Music consumption decisions with non-durable streaming options*

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Abstract

Consumers are increasingly purchasing non-durable music products, consumed through a streaming bundle delivered via a subscription model. In this paper we examine how individual preferences influence a consumer's music format decision. We analyze consumption differences between durable retail music products and non-durable streaming music subscription bundles. A consumer's preferred format depends on the intensity of their music interests, scope of interests, and how quickly a song's utility depreciates. Our theoretical model indicates that consumers prefer a non-durable subscription over a durable purchase of information goods when they have higher depreciation rates or a greater scope of music interests. We identify conditions where users will benefit from retail purchases over streaming formats, as well as conditions where both formats will be utilized. With empirical evidence of depreciation as a guide, we employ a simulation to identify a consumer's ideal consumption format based on her individual listening preferences.

JEL Classification: D11, D12, L82, D83, L15
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1 Introduction

The decline and displacement of physical music has been obvious since the emergence of digital formats in the early 2000s. The decline in album sales was initially blamed on piracy, with the empirical evidence proving inconclusive (Liebowitz, 2004; Waldman and Novos, 2016). More recently, digital sales of both albums and singles have begun to experience a similarly dramatic decline.[1] Early research seems to indicate that the more recent digital sales decline is likely, at least in part, due to streaming music displacement. While the causal link may not be definite, there is no question that fewer consumers are purchasing durable music options (physical and digital) and more consumers are subscribing to non-durable streaming services. The future of durable music is unclear as streaming music could become the preferred format of the future, with durable music limited to consumers with specific listening habits. Determining the degree of transition from durable to non-durable options is important as any shift in music would inevitably extend to other information goods.

Streaming services refer to on-demand subscriptions with digital delivery, which allow consumers to freely choose any song from the service's bundle at any time.[2] Streaming delivery adds substantially to a consumer's choice set in music, providing a subscription with a vast bundle of song options for a monthly fee.[3] Prior to the advent of streaming services, consumers would need to purchase each of the albums or songs they wanted to consume individually to obtain the same array of music on-demand; streaming music allows access to a large library without ownership. The tradeoff for the consumer is impermanence, when the subscription ends access to the library of music also ends, while a durable physical or digital format can be used indefinitely. Unlike traditional music

[1] See https://www.riaa.com/wp-content/uploads/2018/03/RIAA-Year-End-2017-News-and-Notes.pdf. Accessed: 09/05/2018.

[2] This differs from internet radio stations, which provide playlists based on an initial selection of genre or song. This passive choice acts much like a digital form of a traditional radio station.

[3] Several streaming music services also offer an advertising supported tier, we assume the fee model in discussion but the advertising model could be substituted.

options, the consumer that chooses streaming music is subject to an ongoing payment for as long as she wants to listen to the streaming bundle.

To compare music formats available to users, we develop a model of consumption to explain any shift in consumption. We identify consumer idiosyncratic preferences that determine an optimal format. The difference in options means that contemporary music consumers must consider several factors beyond price when deciding which to use. The infrequent music consumer is not likely to purchase a subscription when a less expensive purchase is sufficient. Alternatively, a streaming subscription allows frequent consumers to access their favorite songs, while also providing access to newly released songs users may have recently identified and enjoyed.[4] In some cases, a source preference may heavily influence the choice, where the quality of durable music or convenience of streaming will be a deciding factor. A subscription format has other features that can affect consumer decisions. A streaming subscription incorporates a platform for users to easily organize music, make playlists, provides lyrics, among other advantages.

We hypothesize that the larger set of music available to consumers from streaming platforms encourages consumers to increase their consumption set. Streaming will always be a better format choice for users who focus on new music or have an expansive taste in music. On the other hand, users with specialized or selective preferences receive greater utility from purchases relative to streaming and consumers with rigid preferences that currently own all of the music they consider relevant are unlikely to benefit from switching to streaming in the future.

Beyond the possibility for an expanded library, this paper also explores the decline in usage of a song. It may be true that consumers prefer familiarity in songs (Ward et al., 2014), indicating that song utility will increase with repeated plays up to a certain point. However, most songs reach a threshold where utility begins to decline in repeated

[4]The streaming subscription may facilitate sampling of new songs, but many free methods exists to sample new music including radio, YouTube, artists websites, etc.

consumption and value depreciates.[5] While this seems intuitively obvious, it can be more difficult to prove empirically. A greater rate and more turnover in tastes would imply less value of owning music, making streaming a more valuable alternative.

We perform an empirical analysis that utilizes aggregate digital song sales, radio usage, and streaming music data to examine the rate of decline in utility of new music. We find that stark differences exist in the decline in usage between retail and streaming formats, providing insights into the expansion of the streaming market in the United States, and a range of plausible values for our simulation of individual music consumers. As a direct measure of the decline in song value for consumers using traditional methods of distribution, we use the rate of decline in radio airplay. Given streaming and radio data, we show that a majority of songs reach a peak usage and decline relative to other options thereafter, indicating falling utility for the average user. A decrease in song utility is not obvious from declining sales, as any decline does not necessarily indicate a decrease in consumption of that music. We use sales data only as a gauge of the rate of decline in sales before and after the advent of what we call the streaming era, the period from 2011 onward. We contrast each of these results with the decline in consumption associated with streaming music.

Our results indicate that songs using streaming distribution decline more rapidly from their peak than experienced in radio. We consider this to be observational evidence of a difference in average consumption of popular songs by format. This may be due to the type of consumers using streaming services or the services changing habits, we cannot distinguish the difference, but we can see that aggregate depreciation declines faster under streaming music. We use the range of plausible aggregate depreciation levels to simulate consumer choice. This allows us to identify an individual consumer's optimal consumption method as a function of different depreciation rates, interests, and scope. We also find that sales decline at a slower rate in the streaming era than the period

[5] We define depreciation as the decline in usage of a song due to the combined effect of the consumer discounting the song over time and substituting alternative songs as they enter the choice set.

immediately before. Additionally, radio listens decline slower in the same period. Music is an extremely popular example, but this analysis applies with appropriate changes to any information good that may be distributed in a durable and non-durable form.

2 Background

The music industry in the United States is increasingly dependent on streaming music for recorded music revenue. Beginning in 2015, streaming represented the single largest source of revenue for the music industry in the United States, reaching 34.3% of revenue (compared to 34% from digital download, 28.8% from physical sales), up from 7% in 2010. In 2017 that trend accelerated, with streaming accounting for 65% of total revenues. Despite declining sales of durable products in this period, revenue from recorded music increased, due primarily to the expansion of streaming music. Subscription revenue from music streaming services rose dramatically during this time, increasing from $0.77 to $4.1 billion from 2014 to 2017. Ad supported revenue increased over this period as well, reaching $658 million in 2017.[6]

While streaming has grown substantially, revenue from digital downloads and physical sales have declined in recent years, with 2017 marking the largest percentage decrease relative to peak sales to date. Every major streaming service now offers a premium version of their product, where consumers pay a monthly subscription fee for high quality, commercial-free music. Streaming provides an alternative method of music consumption that allows consumers to avoid purchasing retail versions of music, while also providing access to additional music consumers might not otherwise be willing to purchase. Some major streaming music platforms, like the on-demand company Spotify and internet radio company Pandora, also offer an ad-supported free tier. However, free or ad-supported versions have advertisements and often limit what music the listener can

[6] All preceding statistics are from the RIAA, see https://www.riaa.com/wp-content/uploads/2018/03/RIAA-Year-End-2017-News-and-Notes.pdf. Accessed: 09/05/2018.

consume, whereas premium services let consumers select specific songs. The subscription tier also generates more revenue per user and more total revenue than the advertising supported tier, and for that reason we focus on subscription services in this paper. Our objective is to examine how a consumer's demand for specific songs affects their benefits from streaming and retail formats.

Several papers have considered how consumer behavior has changed with the option to purchase durable digital music, from periods when only physical media options were available. Elberse (2010) considers the unbundling of music with the option of digital singles. Koh et al. (2015) and Lao and Nguyen (2016) perform analyses similar to what we employ in this paper, applying a similar methodology to the music formats predating streaming music. Previous findings show that digital options affect diffusion of music and attrition rates (Koh et al., 2015). These options change the actual popularity of music, allowing more popular musicians to crowd the top charts and creating short lived successes in the song market (Lao and Nguyen, 2016). They test whether new formats such as cassettes and CDs affected survival of albums on top selling charts. Research on piracy shows that other factors, such as willingness to pay (Cremer and Pestieau, 2009) or source preference (Chang and Walter, 2015), may influence consumers' format decisions.

Music research has recently turned to analyzing streaming music. The "freemium" model common among streaming services such as Spotify has been considered by Thomes (2013). Sinclair and Green (2016) use consumer interviews to generate a qualitative analysis of the types of consumers that stream and pirate music, creating consumer types of streaming users that would add to or displace legitimate music consumers.[7] Analysis of producer incentives resulting from a streaming music environment show that a dominant streaming music industry encourages producers to focus on emphasizing singles (Hiller and Walter, 2018a).

Other papers have considered whether the streaming industry has added to the total

[7] We use "stream" as a verb and "streams" as a noun indicating the number of streams, depending on context.

recorded music market or simply displaced durable sales. Hiller (2016) exploits a natural experiment in the YouTube streaming market to find a significant reduction in album sales from streaming music. Kretschmer and Peukert (2014) use a YouTube dispute in Germany to show that new artists benefit more from music video availability. Aguiar and Waldfogel (2017) consider whether the Spotify streaming service affects consumption of popular songs, where song level analysis yields displacement of music sales. Belleflamme (2016) argues that the increasing power of streaming sites as intermediaries necessitates a change in the modeling of information goods.

3 A model of music consumption

While the medium used to consume music is relevant to a consumer's decision, our analysis focuses on the effect of the number of new products consumed and the rate of decline in utility associated with purchasing each format.[8] We begin with a simple analysis to examine format discrepancies, which we expand by including a finite number of songs to identify additional discrepancies between each format. This approach allows us to identify how consumer preferences influence a formats decision when an individual song's utility is dynamic.

3.1 A single song

To begin our analysis, we assume the highly simplified but useful scenario of a single song being available for consumption. An individual consumer must decide between two consumption formats: a non-durable streaming subscription or durable retail purchase. The subscription must be renewed to continue access while the durable purchase is assumed available indefinitely. We also assume that marginal utility from the song will eventually

[8]The model is agnostic to the device on which music is played, considering instead to focus on streaming music versus durable digital music.

fall with increased consumption. Therefore, consumer i purchases song x if net utility is positive, or more specifically:

$$u_i(x) \int_0^{T_r} e^{-\xi_{ir}t} dt - P_r > 0 \tag{1}$$

Where $u_i(x)$ represents the consumer i's maximum utility from song x, ξ_{ir} represents a consumer's depreciation rate of the song's utility over time while using the retail format.[9] P_r represents the price of a durable purchase of song x and T_r represents the amount of time a consumer utilizes the retail version of the song (i.e. $e^{-\xi_{ir}T_r} = 0$). In order for the consumer to purchase the song utility must satisfy: $u_i(x) \int_0^{T_r} e^{-\xi_{ir}t} dt > P_r$. The consumer will continue to listen to a purchased song until period T_r, since $u_i(x) e^{-\xi_{ir}T_r} = 0$.

Streaming subscriptions have additional features that factor into a consumer's utility. Specifically, the payment and platform structure for a subscription service are significantly different from retail formats (physical or digital). Let F_j represent the per-period benefit or cost of utilizing j songs on a streaming platform, which we assume is time invariant.[10] The value of the platform will also depend on the size of the consumer's catalog, and include the inconvenience of requiring an internet connection, but also the benefits of organizing songs and discovering related songs. A consumer that purchases a one-period streaming music subscription for a single song receives utility:

$$u_i(x) \int_0^{1} e^{-\xi_{ir}t} dt + F_1 - P_s \tag{2}$$

[9]We represent depreciation purely as a function of time, however, depreciation may also be a result of repeated listens, or take other forms. We use time as a proxy for these. If a consumer's listening habits are consistent over time then the depreciation rate is equivalent in both scenarios. Later in our analysis, we show that the depreciation rate yields the rate at which songs in a consumer's consumption set are replaced. In terms of a user's optimal consumption format, the rate of song replacement is more important than specifying the exact form of depreciation, therefore we focus on the average depreciation rate.

[10]We describe platform structure as either a benefit or cost because of the additional properties of streaming music. As digital music players are ubiquitous we assume any additional benefit (or cost) is incorporated into the product itself. One important benefit for some users of streaming subscription is the ability to make playlists, for these users F_j has greater value.

where P_s represents the price per period for a streaming subscription.

Our objective is to compare the value of a non-durable subscription option relative to a durable retail version, however, multiple streaming options exist and include ad-supported streaming. We begin by briefly examining scenarios where ad-supported streaming options are relevant alternative for users. Consumers accessing ad-supported streaming receive utility: $(u_i(x) - L_i(x)P_A)\int_0^1 e^{-\xi_{is}t}dt + F_1 > 0$, where $L_i(x)$ is function mapping song x into the number of listens by user i and P_A is the ad-supported "price" or more appropriately the user's dis-utility from watching an ad. In the case of unknown songs, we assume that users expects the number of listens to be one.[11]

If a consumer decides to purchase a one-period subscription to listen to the song, her utility is $u_i(x)\int_0^1 e^{-\xi_{is}t}dt + F_1 - P_s$. If the consumer purchases a subscription for multiple periods, then the stream of utility from a subscription is

$$u_i(x)\int_0^{T_s} e^{-\xi_{is}t}dt + T_s(F_1 - P_s) \tag{3}$$

where T_s represents the length of time a consumer keeps the streaming subscription. In the single song case, the subscription length (T_s) satisfies $u_i(x)\, e^{-\xi_i T_s} + F_1 - P_s = 0$. Or equivalently, the consumer maintains their subscription until the utility from the song is equal to or less than the cost of the service. Similarly, the utility from advertising supported streaming is:

$$(u_i(x) - L_i(x)P_A)\int_0^{T_s} e^{-\xi_{is}t}dt + T_s(F_1) \tag{4}$$

For now, we assume that the depreciation rate for a user $(\xi_{ir} = \xi_{is} = \xi_i)$ is uniform across formats.[12] Generally, we expect that $P_s > P_A$ and $P_r > P_A$. Streaming users

[11] By "unknown" we mean the user has no prior knowledge about the song or artist.

[12] For a rational consumer, future purchases are discounted by the real interest rate. However, the price of a streaming subscription could also change in future time periods, therefore if we assume the price of a streaming music subscription will increase at the same rate, implying that $\int_0^{T_s}[F_1 - (P_s e^{rt})e^{-rt}]\,dt = T_s(F_1 - P_s)$, where r is the monetary discount rate of future purchases. Then the consumer's optimization

will select the ad-supported version if $L_i(x)P_A < P_s$. Furthermore, a user prefers a streaming subscription, relative to purchasing, if a song's utility is sufficiently high (thus yielding many listens, $L_i(x) \gg 0$). Next, we conduct several comparisons across formats. For brevity, we state the results. Proofs and discussion are provided in the relevant appendix.

Comparing the value of ad-supported streaming relative to the retail option, yields the following observation:[13]

Proposition 1 *In the single song case, a user prefers ad-supported streaming (relative to purchasing or a streaming subscription) if the utility from a song is sufficiently low.*

Identifying the ideal format for any consumer requires comparing equations 1 and 2, and finding the sign of the following expression:

$$u_i(x)\int_0^{T_r} e^{-\xi_i t}dt - u_i(x)\int_0^{T_s} e^{-\xi_i t}dt - T_s(F_1 - P_s) - P_r \tag{5}$$

Where a positive value means the consumer should purchase the song, and a negative value implies the consumer should utilize the streaming option. To simplify our evaluation of each option, we make two assumptions. First, we examine the utility received in the last period of each format. Accessing the music is the main attraction to a streaming service, not the interaction or management with the actual platform. Therefore we assume that $P_s - F_1 < 0$.[14] Further examination allows us to conclude the following:[15]

Remark 2 *In the single song case, if $u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt > P_r + T_s(F_1 - P_s)$ then consumers are better off purchasing, ceteris paribus.*

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problem for a subscription can be rewritten as: $\int_0^{T_s}\left[u_i(x)e^{-\xi_i t} + F_1 - P_s\right]dt$ or $u_i(x)\int_0^{T_s} e^{-\xi_i t}dt + T_s(F_1 - P_s)$. Similarly, we assume ads remain equally annoying over time.

[13]Proof and further discussion is provided in Appendix 1.

[14]It is unlikely that $P_s - F_1 > 0$, which implies that the benefits from using the platform is sufficient to maintain a subscription even if the user isn't listening to any music.

[15]Proof and further discussion of Remark 2 is provided in Appendix 2

Remark 3 *In the single song case, a consumer will never purchase a song if they have previously used a subscription service to stream the song, ceteris paribus.*

Examining the change from retail to streaming in the case of only one song may seem trivial, but it suggests that users with large catalogs of music (and no interest in new music) may be unlikely to switch to streaming formats.[16] A zero marginal cost of listening to an already purchased song means that the consumer has no reason to switch. While subscription features are insufficient to influence consumers to start a subscription after purchasing a song, these features may be relevant when multiple songs are considered.

3.2 Bundle value

The previous analysis considering how subscription pricing impacts consumer utility omitted an important aspect of a subscription service, bundled access. Users with a streaming subscription gain access to all songs on a platform, and can easily substitute songs in their bundle, therefore the utility from a song is eroded over time and replaced with the introduction of new music.

To represent this scenario, we assume N songs exist when the user is making a format decision, which the consumer then indexes according to her utility, such that for songs x_j and x_k the consumer's utility satisfies: $u_i(x_j) > u_i(x_k)$, whenever $j < k$. Due to the low-cost availability of sampling, we assume consumers can identify and rank the available songs. For notational simplicity, we denote the group of songs chosen by the user i with a capital letter X and subscript k to denote a subset representing all songs from 1 to k ($k \ll N$), or equivalently, $X_{ik} = [x_1, x_2, ...x_k]$.[17] Without loss of generality, we assume that the group of songs represents the consumer's initial consumption set.[18]

[16] Proof and further discussion of Remark 3 is provided in Appendix 3.

[17] This implies that the song x_1 yields the greatest utility of all songs in the consumer's consumption set.

[18] Our focus is how usage of songs differ by format and over time, but the set examined need not be the initial set of songs selected by the user.

First we consider a consumer who purchases retail music. Her initial consumption set is determined by the following utility optimization problem:

$$\max_{R} \; u_i\left(X_{iR}\right) \int_0^{T_r} e^{-\rho_{im} t} dt - RP_r \tag{6}$$

Where X_{iR} represents the R songs purchased by the user or the retail consumption set, and ρ_{im} represents a consumer's depreciation rate of the song's utility when consumed with format of type m ($m \in [r, s]$). For the retail consumer the consumption set could change in later periods if the consumer purchases new songs, while maintaining already purchased songs that do not provide the highest utility. Therefore, the relative utility from a specific song is influenced by the availability of new music. For example, an older more "played-out" song that has lost most of its utility, but is already purchased, may still be consumed even though a currently higher utility song (with utility that never exceeded the retail price) is available for purchase.[19]

Similar to the retail case, a consumer subscribing to a streaming platform would examine her consumption based on songs available. However, with streaming she has access to the entire platform's bundle, and her set will be the optimal subset of the bundle. As access to new music has no marginal cost a user will optimize her streaming consumption set when new music becomes accessible through the service. Therefore, the relative utility provided from a song is influenced by the availability of other music. Let X_{iS} denote the streaming consumption set, or the initial number of songs accessed by the consumer. Our interest is in the sum of utility from specific songs, so without loss of generality our analysis will focus on this initial consumption set.

Because the consumer purchases access to the entire streaming bundle, consumption of new songs occurs regularly. The costless addition of new songs ensures that a consumer's streaming set is always comprised of only the highest utility songs. The addition of new songs also causes substitution as $u_i(X_{iS-\{y\}}) + u_i(x_y) > u_i(X_{iS})$, where y denotes

[19] We assume a constant price for durable song sales.

an arbitrary song from the consumption set. To state formally, the addition of a song to the consumer's set displaces some utility received from other songs in the set.[20] An added song does not need to be the most preferred song in the consumption set for a consumer to reduce listens of other songs.[21] Overall, the inclusion of song y causes the consumer's net utility from the consumption set to increase.[22]

Incorporating the substitution and discount rate, we can obtain the overall decline of consumption for the initial streaming set as:

$$\max_{S} \; u_i\left(X_{iS}\right) \int_0^{T_s} e^{-(\rho_{is})t} dt - T_s\left(P_s - F_S\right) \tag{7}$$

Where ρ_{is} represents the consumer's depreciation rate on the streaming format which includes that rate at which consumers churn different songs into their consumption set. Therefore, on the streaming platform the consumer's depreciation rate is likely larger than with retail, or equivalently, $\rho_{is} \geq \rho_{ir}$. T_s represents the last period the consumer subscribes to a streaming platform.[23] Our focus is the connection between utility from songs and a consumer's preferred format. A consumer's utility from a specific song represents the additional benefit received relative to passive music consumption available from the format requiring the least effort. Therefore, focusing solely on a song's value requires assuming that $F_S = 0$.

[20] This is similar to adding a new product option to a budget constraint. In this case we are examining the listens of songs, so the consumer's time is the constraint, not their income.

[21] The substitution rate is referring to transferring some (but not all) listens of other songs to a new song, and is equivalent to an alternative allocation with the same time budget due to the introduction of a new song.

[22] It is possible that $u_{is}\left(X_{iS-\{y\}}\right) + u_i\left(x_y\right) = u_i\left(X_{iS}\right)$, this just implies that users increase their listening time solely to accommodate listens of the new song.

[23] Unlike the previous case, the consumer may stop using a song before the end of her subscription.

4 Consumption decision

In this section we consider the characteristics that attract consumers to streaming services: access to new music (price per song), broader song access (scope), platform features, or discounting. While external factors can also affect consumption, we focus on how consumer preferences influence their music format choices. In our empirical analysis we find plausible values for the decline in consumption of songs, and how the rate of decline differs by format. We then use the optimal choice framework with those values to simulate individual utility from streaming versus purchases, and estimate the thresholds of music consumption necessary for consumers to change format under a variety of preferences.

4.1 Comparing Formats

Three options exist for active legal consumption of any songs: make only retail purchases, use only a streaming subscriptions, or use of both formats. We assume that consumers are familiar with their listening habits and recognize their desire to access new music when making the initial format decision, however, we assume users are unable to identify how songs will be replaced in the future, but have a uniform depreciation rate across formats ($\rho_{is} = \rho_{ir} = \rho_i$).[24] We first examine a consumer that is only considering a streaming music subscription, optimizing her utility requires solving:

$$\max_{S} \; u_i\left(X_{iS}\right)\int_0^{T_s} e^{-\rho_i t}dt + \sum_{i=1}^{M} E(y_{it}) + T_s(F_S - P_s) \tag{8}$$

where M is the expected number of future songs with value to the user.[25] $\sum_{i=1}^{M} E(y_{it})$ (or simply, $E(Y_i)$) represents the total expected net value for the set of songs that will

[24] This assumption means that consumers expect new music to increase their listening, equivalently: $u_i\left(X_{iS-\{y\}}\right) + u_i\left(x_y\right) = u_i\left(X_{iS}\right)$

[25] The typical consumer does not know how many songs may be of value in the future, however, most consumers are likely to have some simple expectation of the number of songs to be released in a period that are of value, based on their historical average.

enter the bundle in future periods when a user has a subscription.[26] For some users, "riskless" and "costless" access to future music may factor heavily in their format decision.[27] Relative to the retail consumer, a streaming subscription saves the consumer at least $L_i(|M|)P_A$ due to the additional dis-utility from advertisements when sampling with ad-supported streaming.[28]

For the retail format we assume each song has the same price, and listens of a song are unaffected by other retail purchases, or equivalently: $u_i\left(X_{iR}\right)\int_0^{T_r} e^{-\rho_i t}dt - RP_r$. Therefore, if a consumer utilizes only one format, her decision requires identifying the sign for the following expression:

$$u_i\left(X_{iR}\right)\int_0^{T_r} e^{-\rho_i t}dt - RP_r - \left[u_i\left(X_{iS}\right)\int_0^{T_s} e^{-\rho_i t}dt + E(Y_i) + T_s(F_S - P_s)\right] \tag{9}$$

Comparing the utility from each format we identify the size of a consumer's consumption set, specifically, whether $|X_{iS}| \leq |X_{iR}|$ or $|X_{iS}| \geq |X_{iR}|$ (or equivalently $S \leq R$ or $S \geq R$). To determine the relative size of each set, assume x_j is the song that provides the user with the lowest utility that is in both consumption sets (i.e. $x_j \in X_S$ and $x_j \in X_R$). The cost of listening to a new song with a streaming subscription is only the consumer's opportunity cost, any song that would be purchased in the retail format would provide sufficient utility to be streamed with an existing subscription. Therefore, if x_{j+1} is ever consumed it must be that $x_{j+1} \in X_S$. Users will add songs up to the point where marginal net benefit of a song is zero, therefore $u_i\left(x_j\right)\int_0^{T_r} e^{-\rho_i t}dt - P_r = 0$ for song j and $u_i\left(x_k\right)\int_0^{T_s} e^{-\rho_i t}dt + T_s(F_k) = 0$ for song k, where $j < k$. From this, we conclude:[29]

[26] We assume that expected value for each period is identical, however, we do not assume that the user necessarily knows which songs will appeal to them. We define $E(Y_i)$ as net value which include benefits from future songs, but also the associated search costs of finding the songs.

[27] For example, a streaming subscription could remove any potential buyer remorse while also removing concern about missing out on new music.

[28] An individuals cost of sampling depends on how much search they are willing to undertake, but if a consumer adopts M future songs we expected they sampled at least M songs. $E(Y_i)$ increases if the subscription service provides effective recommendations. For more on platforms reducing search costs see Hiller and Walter (2018b).

[29] Proof and further discussion of Proposition 4 is provided in Appendix 4.

Proposition 4 *Consumers that utilize a streaming subscription will listen to at least as many songs as consumers that only utilize the retail format, ceteris paribus.*

Rearranging equation 9 allows the consumer to choose between formats. If a consumer is to choose a durable purchase the following inequality must hold:

$$u_i\left(X_{iR}\right)\int_{T_s}^{T_r} e^{-\rho_i t}dt - RP_r > u_i\left(X_{i,x\in S-R}\right)\int_{0}^{T_s} e^{-\rho_i t}dt + E(Y_i) + T_s(F_S - P_s) \qquad (10)$$

The utility obtained from the subscription platform is dependent on the number of songs available and the subscription service's investment in future songs. Pricing (P_s, P_r) and platform changes (F_S) are assumed exogenous as they are beyond the control of the consumer and are not the main focus of this article, but are obviously critical in the consumer's decision. Components that depend specifically on individual consumers are: utility from songs $(u_t(x))$, the discount rate of a song's utility (ρ), number of songs with sufficient utility to merit purchasing (R), number of songs the consumer will stream (S), and the value assigned to future new music $(E(Y_i))$.

Using 10, the ideal format can be identified for any consumer with a specific set of preferences. This allows us to conclude the following:[30]

Proposition 5 *In the absence of platform benefits (or costs), consumers that have identical consumption sets on both format, and a sufficiently persistent interest in music* $(T_s > \frac{RP_r}{P_s})$*, obtain greater utility from retail songs, ceteris paribus.*

Next, we examine the utility derived from the optimal consumption set on each format. In our representation we assume that the songs with the highest utility are purchased immediately and consumed using the retail format.[31] Using equation 9 and adding the overlapping usage from each source $(u_i\left(X_{i,x\in R}\right)\int_0^{T_s} e^{-\rho_i t}dt)$, allows us to represent the

[30]Proof and further discussion of Proposition 5 is provided in Appendix 5.

[31]Note that as long as the song usage isn't impacted solely by format, then our representation is equivalent to a user utilizing either format for that song, although it will impact an artist's compensation.

utility from using both formats as:

$$u_i\left(X_{iR}\right)\int_0^{T_r} e^{-\rho_i t}dt + u_i\left(X_{i,x\in S-R}\right)\int_0^{T_s} e^{-\rho_i t}dt + E(Y_i) + T_s(F_{|S|-|R|} - P_s) - RP_r \quad (11)$$

Comparing the use of both formats to benefits of only purchasing (equation 6) shows that users that select both formats must satisfy: $u_i\left(X_{i,x\in S-R}\right)\int_0^{T_s} e^{-\rho_i t}dt + E(Y_i) + T_sF_{S-R} > T_sP_s$, or equivalently receive enough utility from greater song access, expected new music, and the platform to exceed the cost of a streaming subscription. This highlights an unsurprising benefit of streaming, access to new songs. More importantly, this implies that streaming use encourages wide consumption of music, implying that the rate of decline in utility of streaming music should increase as a result of the format or the type of users it attracts.[32]

4.2 Utility and listens

Using this representation, we can represent the rate at which aggregate utility (denoted with subscript "I") declines. Using consumption of all streaming consumers of a set of songs, the rate that aggregate utility declines within a one period subscription is $[U\left(X_S\right)e^{-(\rho_{Is})t}]_0^1 - P_s$. Similar to Hiller and Walter (2018a), we assume utility and listens of a song are directly related. Therefore, we can empirically identify a song's decline for a representative consumer by examining the number of listens for a collection of songs.

[32]Equation (11) also highlights when a consumer should utilize both formats. Previously, we showed that the benefit of retail stems from ownership of the song. In the multi-song scenario, a user knows that a specific song will provide sufficient utility beyond the length of their subscription, then purchasing the song yields greater benefit. By extension, a user could have several songs, an artist, or a genre where purchasing is welfare improving. This is similar to a user having a proper subset of songs that satisfies the condition discussed in Remark (2). In this scenario, a retail subset of songs yields utility long after the user's streaming subscription ends while the streaming subscription provides access to music with greater depreciation rates (not worthy of purchasing). However, for a user to know that concurrently purchasing and streaming is optimal requires a substantial amount of information. Specifically, a user must predict future music production and the properties of their future music consumption, i.e. a user must know for which songs the following condition holds: $P_r < \int_{T_s}^{T_r} u_i(x)e^{-\xi_i}dt$. Due to the challenges identifying when this condition is met, we focus on the case where users make use of only one format.

Let $u_i(X_{iS})$ denote a representative consumer's initial utility from a set of songs X_{iS}, then $u_i(X_{iS}) = \sum_{j=1}^{N} listens_{ij0}$, where $listens_{i0}$ is the number of listens from user i for song j in time period 0. The aggregate number of listens for songs is derived from a variety of users with heterogeneous consumption sets, so we define the initial average utility from a bundle of songs by format as $U(X_S) = a\sum_{i=1}^{I}\sum_{j=1}^{N} streams_{ij0}$. Where $streams_{ij0}$ is the initial number of streaming listens for song j by user i and a is a scalar mapping overall song listens to an average utility for each consumer.[33] As a result, the average rate (denoted with a bar) of decline can be shown to be $e^{-(\overline{\rho_s})t}$, and by definition:[34]

$$a\sum_{j=1}^{N} streams_{jt+1} = a\sum_{j=1}^{N} peak_{jt}e^{-(\overline{\rho_s})} \tag{12}$$

Using the number of listens for individual songs, the aggregate depreciation rate can be estimated with the following equation:[35]

$$streams_{jn+t} = \gamma_{sn+t}peak_{jt} + \alpha_{n+t} + \lambda_j + \epsilon_{jn+t} \tag{13}$$

Where a song peaks in week n, and the change in streams is found for any t weeks after n. α_{n+t} is a week indicator, λ_j a time-invariant fixed effect for each individual song, γ_s captures the decline in utility ($\gamma_{sn+t} = e^{-(\rho_{Is})(n)}$) from the peak streams ($peak_{jt}$) in week t, and n denotes the number of weeks since a song's utility peaked. Using a similar approach with aggregated utility of retail consumers, the aggregate depreciation rate for a set of songs in one period is:$[U(X_R)e^{-\rho_r t}]_0^1 - RP_r$. Using the number of listens for individual songs the average depreciation rate can be estimated with the following equation:

$$streams_{jn+t} = \beta_r peak_{jt} + \alpha_{n+t} + \lambda_j + \epsilon_{jn+t} \tag{14}$$

[33] In our empirical examination we have access to aggregate data on music streaming, so the depreciation rate is derived given the assumption that we are discussing the average user, as utility depreciation must equal the average aggregate decline.

[34] We examine how a set of songs would decline by examining the aggregate decline of each song individually making identification of the initial set as discussed in the theory section unnecessary.

[35] We estimate the average rate ($\bar{\rho}$) of decline over time. Similarly, we estimate the average ($\bar{\rho}$) for a traditional format more directly using radio data.

Where β_r captures the average depreciation rate ($\beta_r = e^{-\overline{\rho_r}(n)}$). Although we cannot observe individual depreciation rates, this approach provides an average which can be compared across formats.[36] Additional factors may contribute to varying discount rates. Specifically, the type of consumer using each format may differ; the usage of each format may suffer from self-selection bias. As a result, the discount rate of songs for each platform may be due to user characteristics and formats.[37] Using this model with aggregate data we can test whether song consumption declines at a faster rate for streaming versus retail formats.

5 Empirical model

In this section, we test whether on average music consumption habits across formats are different with the availability of streaming options. In using aggregate data of music consumption to search for differences, we also identify a plausible starting point for the average consumer's depreciation rate.

In the theoretical model we assume that the peak number of listens across all formats is exogenous. We then hypothesize that relative to that peak the number of streams, radio listens, and sales are a function of time and fixed effects such that:

$$listens_{jn+t} = \gamma_{n+t} peak_{jt} + \alpha_{n+t} + \lambda_j + \epsilon_{jn+t} \tag{15}$$

Where $\gamma = e^{-(\rho_{Is})(t)}$ for streams and $\gamma = e^{-(\rho_{Ir})(t)}$ for listens of durable sales and radio. As the peak number of streams (and sales) will differ by song we transform this equation to find the rate of decline by dividing both sides by the individual song's peak

[36] This approach also provides a useful reference point which we later exploit to simulate format preference and retail price changes.

[37] We explore the differences individual preferences may create in the next section.

number of listens, generating

$$PercentageofPeak_{jn+t} = \gamma_{n+t} + \phi_{jn+t} + \tau_j + \sigma_{jn+t} \quad (16)$$

Where ϕ and τ are the fixed effects α and λ, and σ the error term ϵ, all scaled by the peak number of streams for song j. Taking the natural log of equation 16 transforms γ to $\overline{\rho_s}$ for streaming music, and $\overline{\rho_r}$ for individual sales and radio. The probability must be bound between zero and one while allowing for fixed effects. Therefore, we take a log transformation of the percentage, ln(P/1-P), before performing a least squares regression. All coefficients on indicator variables are therefore the base odds ratio of the excluded group, and coefficients on continuous variables represent the change in the odds ratio associated with a one unit increase in the variable.

5.1 Estimation

As we have shown above, the depreciation rates of an information good are crucial in the decision to subscribe or purchase. The quicker consumer utility of a song depreciates, the more attractive a streaming subscription becomes. We can observe an approximation of that depreciation when considering the rate of change in streaming music. Given Spotify only releases aggregate data, we may capture an additional factor in our analysis. The aggregate data contains the depreciation we are interested in, but also potentially the addition of new listeners each week, even post-peak. The estimated depreciation rates are accurate only if the addition of listeners is minimal after the peak. If a substantial number of listeners are added afterwards then our results are only a lower bound on the combined effect for individuals, making depreciation of streaming music more rapid. This means that what we find for decline in consumption should not be considered a precise estimate of each individual using streaming music, but rather a plausible lower bound for the average consumer that listens to the most popular music on the platform.

In our first empirical analysis, we use Spotify data to quantify this decline. We assume that once price and format are accounted for the peak utility of a song is exogenous.[38] The goal, then, is not to determine how consumers determine the number of times to stream a song but the effect time has on the rate of decline from that peak. With that in mind, the general specification for determining the discount rate is:

$$ln(P_{jt}/(1 - P_{jt})) = \delta_0 + \gamma WeeksAfter_{jt} + \delta' z_{jl} + \alpha_t + \lambda_j + \epsilon_{jl} \tag{17}$$

Where P is the percentage of the peak of song j in week t, and takes a value strictly between zero and one. We allow for decline from the peak with $WeeksAfter$, which gives the temporal relationship after the peak week for song j in week t. The coefficient γ is the average decline in utility due to depreciation, $-(\overline{\rho_m})$. When $WeeksAfter$ takes a positive value it indicates streaming of the song has peaked and is now declining. As all weeks are in comparison to the peak week, the peak is excluded from each specification. The vector z contains terms for the debut of song j, where indicator variables for debuting in the top of the charts are interacted with the $WeeksAfter$ variable to determine if songs with a strong premiere behave differently in relation to their peak. We include the week indicator α_t, and λ_j is a time-invariant fixed effect for each individual song.[39]

Since sales data does not directly represent utility, we use radio data as a plausible proxy for the more traditional forms of media tied to consumption through sales. Dewan and Ramaprasad (2014) find a strong connection between radio airplay and song sales, with little connection to social media buzz in the same analysis. The measure of declining song plays in radio data is the closest to a pure depreciation rate, as the number of slots available for songs on radio and total listeners does not vary dramatically from week to week. Therefore, the relative decline in a song's position from a peak is primarily due to decline in utility and substitution for new songs.[40]

[38] Importantly, once a consumer purchases a subscription for a month each additional stream has no marginal cost, and therefore the consumer will listen to the song again if the utility is positive and greater than all other song given time constraints.

[39] We also try a random effects specification with very similar results.

[40] More accurately, due to what radio programmers expect decline in consumer utility to be.

Despite the fact that sales of durable singles are not directly comparable to streams, we run a similar analysis on Nielsen sales data. While this does not provide a representation of the declining value of songs, it generates a reference for the difference in formats. Specifically, we observe the difference in the rate of decline of sales before and after the entry of streaming music into the United States. The sales data reveal the decline in new consumers, whereas changes in Spotify consumption and radio data provides estimates of declining utility from a song as discussed in the model.

5.2 Data

We use several sources for data on song consumption. Streaming music data is from Spotify, the largest on-demand streaming platform in the United States. Spotify releases the top 200 songs in rank on the service as well as number of streams weekly for those songs. All of the data contains only the top 200 songs on the platform in the United States. This creates a restricted sample as only songs appearing at the top of the charts are included. The sample is not necessarily representative of the entire market, excluding any relationship consumers have with less popular songs. The exclusion is important if the rate of decline differs between top 200 songs and other, less popular songs. Our focus is on the rate of decline in streaming for a popular song and observing differences in sales behavior of a song due to inclusion in this important streaming chart. Our estimates using aggregate data can be thought of as a plausible analysis of the lower bound for a representative consumer of the most popular music on each format. The charts run from July of 2015 to June of 2018.

We also analyze the weekly Hot 200 US radio airplay datasets for two time periods.[41] The earlier set is from the week of February 8, 2009 to the week of January 4, 2015, and the later set from the week of May 31, 2015 to the week of February 26, 2017. The Hot 200 is a ranking of popularity in the United States market, but does not provide the

[41] The Hot 200 can be found at http://www.charly1300.com/usaairplay.php, Last Accessed: 8/26/2018.

number of plays a song receives or the audience that listens. We combine this dataset with daily updates on radio plays and audience, which we sum to create weekly data.[42] These updates only provide the top 50 songs, so the data is extrapolated out to the top 200 ranking assuming an average percentage decline between ranks. Each song in the Hot 200 is assigned the average spins and audience of the appropriate rank. With this dataset, we compare decline in consumption in the radio market relative to other formats. We have digital sales data at the song level from Nielsen Soundscan. This includes sales through most major digital platforms, including iTunes and Amazon. The dataset includes digital sales from 2009 to 2017.

Table 1 provides summary statistics for the data used. We exclude songs that appeared in the first week of data as we cannot be sure of the peak of these songs, leaving 1,681 unique songs in the Spotify sample, 6,006 in the Nielsen sample, and 4,872 in the radio sample.[43] The average opening streams of 2.47 million represent about 58 percent of the average peak of weekly streams at 4.26 million. Nielsen data description is limited because it is proprietary, but the average song opens at a rank of 92 and peaks at a rank of 32. Radio statistics show that the top of the chart receives heavy airplay relative to the rest of the top 200, with the average song peaking at an audience of six million on one thousand spins, and the top of the charts topping at 121 million on 18,245 spins.

5.3 Depreciation rates

We begin our empirical analysis by estimating the rate of decline in aggregate consumption from the Spotify data. With this model the first week for each song is excluded from analysis, as is the peak week, and any song which first entered in the opening week of a set. We continue by analyzing the decay of Nielsen sales, crucially measuring the difference in the decline in sales before and after the streaming era. Finally, we use the

[42]Daily updates found at https://kworb.net/aradio/, Last Accessed 8/26/2018.

[43]None of our samples are round numbers as might be expected for "top" lists. This is due to songs that only appear for one week in a chart, and therefore never decline against a peak.

same analysis to measure the decline in aggregate radio airplay over a similar period to sales as a plausible measure of the depreciation rate among traditional music sources.

Table 2 provides the results from estimation of the total depreciation of streaming music on Spotify. Our representation of total decline post-peak, the $WeeksAfter$ variable, shows a coefficient on the odds ratio of -0.1. This coefficient is a measure of $\overline{\rho_s}$ values, which we use to calculate the decline in streams by using equation 12. This result implies a 9.1 percent decline in a song's consumption each week past the peak on the Spotify platform. We also test the significance of peak position and the period when a song peaks, however, both lack significance in this specification.[44]

As a retail comparison to streaming music we consider terrestrial radio. Radio is much older than streaming and a passive means of delivery. Radio provides a direct, stable comparison to the weekly streaming charts. While radio is not durable, consumers that continue to regularly listen to radio are less active in their music consumption, and are more likely to still purchase music when paying for it (Dewan and Ramaprasad, 2014). Table 3 shows a similar specification with radio data. Given that time allotted for music does not change much from week to week on the nation's radio stations, each rank has a very similar number of listeners over time, and the decline in listens comes primarily from falling down the relative ranks from discounting and substitution. Columns 1 and 3 use the "spins," or number of times a song is played on the radio airwaves, while columns 2 and 4 use the adjusted audience for those spins. All dependent variables are converted to a percentage of the peak for that song, and tested as an odds ratio.

For the $WeeksAfter$ variable the decline in listening is greater in audience than spins, indicating that larger stations decrease the number of plays faster than smaller stations. The coefficients in columns 1 and 2 show reductions in the log odds of 0.055 and 0.072 or approximately 5.2 and 6.7 percent declines in listening per week. The rates are lower than the decline in Spotify rates. Whether this difference is purely due to a lower discount rate

[44]The lack of significance of peak position signifies the absence of any "herding" effect with users of streaming music.

of listeners, or if the availability of easier substitution is important cannot be determined from the data we have. However, the difference in the overall effect demonstrates that consumers of streaming music experience a faster depreciation.

In columns 3 and 4 the streaming indicator variable is included. The coefficient on $WeeksAfter$ is much larger in absolute value, however the streaming interaction term indicates that the years prior to 2011 experienced a more rapid rate of decline than those after.[45] The base level of decline in listening is approximately 11.5 percent per week, but for the years after 2010 that number drops to roughly 5.3 percent. The decline in radio consumption is both much lower in the streaming era and substantially lower than that of Spotify. This direct comparison to streaming shows that those still using traditional distribution of music experience a slower discounting and substitution of music consumption, and that consumers of these two formats are quite different.

Table 4 displays results for the specification using Nielsen sales data. While the decline of sales is not the same as depreciation, this specification measures how quickly a song loses new retail consumers relative to the peak, as well as to test whether the decline has changed in the streaming era, from 2011 on. In the first two columns we try a specification that is the same as in Table 2. In columns 3 and 4 we use an indicator for the period we call the streaming era, while in the fifth and sixth columns we try to find a post peak effect for every individual year. The decline in sales is represented by $WeeksAfter$, with the same interpretation of weeks past peak as the Spotify chart. In the first two columns, the rate of decline in sales shows an approximately 0.045 decrease in log odds, or about 4.3 percent per week, a rate much slower than Spotify. This, of course, is solely measuring the loss of consumers which we consider only as a baseline.

Columns 3 and 4 include the *Streaming* variable which has a value of one from 2011 onward, and zero beforehand. The year 2011 is when Spotify entered the market in the United States, and our analysis clearly shows that the rate of decline was faster prior

[45] A year by year test, similar to that done with Nielsen, yielded results with the expected signs but not significant.

to the streaming era. In columns 3 and 4 the rate of decline before streaming is about 6.4 percent per week. The interaction $Streaming * WeeksAfter$ shows that the rate of decline of music falls to about 4.1 percent in the period after Spotify enters. Columns 5 and 6 use indicator variables from each year to find the individual comparisons in the rate of decline of sales, where all effects are compared to the excluded year of 2011. The broad $WeeksAfter$ is unchanged from the base model, and it is clear that the years before streaming (2007-2010) drive the rate lower. The rate of decline in song sales was faster before widespread streaming, and the rate of decline in sales slowed as more consumers moved toward streaming in the later years of the sample.[46]

6 Ideal format

Our estimated range of decline in consumption for the average user is a plausible starting point in determining the ideal music format based on a consumer's idiosyncratic preferences. Using our estimates for depreciation, and outside estimates of intensity and scope of music interest we compare the benefits for each format. Obviously, identifying the value of the platform and future music yields several challenges. To address this, we assume that utility per period is consistent, which allows us to examine scale and scope of musical interest in the context of price to identify a "replacement cost" of music. [47]

6.1 Listening expansion and replacement

We begin by assuming that the consumer's time spent listening to music and size of her consumption bundle are relatively consistent across time but may differ for each

[46]Finally, in results not reported here to save space, we include data for the weeks prior to peak. Existing results are not qualitatively changed, and the mildly interesting results of pre-weeks are reported here. Most songs premiere at their peak, Spotify at 76.02%, 61.65% on radio, and 76.42% of Nielsen sales. For the minority that do not peak in the first week, there is not much growth on average, and growth is much slower in streaming (1%) and sales (2.3%) than the growth for radio (about 16.5%).

[47]We focus on the discrete decision to make retail purchases or a streaming subscription the user's primary format.

format.[48] Using a time budget has the benefit of incorporating addition, replacement, and depreciation of songs over time, making the consumer's first period consumption where the amount of music that user i utilizes satisfies:[49] $B_{i0} = a_1 x_1 + a_2 x_2 + ... + a_M x_M = \sum_{j=1}^{M} a_j x_j$, where $M \in [R, S]$. If we assume the initial value of a song, along with the initial number of listens (denoted a), is consistent for songs selected by the user then $B_{i0} = a\,|X_{iM}|$. User i's next period consumption must satisfy: $B_{i1} = (a\,|X_{iM}|)\,e^{-\rho_i} + a|Y_{iM}|$, where Y represents the set of new additions to the consumer's consumption bundle or, equivalently, the replacement rate of songs for user i on format M per period. Therefore, the term $a|Y_{iM}|$ represents the addition of new music which is replacing older music.

Using the change in the composition of songs and listens between two periods, we can identify the replacement rate of songs Y_{iM} for user i as: $Y_{iM} = (1 - e^{-\rho_i})\,|X_{iM}|$. This implies that the song replacement rate depends on two things: the scope of a consumer's listening habits (number of songs, or $|X_{iM}|$) and the consumer's rate of decline in utility (ρ_i). Our previous findings show that the streaming consumption bundle will be larger than the retail bundle. If a consumer's time budget and scope are relatively stable (but still differ by format), we would expect that the depreciation rate must differ by format, as we found empirically. Why is this the case? As retail users add Y_{iR} in the next period, it must be the case that streaming users add Y_{iS}, where $S \geq R$. The additional songs a user adds to her streaming consumption bundle is directly related to the streaming depreciation rate and ease of discovering new music. As a result, the differing depreciation rates and sampling costs that occur across formats can indirectly be captured by evaluating the consumer's difference in utility stemming from "song-expansion" that occurs with streaming music.

For convenience we assume that the demand for unique songs is linear for low utility or

[48] If we denote each period's consumption bundle with a subscript, then these assumptions are equivalent to $|X_{iMt}| = |X_{iMt+1}|$ and $u_{iSt}(X_{iSt}) = u_{iSt+1}(X_{iSt+1})$.

[49] This could be interpreted as a time budget constraint, but our analysis only requires that the number of songs replaced each period is uniform.

less favored songs, specifically those that are only in the streaming consumption bundle.[50] To simplify our estimation of utility, we assume a proportional relationship exists between user i's selection on each format, i.e. $|X_R|(\delta_i) = |X_S| - |X_R|$, where δ_i is the previously mentioned song-expansion that occurs with streaming music. Simply put, this represents additional song variety due to zero marginal cost access to a streaming bundle. From the consumer's perspective, the decision to utilize a streaming subscription relative to utilizing the retail format rests on her rate of decline in utility and scope of music interest.

Comparing a consumer's utility from each format is challenging due to the differences in number of unique songs and the quantity of listens. To simplify our analysis, we represent the consumer's utility from each format as the consumer surplus stemming from demand for music from that format. This provides the additional surplus derived from streaming in terms of the number of unique songs utilized. To identify the value of $u_i(X_{iS}) - u_i(X_{iR})$, we assume the consumer is myopic such that their format decision is based on the current period's utility, but acknowledge that future value can still be obtained. As a result, we can illustrate the demand and benefits from individual songs on both formats, as shown in figure 1.

We consider that all users have access to music in some form whether it be older songs, radio, or free streaming with shuffled playback.[51] Therefore, a representative consumer's utility from each format in each time period represents the increase in utility from specific songs over DJ or algorithm selected passive consumption. Users may be unable to predict their future music consumption. This allows us to use our previous finding to identify a consumer's benefit per period and identify the consumer's optimal format for music consumption. For streaming, the maintenance costs are straightforward as adding new songs to a consumer's bundle is free, therefore the "average" cost per period is just P_s. The consumer's net benefit from the streaming format (per period) can therefore be

[50]This approach places no restrictions on the initial shape of the demand curve for high value songs.

[51]Pandora and Spotify let users listen to random songs or playlists with ads for free but require a subscription to avoid ads and listen to specific songs.

represented as: $u_i(X_{iS}) - P_s$. For retail music each new song has price P_r, so the cost per period (or replacement cost) is $P_r Y_{iR}$, which implies the net benefit from the retail format (per period) is: $u_i(X_{iR}) - P_r Y_{iR}$ or equivalently, $u_i(X_{iR}) - P_r(1 - e^{-\rho_i})|X_{iR}|$.

Although utility may decrease at a continuous rate, we assume a user's decision to switch or maintain her current format occurs periodically. Using the user's utility per period, equation 18[52], and the replacement rate of songs, we analyze the parameters impacting the user's format decision:[53]

$$\underbrace{u_i(X_{iS})\int_0^{T_s} e^{-\rho_i t}dt}_{u_i(X_{iS})} - \underbrace{u_i(X_{iR})\int_0^{T_r} e^{-\rho_i t}dt}_{u_i(X_{iR})} - \underbrace{T_s P_s}_{P_s} + \underbrace{Y_{iM} P_r}_{P_r(1-e^{-\rho_i})|X_{iR}|} \tag{18}$$

These results show that a consumer's optimal format is a function of prices, difference in utility between formats, depreciation rate, and the size of the consumption set. This requires signing the following equation:

$$u_i(X_{iS}) - u_i(X_{iR}) - P_s + P_r\left(1 - e^{-\rho_i}\right)|X_{iR}| \tag{19}$$

Where a positive value indicates streaming is the ideal format for the user.

6.2 Simulation

For the initial consumption values we do not consider empirically within this paper, we utilize previous research by Datta et al. (2018) which examines individual consumption habits on streaming and retail platforms. We take two values from their research to provide plausible examples of song expansion. Specifically, we first use the finding that the adoption of Spotify increases a consumer's overall music consumption by 49% and the

[52]For convenience, we assume that platform benefits are zero.

[53]In this representation with uniform utility across periods, the value of the future music in the next period is equal to the utility from consuming the current consumption set in the next period, or equivalently, $E(y_i) = \rho_i u_i(X_{iS})$.

quantity of unique songs they listen to by 31% on average,[54] relative to similar users that do not utilize streaming methods. As a low end value, we take the result that the number of new songs is increased by 3.4 percent for streaming adopters versus non-streamers.[55] These findings allow us to calculate song expansion from a consumer's scope of retail music or more specifically, $\delta_i \cdot |X_R| = 31\% \cdot |X_R|$ on the high end and $\delta_i \cdot |X_R| = 3.4\% \cdot |X_R|$ on the low end. For now, we assume these proportions hold (or that δ_i is constant for each type) regardless of a consumer's scope of music interest or rate of decline in utility.

Using a retail price per song of $1.29 and the price of a streaming subscription of $9.99 per month, we can identify the conditions under-which the streaming format yields a higher utility.[56] Substituting these values in 19 yields:

$$\underbrace{\$1.29\left(\frac{\delta_i}{2}\right)|X_{iR}|}_{[u_i(X_{iS})-u_i(X_{iR})]/\text{wk}} - \underbrace{\$2.30}_{P_S/\text{wk}} + \underbrace{\$1.29\left(1-e^{-\rho_i}\right)|X_{iR}|}_{\text{Price of retail/wk}} \tag{20}$$

We illustrate the effect of each component by using two simulations of different consumer characteristics. The range of depreciation rates we use in both are based on our weekly estimations from the three formats we examine (4.3%, 5.3%, and 9.1%) and an additional lower rate of 1.5%[57] If we assume a consumer's weekly depreciation rate follows our previous estimates of $\overline{\rho} = .053$, then in order for the user to benefit from the streaming format relative to the retail format, her consumption bundle must contain at least 8.6 unique songs with a δ_i =31% and 26.0 songs with δ_i=3.4%. Holding the consumer's song-expansion constant with either value, we can identify a consumer's ideal format, which

[54]Datta et al. (2018) estimate the long-run change in the number of unique songs to be 0.27, which implies 31% ($= e^{(0.27)} - 1$) increase in the number of unique songs, providing empirical evidence of our Proposition 4. Importantly, MP3 (retail) prices have been relatively stable since any prices change affects the expansion effect between formats (we examine this possibility later in this section).

[55]There is a 2.2 percentage point increase over a 33 percent average pre-adoption. When we assume that the additional new songs only adds to the bundle, that yields an expansion of 3.395%, rounded up to 3.4.

[56]This reflects the price of pop songs on Amazon and Spotify's Premium account, which is approximately $2.30 per week.

[57]If 9.1% represents users with higher depreciation rates, then 5.3% ± 3.8% is the range of depreciation rates for the most users.

depends on their scope of listening habits (number of songs or $|X_M|$) and the consumer's depreciation rate (ρ_i). Figure 2 identifies the ideal format based on the consumer's depreciation and scope of listening habits given the two levels of song-expansion.

Figure 2 illustrates the relative importance of depreciation versus expansion. For the low expansion consumer (δ_i =3.4%) the depreciation rate is extremely important. The bundle must be very large (almost 56 songs) to justify streaming at a 1.5% rate, while the consumer with a 9.1% rate would only need 17.15 songs. When expansion is substantial, on the other hand, as is the case in the δ_i =31% example, the consumer is not sensitive to depreciation. The amount of expansion generates sufficient value to justify streaming for a much smaller set of songs. With a lower discount rate, consumers will enjoy a song for longer, which lends itself to purchases. Similarly, if the consumer does not substitute often they will not find the value in more song options.

We can also find the value to the typical consumer. Using Datta et al. (2018), we consider a starting value of 34 listens which we use for the consumer's initial retail consumption set.[58] For the average consumer with a depreciation rate of 5.3%, a unique retail bundle of 34, and song-expansion of 31% (or 10.5 songs), streaming is significantly more appealing. The retail cost per week for the average consumer would be approximately \$3.82, while streaming would cost only \$2.30 per week and provide an additional \$6.80 in (weekly) value. Therefore, streaming yields \$8.31 per week in additional value over retail. Lower song expansion significantly increases the threshold necessary for the streaming subscription to yield a higher net value. The same values with a song expansion of 3.4% yield a retail cost per week of approximately \$2.26, while streaming cost remains at \$2.30, but only provides an additional \$0.75 in (weekly) value. However, streaming still yields a greater overall (weekly) value of \$0.71.

We further consider the song-expansion from streaming necessary for a user to be

[58]Datta et al. (2018) report that when consumers adopt a streaming subscription, iTunes play counts decrease by 34. Note that these songs were not necessarily purchased in that period. By focusing solely on changes to song usage on iTunes and not other sources, we hope to limit inference from passive music consumption.

indifferent between the retail and streaming format for three different depreciation rate and scope of listening habits in Table 5. The scope of listening habits are based on the 34 song estimate (34 ± 17). Table 5 provides the additional value users would receive from the ideal format based on their individual characteristics. Our simulation yields several interesting results. For a user with a 34 song retail set and 31% expansion from streaming, regardless of their depreciation rate, the streaming format yields greater value. The retail format is still a more viable option for users with narrow listening habits, very low depreciation rates, or those that would not expand their song selection under the streaming format. Unsurprisingly, this indicates that the average consumer would receive more value from the streaming format than from making retail purchases. Our findings also support Proposition 5, users with low depreciation rates (1.5%) and no song expansion experience greater value from retail purchases.

Prices could change in the future as a result of the relative format popularity. Due to the recent increase in streaming subscriptions, we turn our attention to retail pricing of individual songs. Lower retail pricing impacts consumers in two ways. First, net benefits from each song increase. Second, as the retail price decreases the reservation value falls, meaning retail consumers will purchase more songs. This means that the associated expansion effect from selecting the streaming format instead of purchasing could decrease. However, holding the expansion effect constant allows us to examine how decreasing retail prices to \$0.75/per song affects format preference for a distribution of users with differing consumption set sizes and depreciation rates. The lower retail price changes the threshold at which each format is preferred. Figure 3 provides users preferred format when retail prices change to \$0.75/per song.

Figure 3 highlights how lower retail prices can significantly improve the appeal of purchasing music. However, even at a retail price of \$0.75 per song, users with a 31% expansion effect and an average consumption set (34), maintain a strong preference for a streaming subscription. Users with a lower expansion effect and an average depreciation rate (5.3%) and consumption set, prefer retail only slightly more.

Finding the competitive retail price requires identifying the characteristics of the "average" consumer.[59] Our previous calculations assume the average consumer would stream 44.5 songs, but only listen to 34 songs weekly if purchasing music at \$1.29. If we assume the average consumer has a linear demand and expansion is only based on price,[60] then lower retail prices increase the net benefit of purchasing song and decreases the expansion that occurs choosing streaming. If we examine the average consumer's demand for music using a retail price change to \$0.75 per song, we find how the relative utility changes between formats. Using equation 20, we find that at a retail price of \$0.75 per song, the average consumer increases their consumption to 38.4 (from 34) songs per week, which implies that the expansion rate from switching to the streaming format decreases from 34% to 15.9%. However, even at a retail price of \$0.75, the average consumer still obtains an additional \$1.48/week benefit from choosing the streaming format. Therefore, a retail price reduction to \$0.75 per song is unlikely to significantly shift consumers from streaming to the retail format. Figure 4 illustrates how the retail price of \$0.75 increases consumer benefits from purchased music and decreases the expansion that would occur by switching to the streaming format.

The lower retail price shown in Figure 4 shows that any song the consumer would have previously purchased (under the original price regime) yields additional utility of \$0.54. In addition, retail purchases increase by $|X_{iR}^{*}|$-$|X_{iR}|$, whereas streaming consumption is unchanged. This implies that selecting streaming over retail now only results in a smaller increase in the number of songs consumed. Overall, choosing streaming access now only increases a consumer's consumption by $|X_{iS}|$-$|X_{iR}^{*}|$, signifying a decrease in the expansion effect.[61] While both of these affects increase the consumer's net utility from

[59]By competitive, we mean that the average music listener is indifferent or more likely to utilize the retail format. It is likely that there will always exist consumers indifferent between each format.

[60]Previously, we assumed that the expansion effect is a result of switching format and is not related to retail prices.

[61]The expansion rate changes with price, for example we would expect a retail price of \$0 would be associated with an expansion rate of 0%.

retail purchases, the gain is insufficient at the retail price of \$0.75 to make purchasing the average user's preferred format.

Given our previous analysis, one obvious question is: at what price does retail music become competitive? This requires making the average consumer prefer retail purchases. To identify this, we continue assuming that the average consumer has a depreciation rate of 5.3% and would select a streaming set of size 44.5 songs.[62] Using equation 20, we find that a retail price of \$0.54 per song the additional song purchases and utility gain is sufficient to make the average consumer prefer purchasing music, i.e. the retail format becomes competitive. At this price, the average consumer increases their retail consumption set to 40.1 songs per week, which decreases the streaming expansion rate from 34% to 11%. Using the higher depreciation rate found from our streaming analysis (9.1%), we find that decreasing the retail price to \$0.41 per song makes the average streaming user prefer the retail format relative to the streaming alternative. At this price, the average consumer increases their retail consumption set to 41 songs per week, which implies that the expansion that occurs by switching to streaming is reduced from 34% to 8.6%. From this analysis, we can conclude that a retail price of \$0.41 would significantly alter the number of streaming subscriptions.

Our results also come with a few caveats. First, we assume that the length of consumption is fairly uniform for each format. Regardless of a consumer's actual habits, it may be that she expects, and usually does consume a song long after she would have ended a streaming subscription. Therefore, users with very low depreciation rates will receive additional value from the retail format. Second, other factors represented in our model may lead to different results. For instance, consumers may value the platform's distribution method more than the music. Previous research finds that "music listeners use on average 3.4 devices in a typical week to engage with music," with smartphones

[62] To calculate $u_i(X_{iS}) - u_i(X_{iR})$, we use the previous derived linear demand equation for individual songs, assuming a depreciation rate of 5.3%, retail consumption set of size 34, and an initial expansion rate of 31%, yields the following demand equation: $P = 5.467 - 0.122857|X|$.

(44%), laptop/PC (37%), television (23%), and tablet/e-readers (20%) being the most common devices (Nielsen.com, 2017). For some consumers, the device may have an outsized impact on format choice relative to music intensity, depreciation, and scope. If the device effect is significant enough, it may determine the format a consumer uses for music consumption.[63] Third, in our price analysis we make no inference about revenue. The retail format will likely always be more attractive to music listeners with relatively limited interests, whereas heavy users will purchase bundle access through a streaming subscription. However, the sustainability of each format depends on the cost structure, which differs by format.

Our simulation illustrates how the extent of how format differences impact a consumer's decision. For the durable good, the consumer can listen to a song indefinitely. The non-durable option has two potential benefits to counter that. The library of songs the consumer will listen to will be larger because of the near zero marginal cost. This may be thought of as a consumer being able to churn through music faster. Also, if the consumer has an expectation of considerable utility from music in the future, that can help justify a subscription fee in the present. With a subscription model, there is no marginal cost to listening, only a renewal decision each month whether to continue the subscription. The discount and substitution rates of the consumer are essential to deciding format. With a lower discount rate the consumer will enjoy a song for longer, which lends itself to purchases. The extent to which streaming music will expand will therefore depend on what percentage of music consumers have higher discount rates and consumption sets, the more the streaming services can do to increase these values, the faster streaming will expand.

[63]In our model, this is represented by a significantly large "F_M," which would change our estimates.

7 Conclusion

Consumers have individual preferences about music consumption and experience different depreciation rates, interests, and scope when it comes to music. These preferences are crucial in determining which format to choose for delivery of the music she enjoys. Consumers with a more rapid decline in song listening, seen through higher discounting and substitution, are more likely to prefer the non-durable streaming bundle. The empirical evidence shows that there is a substantial difference in depreciation of music between the streaming and radio formats. Additionally, song sales and radio airplay decline slower in the streaming era, possibly because consumers that churn through music quicker convert to streaming sources. The relative price differential and ability to substitute new music will likely continue to attract consumers to streaming services, while the heterogeneity in depreciation and limit of interest for new music by some consumers will limit the adoption of streaming subscriptions.

As noted, the potential exists for some overlap in subscription and ownership. This paper only compares digital sales purchases to streaming music. However, within the music industry physical album sales in CDs, or vinyl records, may provide a source preference value that generates additional durable sales even in the presence of streaming. This would likely occur among consumers with extremely high value from music that are interested in more than simply the entertainment derived from the song. We anticipate this will remain a small percentage of the market.

Our theories of decline and characterization of sampling are certainly applicable to other information goods with appropriate adjustments. For example, the movie industry may provide an extreme case of depreciation, where the consumer values one or two viewings of a film, and rarely more. As an experience good, movies also create significant search costs. In this environment the non-durable good thrives. Bundles such as Netflix and Amazon video provide something similar to the streaming music bundle, but film “rentals” provide a third non-durable option not common in the music industry. Additionally, source preference may be the main driver of durable purchases for all consumers beyond those with the slowest depreciation and substitution rates.

Alternatively, the video game industry may be one where depreciation is very slow. Video games may possess a unique trait in that utility from a game could increase as the user gets engrossed into the content, and decline slowly after. Furthermore, interactive game play creates network effects among users which could potentially reduce search costs. If utility from a single good increases, durable options become a more attractive option for users. However, retail versions of video games is considerably more expensive than individual songs or movies. Streaming delivery may require much lower prices in order to compete with retail versions. These ideas may also apply to the publishing industry, the news industry, and others.

The music industry is advancing quickly toward streaming music, with limits determined only by price, discount and substitution rates, and source preference. While there may be some limits to expansion given idiosyncratic preferences, broad expansion seems all but guaranteed as our simulations indicate that the average consumer likely benefits from streaming music relative to retail formats. Future research in this area could examine similar evidence of differences in formats as the number of distribution options grows and the non-durable options expand.

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Appendix 1: Value of streaming versus retail

We find that users select the ad-supported version if $T_sF_1 - L_i(x)P_A\int_0^{T_s}e^{-\xi_{is}t}dt >$ $u_i(x)\int_{T_s}^{T_r}e^{-\xi_i t}dt - P_r$. This means a user prefers durable purchases when a song's utility lasts sufficiently long ($u_i(x)\int_{T_s}^{T_r}e^{-\xi_i t}dt \gg 0$), or similar to the streaming subscription case, a song's utility is sufficiently high.

This may seem a fairly unassuming result especially in the context of music, however it yields important implications in the context of experience goods. Thus far, our analysis has assumed users know or have a reasonable estimate of the initial utility from a song. For many fans, familiar artists or bands likely satisfy this condition. However, for new music or other experience goods this is likely not the case.[64] Sampling music through a subscription or purchase is costly. Ad-supported streaming provides a low-cost alternative, thus lowering risk if the consumer later selects a different format.

In the context of music, the results from Proposition 1 can be described another way, users that prefer ad-supported streaming are likely sampling music or casual listeners. In the context of multiple songs, which we examine next, a user with a streaming subscription has no reason to use ad-supported streaming since they have no reason to endure any advertising. However, retail users may utilize ad-supported streaming to discover new music, but overall, ad-supported streaming yields little utility.[65] For this reason, the reminder of the paper focuses on non-casual music consumers and assumes that all users examined have a low-cost or free method of discovering music, but purchase some form of music.[66]

In the case of a single song, the consumer will only subscribe until net utility from the subscription service inevitably becomes zero. This occurs when the consumer's utility

[64]Ad-supported software, online news, and games are examples. Often, these approaches also limit the duration or features users can access to encourage purchase or subscriptions.

[65]For any song with enough listens such that $P_r < L_i(x)P_A\int_0^{T_s}e^{-\xi_i t}dt$, a user is better off purchasing the song.

[66]We recognize that ad-supported streaming accounts for a significant amount music consumption, however, we believe the majority users are casual or passive listeners that utilize these services like a traditional radio station.

satisfies $u_i(x)e^{-\xi_i T_s} + F_1 - P_s = 0$ or $u_i(x)e^{-\xi_i T_s} + F_1 = P_s$. This implies that usage from the streaming service will continue until the subscription price exceeds the net benefits.

Appendix 2: Proof for single song case

Given that $u_i(x)e^{-\xi_i T_s} = P_s - F_1$ and $u_i(x)e^{-\xi_i T_r} = 0$, this implies that $T_r > T_s$, or equivalently in the case of a single song, consumers will utilize the retail format for a longer amount of time than the subscription format, ceteris paribus. Rewriting equation 5 gives:

$$u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt - T_s(F_1 - P_s) - P_r \tag{21}$$

If the longevity of the song (beyond the continued streaming duration) is longer than the price differential for the retail format and any format benefits if $u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt > P_r + T_s(F_1 - P_s)$, thus proving Remark (2).

This result provides the optimal format condition in the single song case, but it could also apply if the format decision of a specific song is independent of a user's other music consumption. This condition implies that the utility stream from a song has a significant effect on a consumer's decision to subscribe or purchase. In this way music is generally utilized differently than other information goods, such as films and e-books, due to the value in repeat consumption of the good.[67]

Appendix 3: Proof for continued streaming

Let $P_r - T_s P_s$ represent the price premium for ownership. Then, in order for the net benefits of a durable good to exceed the net benefits of subscribing to receive non-durable goods, the stream of utility for a durable good must exceed the premium paid for ownership. In the case of one song, this condition is easily met if the song yields utility

[67]One exception is if a user generates value from having a collection.

for a sufficient duration.[68][69] If a consumer re-evaluates their format decision in a future time period (or every period) to determine if it is possible that a consumer could change formats. In order for the consumer to switch to the retail version from the streaming version, their utility in some period t must satisfy:

$$u_i(x)\int_t^{T_r} e^{-\xi_i t}dt - P_r > u_i(x)\int_t^{T_s} e^{-\xi_i t}dt + (T_s - t)(F_1 - P_s) \tag{22}$$

Which can be rewritten as: $u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt - P_r > (T_s - t)(F_1 - P_s)$. If a consumer initially decided to use the subscription format for a single song, it implies that the expression in 21 yielded a negative value, or equivalently her utility satisfied: $u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt - T_s(F_1 - P_s) - P_r < 0$.[70] Let B represent the format condition provided in 21 or equivalently $B = u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt - T_s(F_1 - P_s) - P_r$, where B represents the net benefit of utilizing the retail format relative to a subscription.[71] If the user initially streamed the song, we can conclude that $B < 0$. Simplifying 22, we obtain the necessary condition for a consumer to switch to the retail format: $B > -t(F_1 - P_s)$. As $B < 0$ and $F_1 - P_s < 0$, the necessary condition will never be satisfied, therefore proving Remark (3).

The utility a consumer receives from either music sources decreases over time. This result shows that a song cannot be appealing enough to initially subscribe, but have the longevity to encourage consumers to then purchase the song after the subscription window ends. Retail price changes could potentially reverse the streaming trend and convince users to switch. This requires dropping retail prices to the point where $P_r < u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt + (T_s - t)(P_s - F_1)$ would cause consumers to switch formats. Basically, retail prices must drop to the point where the ownership benefits $\left[u_i(x)\int_{T_s}^{T_r} e^{-\xi_i t}dt - P_r\right]$ exceed the remaining platform benefits $[(T_s - t)(P_s - F_1)]$.

[68] This analysis is a comparison of subscription vs purchasing decisions, which mirrors other consumption options consumers face for information goods. For example, purchasing versus streaming films, or purchasing eBooks versus an unlimited subscription.

[69] In the case with only one product and trivial platform benefits, this condition is met if $P_r < T_s P_s$

[70] Note that our analysis is only meaningful if $1 < t \leq T_s$.

[71] This means that $B > 0$ if the consumer would initially purchase the song and $B < 0$ if the consumer would initially subscribe to the streaming format.

Appendix 4: Proof for size of streaming library

Because of the ordering we've employed, it must be that $u_i(x_j) > u_i(x_{j+1})$. This implies that $u_i(x_{j+1}) \int_0^{T_r} e^{-\rho_i t} dt < P_r$, so x_{j+1} will not be purchased. However, for song $j+1$ it may be that $u_i(x_{j+1}) \int_0^{T_s} e^{-\rho_i t} dt + T_s(F_{j+1}) \geq 0$. Therefore, it must be that $S \geq R$ for any user.

In simpler language, the near-zero marginal cost of streaming songs means that songs that are not worth purchasing may still provide utility and be consumed with a streaming subscription. Using this relationship, 9 can be rewritten as:

$$u_i(X_{iR}) \int_{T_s}^{T_r} e^{-\rho_i t} dt - u_i(X_{i,x\in S-R}) \int_0^{T_s} e^{-\rho_i t} dt - E(Y_i) - T_s F_S + T_s P_s - RP_r \tag{23}$$

This expression can be separated into several components: the additional stream of utility from owning that extends beyond the subscription ($u_i(X_{iR}) \int_{T_s}^{T_r} e^{-\rho_i t} dt$), the additional utility from songs with insufficient utility to purchase accessible from a streaming subscription ($u_i(X_{i,x\in S-R}) \int_0^{T_s} e^{-\rho_i t} dt$), expected value from access to future songs ($E(Y_i)$), platform benefits ($T_s F_S$), and price differential ($T_s P_s - RP_r$). Note that the utility stemming from the additional stream of utility from owning that extends beyond the subscription and the expected value from access to future songs will only factor into a consumer's decision if they are forward-looking.

Appendix 5: Preference for retail sets

We evaluate the utility from each source when$|S| = |R|$ in any given time period. In addition, the lack of platform benefits implies that $F_S = 0$. Therefore, it is necessary to show that $u_i(X_{iR}) \int_{T_s}^{T_r} e^{-\rho_i t} dt > RP_r - T_s P_s$. Given $T_s > \frac{RP_r}{P_s}$, this implies that $0 > RP_r - T_s P_s$. Due to the substitution associated with streaming, retail songs will be consumed longer than the streamed version, or equivalently, $u_i(X_{iR}) \int_{T_s}^{T_r} e^{-\rho_i t} dt > 0$. Therefore, we can conclude that $u_i(X_{iR}) \int_{T_s}^{T_r} e^{-\rho_i t} dt > RP_r - T_s P_s$.

For users that purchase every song that yields utility, the format decision no longer involves an expansion of access from the streaming bundle. The user's decision is based on the length of their musical interests and song utility. Greater longevity makes the retail format more valuable, thus showing how duration of musical interest would drive format decisions. Importantly, this result indirectly highlights a subtle effect that subscription services have on a user identifying her consumption set. For this result to hold, the search costs necessary to identify the user's retail consumption set must be negligible, or equivalently, the cost of finding R songs of interest from the songs available must be sufficiently low (i.e. if $c|R|$ represent the number of songs of potential interest, with $c > 1$, then it must be that $(|R|(c-1))P_A \approx 0)$. This requires users to easily predict or identify which songs with sufficient value ($c \approx 0$) and/or have any sample costs be sufficiently low ($P_A \approx 0$). In this case, the format of delivery is unlikely to be the driving force behind users switching to the streaming format. Instead, reduced search costs increases the value of future new music ($E(Y_i) \gg 0$), thereby changing the consumer's consumption set and making the subscription service more appealing.

Table 1: Summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Spotify				
PeakRank	38.51	40.39	1	198
OpeningRank	92.11	65.17	1	200
OpeningStreams	2.47	2.91	0.17	26.35
PeakStreams	4.26	3.50	0.52	28.71
N		25,778		
Nielsen				
PeakRank	32.38	35.41	1	199
OpeningRank	92.22	66.45	1	200
N		96,477		
Radio				
PeakRank	68.43	52.39	1	199
OpeningRank	155.85	48.075	1	200
OpeningAudience	0.95	6.37	0	118.42
OpeningSpins	176.43	1062.74	0.01	17,294
PeakAudience	6.098	16.485	0	121.36
PeakSpins	1,033.71	2,583.15	0.01	18,245
N		67,728		

Rank variables are position in the top 200. Streams and audience are in millions. The peak week for each song is excluded from analysis and summary statistics. Nielsen sales data is excluded from this table as as it is proprietary.

Table 2: Spotify decline estimates

	(1)	(2)
	OddsRatio	OddsRatio
WeeksAfter	-0.10***	-0.10***
	(0.0064)	(0.0071)
TopTen*WeeksAfter	-0.0075	
	(0.0073)	
TopFifty*WeeksAfter		-0.0026
		(0.0078)
PeakedFirst*WeeksAfter	-0.0051	-0.0067
	(0.0085)	(0.0091)
Constant	5.20***	5.21***
	(0.41)	(0.42)
N	25778	25778
Fixed Effects	Yes	Yes

Standard errors in parentheses. Coefficients on indicators are the base odds ratio of the excluded group, and coefficients on continuous variables are the change in the odds ratio associated with a one unit increase in the variable. Fixed effects for song and week are not reported.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Radio listens decline estimates

	(1) Spins	(2) Audience	(3) Spins	(4) Audience
WeeksAfter	-0.055***	-0.072***	-0.12***	-0.14***
	(0.0041)	(0.0051)	(0.026)	(0.031)
TopTen*WeeksAfter	-0.012	-0.0088	-0.011	-0.0081
	(0.029)	(0.035)	(0.026)	(0.032)
PeakedFirst*WeeksAfter	0.022**	0.030**	0.017*	0.025**
	(0.0098)	(0.012)	(0.0095)	(0.012)
Streaming*WeeksAfter			0.069***	0.076**
			(0.026)	(0.032)
Constant	-2.37***	-2.86***	-2.35***	-2.84***
	(0.0080)	(0.0099)	(0.012)	(0.015)
N	67728	67728	67728	67728

Standard errors in parentheses. Coefficients on indicators are the base odds ratio of the excluded group, and coefficients on continuous variables are the change in the odds ratio associated with a one unit increase in the variable. Fixed effects for song and week are not reported.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Nielsen sales decline estimates

	(1) OddsRatio	(2) OddsRatio	(3) OddsRatio	(4) OddsRatio	(5) OddsRatio	(6) OddsRatio
WeeksAfter	-0.045***	-0.046***	-0.068***	-0.069***	-0.044***	-0.046***
	(0.0026)	(0.0026)	(0.0040)	(0.0037)	(0.0032)	(0.0034)
TopTen*WeeksAfter	-0.015**		-0.015**		-0.014**	
	(0.0067)		(0.0060)		(0.0058)	
TopFifty*WeeksAfter		-0.0074		-0.0098		-0.016**
		(0.0090)		(0.0090)		(0.0074)
PeakedFirst*WeeksAfter	0.014**	0.0062	0.015***	0.0067	0.012**	0.0046
	(0.0057)	(0.0044)	(0.0053)	(0.0045)	(0.0050)	(0.0037)
Streaming*WeeksAfter			0.025***	0.026***		
			(0.0041)	(0.0037)		
2007*WeeksAfter					-0.088***	-0.086***
					(0.0093)	(0.0091)
2008*WeeksAfter					-0.043***	-0.042***
					(0.0043)	(0.0045)
2009*WeeksAfter					-0.020***	-0.019***
					(0.0048)	(0.0046)
2010*WeeksAfter					-0.0078***	-0.0077***
					(0.0026)	(0.0026)
2012*WeeksAfter					0.0027	0.0039
					(0.0028)	(0.0027)
2013*WeeksAfter					-0.00037	0.0027
					(0.0041)	(0.0043)
2014*WeeksAfter					-0.0064	-0.0016
					(0.0044)	(0.0047)
2015*WeeksAfter					0.0037	0.0078*
					(0.0043)	(0.0046)
2016*WeeksAfter					0.0062	0.011***
					(0.0039)	(0.0040)
2017*WeeksAfter					0.018***	0.024***
					(0.0043)	(0.0044)
Constant	0.73***	0.86***	0.46**	0.62***	-0.55**	-0.63***
	(0.21)	(0.21)	(0.20)	(0.20)	(0.23)	(0.24)
N	96477	96477	96477	96477	96477	96477

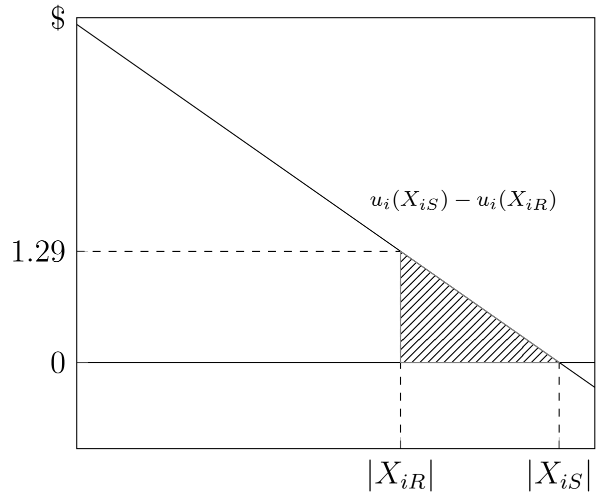
Standard errors in parentheses. Coefficients on indicators are the base odds ratio of the excluded group, and coefficients on continuous variables are the change in the odds ratio associated with a one unit increase in the variable. Fixed effects for song and week are included, but not reported.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: User Format Preferences

Depreciation (ρ_i)	Unique Songs ($\lvert X_{iR} \rvert$)	Expansion (δ_i)	Value ($)	Preference
		31%	8.31	Streaming
9.1%	34	3.4%	2.26	Streaming
		0.0%	1.52	Streaming
		31%	6.76	Streaming
5.3%	34	3.4%	0.71	Streaming
		0.0%	-0.04	Retail
		31%	6.34	Streaming
4.3%	34	3.4%	0.29	Streaming
		0.0%	-0.45	Retail
		31%	5.15	Streaming
1.5%	34	3.4%	-0.90	Retail
		0.0%	-1.64	Retail
	51		11.29	Streaming
5.3%	17	31%	2.23	Streaming
	8.6		0.00	Indifferent
	51		2.21	Streaming
5.3%	26.0	3.4%	0.00	Indifferent
	17		-0.76	Retail
	51		1.09	Streaming
5.3%	34.5	0.0%	0.00	Indifferent
	17		-1.16	Retail

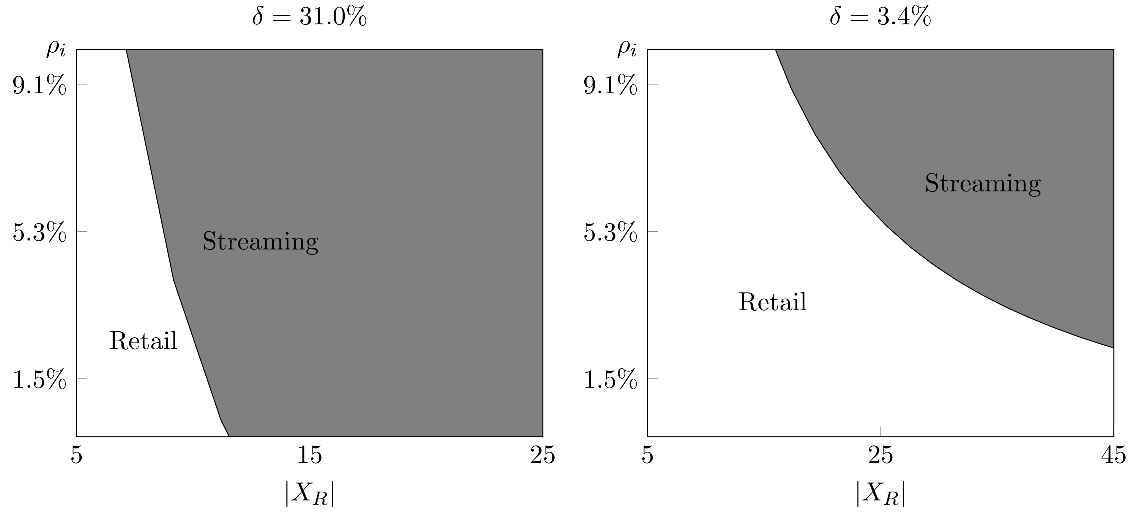
Notes: A retail price of $1.29 per song is assumed for all calculations. "Value" represents the estimated monetary benefit a user receives by utilizing the streaming format instead making retail purchases. "Preference" denotes a user's prefer format based off the value they receive, where any values below 0.0 indicate that the user would prefer the retail format.

Figure 1: Consumer Benefits from Music Consumption



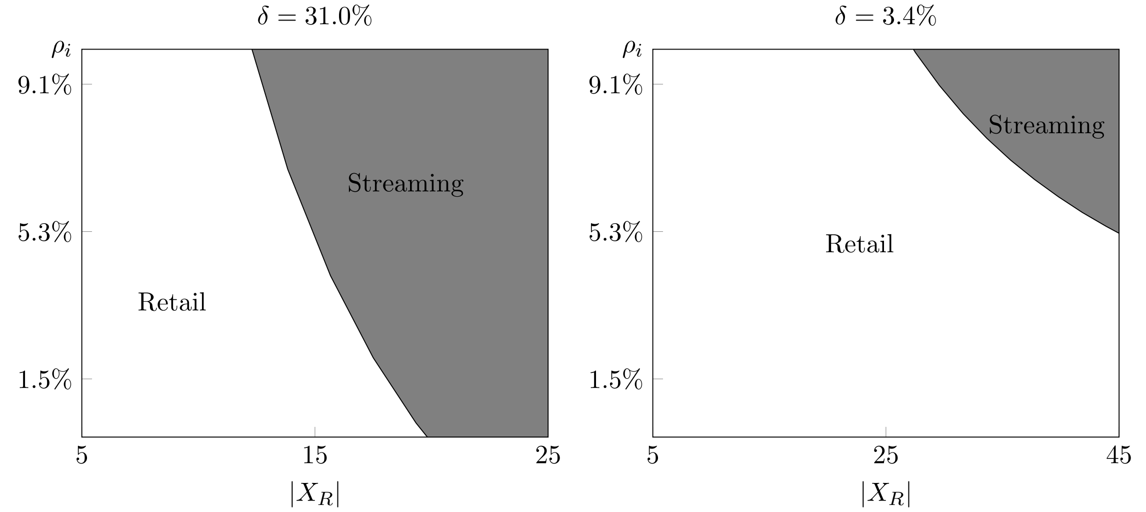
Notes: The height of the diagonal line represents utility from individual songs when aligned by user value. The song located at $|X_{iR}|$ ($|X_{iS}|$) denotes the last song yielding sufficient utility to be purchased (streamed). The shaded region represent forgone utility for retail consumers due to the retail price exceeding the song's utility.

Figure 2: Optimal Music Format



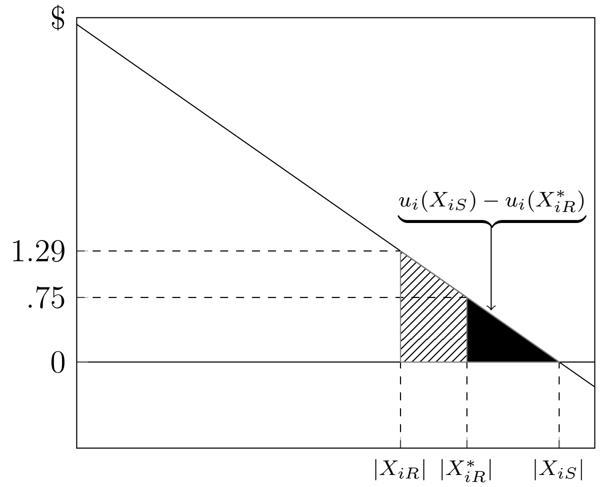
Notes: The vertical axis measures user depreciation rate and the horizontal axis measures user scope of listening (number of unique songs listened to weekly). A retail price of $1.29 per song is assumed for all calculations. The left (right) figure illustrates the optimal music format for users where streaming access would expands listening by 31% (3.4%) over the retail format. Users that fall in the light (shaded) region yield greater value from the retail (streaming) format.

Figure 3: Optimal Format with Lower Retail Song Prices ($0.75/song)



Notes: The vertical axis measures user depreciation rate and the horizontal axis measures user scope of listening (number of unique songs listened to weekly). A retail price of $0.75 per song is assumed for all calculations. The left (right) figure illustrates the optimal music format for users where streaming access would expands listening by 31% (3.4%) over the retail format. Users that fall in the light (shaded) region yield greater value from the retail (streaming) format.

Figure 4: Consumer Benefits after Retail Price Change



<u>Notes:</u> The height of the diagonal line represents utility from individual songs when aligned by user value. The song located at $|X^*_{iR}|$ denotes the last song with sufficient utility to warrant purchase at a retail price of $0.75. The solid region represents forgone music consumption for retail consumers.