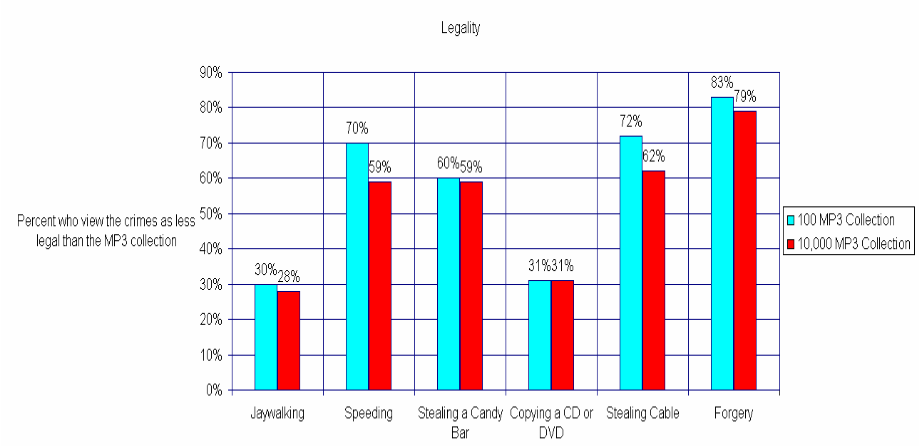


The red data points represent the percentage of people who picked the original sound clips over the analog hole copies based on legality.

The blue data points represent the percentage of people who picked the original sound clips over the analog hole copies based on cost.

Furthermore, those respondents that indicated that they used an illegal downloading service were more than four times as likely to select a "without permission" song as those who did not use an illegal downloading service. This trend continued for those who indicated that $1 was not a fair value to a song as they were over five times as likely to select the "without permission" song. The intersection of these two populations was over seven times more likely to choose the "without permission" over those who did not use illegal downloading services and felt that $1 was a fair value for a song.

Respondents also had interesting views of the legality of having illegal music.



The percentage of respondents who view crimes as less legal than a 100 and 10,000 MP3 collection

Our preliminary data suggests that respondents have a slighted view about the legality of music. For instance, 59% of respondents felt that stealing a candy bar is more illegal than having a collection of 10,000 MP3s, and about half of the respondents felt that stealing cable is more illegal than the same collection. A result that intrigued us was the fact that we expected the results to be monotonic—that is, we ordered each crime in what we felt was a progressive order of illegalness, so we felt that a linear representation would be increasing. This was obviously not the case.

Conclusions

The analog hole is a useable method that can circumvent many Digital Rights Management schemes. Using easily obtainable hardware and software, we set out to exploit the analog hole and determine if it has any value. To this end we formulated four research questions for which we hoped to find answers. Based on the pilot survey we have discovered some interesting answers to our questions.

At this point we have only done a pilot survey with 30 respondents. The conclusions reached here only describe the surveyed population and a larger sample survey will have to be conducted to gain insight into the population at large. We have used some basic inferential statistics to draw conclusions. In the future, we hope to do some more sophisticated analysis using stated preference to quantify the value of unprotected content.

Our first research question was used to determine whether the analog hole processed (AHP) copy would be significantly different or degraded from the original. Our original hypothesis was that there would be no notable difference between the original and AHP copy. The results of our pilot survey showed that our hypothesis was incorrect. The results show that 69% of respondents were able to tell a difference and picked the original over the AHP copy. Using inferential statistics, we calculated the confidence interval of 95% that the mean value is in fact 69 ± 13%.

Next we wanted to determine if there was an economic value related with the analog hole copy of the sound clip. Based on survey responses we believe that there is an economic value to the analog hole copy and that value is not zero. Based on our data, we can conclude that the approximate value of the media is 65 cents. This is the cost where respondents are indifferent between the AHP clip and the original clip.

Now that we have determined there is an economic value to the AHP copy, we want to determine if that value changes when the clip was known to be copied without permission. The respondents of our survey showed a significant change in the value of the AHP clip if the song is not legally obtained. Their responses landed anywhere from an 18-30% difference selecting the original over the AHP clip.

Finally we attempt to discover the relative legality of obtaining and possessing copyrighted content without permission. Our results show that consumers do not view possessing illegal MP3s as a major offense. 59% of the people thought that stealing a candy bar was worse than having an illegal collection 10,000 MP3s, and 28% of people thought that jaywalking was worse than the same collection. Even though the respondents put a premium on the legality of the AHP copies, it appears that the surveyed population does not feel that obtaining and possessing copyrighted materials constitutes a severely illegal act.

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Appendix A

To create the needed questions, we first construct the sets of alternatives with various parameters spanning the parameter space:

Genre g in {1, 2, …m}

Audio clip Cg in {1, 2, …Ng} for each genre g.

Attribute quality in {original, analog hole processed (AHP)}

Attribute legality in {copied with approval of music provider, copied without approval of music provider}

Attribute cost in {$0.50, $1, $1.50}

From this, we created a list of twelve different parameter combinations (A, B…L) with the original acting as a standard, and the AHP having variations in price, permission, and placement (first or second).

A

Original	AHP
$1	$.50
With Permission	With Permission

B

Original	AHP
$1	$.50
With Permission	Without Permission

C

Original	AHP
$1	$1.00
With Permission	With Permission

D

Original	AHP
$1	$1.00
With Permission	Without Permission

E

Original	AHP
$1	$1.50
With Permission	With Permission

F

Original	AHP
$1	$1.50
With Permission	Without Permission

G

AHP	Original
$.50	$1
With Permission	With Permission

H

AHP	Original
$.50	$1
Without Permission	With Permission

I

AHP	Original
$1.00	$1
With Permission	With Permission

J

AHP	Original
$1.00	$1
Without Permission	With Permission

K

AHP	Original
$1.50	$1
With Permission	With Permission

L

AHP	Original
$1.50	$1
Without Permission	With Permission

With this list of parameters, a random series of numbers (from one to twelve) is created for each genre, so the respondent is asked all twelve combinations in a random order. Additionally, to ensure that varying responses are not due to the actual song selected, but due to changes in quality from the conversion process, we created a permutation to apply to the random series of numbers that varies every parameter combination for each song. (Thus, if song one was originally assigned to combination G, it was now assigned to either D or F). Finally, for each genre, the respondent was randomly assigned (based on their birth-month) to the original or permuted order of questions.

Appendix B

According to economic theory, consumers maximize their utility whenever a choice is made. In our case, the respondent maximizes their utility between Clip A and Clip B according to the parameters in the parameter space. A linear approximation of the consumer's utility function is:

$$U = \mathrm{B}_1 COST + \mathrm{B}_2 QUALITY + \mathrm{B}_3 LEGALITY + \varepsilon$$

Where *U* is utility, $\mathrm{B}_1 \ldots \mathrm{B}_3$ are the parameters being estimated, and ε is the random disturbance.

To estimate these values of B, let the utility for each parameter be equal to:

$$U_{rq}^{c} = \mathrm{B}' x_{rq}^{c} + \varepsilon_{rq}^{c}$$

Where U_{rq}^{c} is equal to the utility of the alternative *c* chosen by the respondent *r* for a question *q*, *x'* is the vector space of the parameters, and ε is the disturbance in the evaluation of utility that is assumed to be an independent and identically distributed mean zero normal random variable, uncorrelated with x_{rq}^{c}, with constant variance σ_{ε}^{2}.

Since the respondent maximizes utility with each comparison made, the probability of choosing Clip A over Clip B is:

$$P_{rq}^{A} = P(\mathrm{B}' x_{rq}^{A} + \varepsilon_{rq}^{A} > \mathrm{B}' x_{rq}^{B} + \varepsilon_{rq}^{B})$$
$$P_{rq}^{A} = P(\varepsilon_{rq}^{B} - \varepsilon_{rq}^{A} < -\mathrm{B}'(x_{rq}^{B} - x_{rq}^{A})$$
$$P_{rq}^{A} = \Phi(-\mathrm{B}'(x_{rq}^{B} - x_{rq}^{A}) \Big/ \sqrt{2\sigma_{\varepsilon}}$$

where Φ is the univariate standard normal distribution function (that is, a standardized distribution function), and $\sqrt{2\sigma_{\varepsilon}}$ is the standard deviation of $\varepsilon_{rq}^{B} - \varepsilon_{rq}^{A}$ (or the standard deviation of the difference in disturbances).

These probabilities are measured by the pair (respondent/question). Since each probability is independent, the total probability *L* (that is, the likelihood of Clip A being chosen) is the product of each individual probability:

$$L^{A/B} = \prod_{r=1}^{r} \prod_{q=1}^{q} P_{rq}^{A/B}$$

This is difficult to calculate. To simplify, take the log of each side. This leaves the log likelihood (which, by the properties of the logarithmic function, has corresponding maximums and minimums to the original likelihood function):

$$\log(L^{A/B}) = \log(\prod_{r=1}^{r} \prod_{q=1}^{q} P_{rq}^{A/B})$$

$$\log(L^{A/B}) = \sum_{r=1}^{r} \sum_{q=1}^{q} \log(P_{rq}^{A/B})$$

Further information about the stated preference model will be included in the final version of the paper.

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