Music consumption decisions with non-durable streaming options

Jason M. Walter[*] R. Scott Hiller[‡]

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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 user's preferred format depend on the intensity of their music interests, scope of interests, and how quickly a song's utility depreciates. Our empirical analysis shows that streaming consumers have greater depreciation rates than the traditional distribution of terrestrial radio, and that digital sales decline at a slower rate than does the usage of the streaming version. Our theory model and empirical evidence suggest 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. Using simulation, we identify the ideal consumption format for consumers based on their individual listening preferences.

JEL Classification: D11, D12, L8

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[*]Social Science Department, University of Wisconsin-Stout, 721 3rd St. E - Harvey Hall 441B, Menomonie, WI 54751. Email: walterja@uwstout.edu

[†]Corresponding Author: Department of Economics, Fairfield University, 1073 N. Benson Rd., Fairfield, CT 06824. Email: rhiller@fairfield.edu

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1 Introduction

The decline and displacement of physical music albums has been obvious since the emergence of digital formats in the early 2000s. The decline in album sales was blamed on music 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] Access to a large bundle could cause an increased substitution effect, where consumers switch between songs more quickly due to increased availability. 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

[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.

subscription ends access to the library of music also ends, while a durable physical or digital format can be used indefinitely. Unlike traditional music 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.

In order 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 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.We also find that there are scenarios where a rational consumer would prefer to purchase some songs, while still having a streaming subscription.

Beyond the possibility for an expanded library, this paper also explores the decline in utility of a song. It may be true that consumers prefer familiarity in songs (Ward et

[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.

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 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 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 lifetime utility between retail formats and streaming subscriptions, providing insights about the expansion of the streaming market in the United States. 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. This provides little insight about how much utility the music continues to provide consumers who have already purchased a song. 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. As a more direct measure of the decline in song value for consumers using traditional methods of distribution, we use the rate of decline in radio airplay. We contrast each of these results with the decline in consumption associated with streaming music. Given streaming and radio data, we show that a vast majority of songs reach a peak usage and decline relative to other options thereafter, indicating falling utility for the average user.

Empirically, we find that sales decline at a slower rate in the streaming era than the period immediately before. Additionally, radio listens also decline slower in that period. Our results indicate that songs using streaming distribution decline more rapidly from their peak than that experienced in radio. We consider this to be evidence of consumers with larger discount rates moving from traditional distribution to streaming, as well as the potential for these users to find value in the ability to expand listening among the vast

[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.

library of a streaming service. Finally, we calculate the ideal format based on consumer idiosyncratic preferences. This allows us to identify the optimal consumption method as a function of consumer depreciation, interests, and scope. 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 in-

[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.

ternet 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 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

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

and Walter, 2018).

Other papers have considered whether the streaming industry has added to the total 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, finding song level analysis yields inconclusive but definite results. 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 nondurable subscription or durable retail purchase. The

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

subscription must be renewed to continue access while the durable purchase is assumed available indefinitely. We make the simple assumption that marginal utility from the song will eventually fall with increased consumption. Therefore, consumer i purchases song x if net utility is positive, or more specifically:

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

Where $u_{ir}(x)$ represents the consumer's peak utility from a retail song, which we assume to occur in the period the song was purchased.[9] We focus on how a consumer's utility changes over the life of a song, specifically, we are interested in ρ_i, which represents a user's depreciation rate of the song's utility over time. 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. In order for the consumer to purchase the song utility must satisfy: $\int_0^{T_r} u_{ir}(x)\, e^{-\rho_i t} dt > P_r$. The consumer will continue to listen to a purchased song, x until period T_r, which satisfies: $u_{ir,T_r}(x)\, e^{-\rho_i T_r} = 0$. Using this framework, we can compare the benefits for a retail purchase of a song to a streaming subscription.

Streaming subscriptions have additional features that factor into a user'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 user's catalog, and include the inconvenience of requiring an internet connection, but also the benefits of organizing songs and discovering related songs.

A consumer will purchase a one-period streaming music subscription for a single

[9] Although we assume the peak happens in the first time period, we relax this assumption in the empirical section.

[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.

song if $\int_0^1 u_{is}(x)\,dt + F_1 > P_s$, where P_s represents the price per period for a streaming subscription. Note for a single song, utilizing the streaming platform will incorporate additional costs, therefore $F_1 < 0$. If a consumer decides to purchase a one-period music subscription to listen to the song, their utility will be $u_{is}(x) + F_1 - P_s$, where $u_{is}(x) = \int_0^1 u_{is}(x)\,dt$. If the consumer purchases a subscription for multiple periods, then the stream of utility from a subscription is:

$$\int_0^{T_s} u_{is}(x)\,e^{-\rho_i t}dt + T_s(F_1 - P_s) \tag{2}$$

where T_s represents the amount of time a consumer keeps the streaming subscription.[11] For now, we assume that the depreciation rate for a user (ρ_i) is uniform across formats.[12]

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 satisfies $u_{is}(x)\,e^{-\rho_i T_s} + F(1) - P_s = 0$ or $u_{is}(x)\,e^{-\rho_i T_s} + F_1 = P_s$. This implies that usage from the streaming service will continue until the subscription price exceeds the net benefits.

With both formats properly represented, we can identify the ideal format for any consumer. This requires comparing equations 1 and 2, and identifying the sign of the following expression:

$$\int_0^{T_r} u_{ir}(x)\,e^{-\rho_i t}dt - \int_0^{T_s} u_{is}(x)\,e^{-\rho_i t}dt - T_s(F_1 - P_s) - P_r \tag{3}$$

Where a positive value means the consumer should purchase the song, and a negative

[11] In the single song case, the user will continue to listen to the song x and keep the subscription until period T_s, which satisfies: $u_{is}(x)\,e^{-\rho_i T_s} - P_s = 0$.

[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 problem for a subscription can be rewritten as: $\int_0^{T_s} [u_{is}(x)\,e^{-\rho_i t} + F_1 - P_s]\,dt$

value implies the consumer should utilize the streaming option. To simplify our evaluation of each option, we make two assumptions. First, we assume that the utility of listening to a song is independent of the format, therefore $u_{ir}(x) = u_{is}(x) = u_i(x)$, and then examine the utility received in the last period of each format. Since $u_i(x) e^{-\rho_i T_s} = P_s - F_1$ (note: $P_s - F_1 > 0$) and $u_i(x) e^{-\rho_i T_r} = 0$, this implies that $T_r > T_s$, or equivalently:

Remark 1 *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.*

This allows us to rewrite equation 3 as:

$$\int_{T_s}^{T_r} u_i(x) e^{-\rho_i t} dt - T_s(F_1 - P_s) - P_r \tag{4}$$

We use this expression to examine the user's preferred format by determining the sign of the variable.[13] Further examination allows us to conclude that 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, or equivalently if $\int_{T_s}^{T_r} u_i(x) e^{-\rho_i t} dt > P_r + T_s(F_1 - P_s)$ then consumers are better off purchasing the song. This 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.

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 for a sufficient duration.[14] In the case with only one product and trivial platform

[13] As before, a positive (negative) value implies that retail (streaming) format is preferred.

[14] 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.

benefits, this condition is met if $P_r < T_s P_s$.

Next, we examine what happens 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. The consumer's decision to switch from a subscription to retail requires analyzing the stream of utility each format provides. In order for the consumer to switch to the retail version from the streaming version, their utility in some period t must satisfy:

$$\int_t^{T_r} u_i(x)\, e^{-\rho_i t} dt - P_r > \int_t^{T_s} u_i(x)\, e^{-\rho_i t} dt + (T_s - t)(F_1 - P_s) \tag{5}$$

This expression can be further simplified to: $\int_{T_s}^{T_r} u_i(x)\, e^{-\rho_i t} dt - P_r > (T_s - t)(F_1 - P_s)$. If a consumer initially decided to use the subscription format for a single song, it implies that the expression in 4 yielded a negative value, or equivalently her utility satisfied: $\int_{T_s}^{T_r} u_i(x)\, e^{-\rho_i t} dt - T_s(F_1 - P_s) - P_r < 0$.[15] Let B represent the format decision condition provided in 4 or equivalently $B = \int_{T_s}^{T_r} u_i(x)\, e^{-\rho_i t} dt - T_s(F_1 - P_s) - P_r$, where B represents the net benefit of utilizing the retail format relative to a subscription.[16] Since the user initially streamed the song, we can conclude that $B < 0$. Simplifying 5, we obtain the necessary condition for a consumer to switch to the retail format: $B > -t(F_1 - P_s)$. Since $B < 0$ and $F_1 - P_s < 0$, the necessary condition will never be satisfied, therefore, we can conclude that:

Remark 2 *In the single song case, a consumer will never purchase a song if they have previously decided to stream the song, ceteris paribus.*

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. Examining the change from retail to streaming in the case of only one song may

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

[16]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.

seem trivial, but it illustrates that users with large catalogs of music (and no interest in new music) are unlikely to switch to streaming formats. 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 using a subscription after purchasing a song, these features may be more relevant when multiple songs are considered.

3.2 Bundle value

The previous analysis provided insights into how subscription pricing impacts consumer utility derived from music consumption. However, this simple analysis 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. For the remainder of our analysis, a user's utility from a specific song represents the extra benefit received relative to passive music consumption available from the format requiring the least effort.[17]

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 user's utility satisfies: $u_i(x_j) > u_i(x_k)$, whenever $j < k$. 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, $X_{ik} = [x_1, x_2, ...x_k]$.[18] Without loss of generality, we assume that the group of songs represents the user's initial consumption set.[19]

First we consider a consumer who purchases retail music. Her initial consumption

[17]Since our focus is on a song's value, we assume $F_i = 0$ in this section.

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

[19]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.

set is determined by the following utility optimization problem:

$$\max_{R} \int_{0}^{T_r} u_{ir}\left(X_{iR}\right) e^{-\rho_i t} dt - RP_r \tag{6}$$

Where X_{iR} represents the songs purchased by the user or the retail consumption set. For the retail user, the consumption set could change in later periods if the user purchases new songs. In the retail scenario it is also possible that the user's consumption set in later periods is not comprised of the highest utility songs. For example, an older more "played-out" song that has depleted most of its utility, 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.[20]

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 users will optimize their streaming consumption set when new music becomes accessible through the service. 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 user purchases access to the entire streaming bundle, consumption of new songs occurs regularly. The costless addition of new songs ensures that a user's streaming set is always comprised of only the highest utility songs. The addition of new songs also causes substitution as $u_{is}(X_{iS-\{y\}}) + u_{is}(x_y) > u_{is}(X_{iS})$, where y denotes an arbitrary song from the consumption set. To state formally, the addition of a song to the user's consumption set displaces some utility received from other songs in the set.[21] An added song does not need to be the most preferred song in the consumption set for a

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

[21] 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 user's time is the constraint, not their income.

user to reduce listens of other songs.[22] Overall, the inclusion of song y causes the user's net utility from the consumption set to increase.[23]

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

$$\max_{S} \int_{0}^{T_s} \left[u_{is} \left(X_{iS} \right) e^{-(\psi_i + \xi_i)t} - P_s \right] dt \tag{7}$$

Where ψ_i represents the discount rate of a song, which corresponds to a song becoming played-out. ξ_i represents the substitution rate, which is the rate at which users churn different songs into their consumption set. Therefore, on the streaming platform the user's depreciation rate is $\rho_i = \psi_i + \xi_i$. The last period the user subscribes to a streaming platform is represented by T_s.[24]

Since our focus is on the rate at which usage of the initial streaming set decreases over time, we set $e^{-\xi_i t} = \frac{u_{itS}(X_{itS} - Z_{it})}{u_{itS}(X_{itS})}$, where Z_{it} is the set of music a user has in a streaming set in time t that was added after period 0. Therefore, utility from a specific song or set of songs is expected to decrease at a rate of $e^{-\xi_i}$ due to the user replacement or substitution to other songs. Essentially, we expect that any decrease in song usage and relative utility are at least partially attributable to the increasing in user acess to other songs from streaming.

Using this representation, we can represent the rate at which aggregate utility (denoted with subscript "I") declines. Using consumption of all streaming users of a set of songs, the rate that aggregate utility declines within one period subscription is:

$$\left[U_s \left(X_S \right) e^{-(\psi_I + \xi_I)t} \right]_0^1 - P_s \tag{8}$$

[22]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.

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

[24]Unlike the single song case, the user may stop using a song before the end of her subscription.

Similar to Hiller and Walter (2018), we assume utility and listens of a song are directly related. Therefore, we can empirically identify a song's decline by examining the number of listens for a collection of songs. Let $u_i(X_{iS})$ denote a representative user'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,[25] so we define the initial average utility from a bundle of songs by format as $U_s(X_S) = \alpha \sum_{i=1}^{I} \sum_{j=1}^{N} streams_{sij0}$. Where $streams_{sij0}$ is the initial number of streaming listens for song j by user i and α is a scalar mapping overall song listens to an average utility for each consumer.[26] As a result, the average rate (denoted with a bar) of decline can be shown to be $e^{-(\overline{\psi}+\overline{\xi})t}$, and by definition:[27]

$$\alpha \sum_{j=1}^{N} streams_{sjt+1} = \alpha \sum_{j=1}^{N} peak_{sjt} e^{-(\overline{\psi}+\overline{\xi})} \tag{9}$$

Using the number of listens for individual songs, the depreciation rate can be estimated with the following equation:[28]

$$streams_{sjn+t} = \gamma_{sn+t} peak_{sjt} + \alpha_{n+t} + \lambda_j + \epsilon_{jn+t} \tag{10}$$

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 ($\gamma_{sn+t} = e^{-(\psi_I+\xi_I)(n)}$) from the peak streams ($peak_{sjt}$) 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 average depreciation rate for a

[25] We make the distinction that *listens* are from a single consumer, while *streams* represent the aggregate.

[26] 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.

[27] We examine how a set of songs would decline by examining the aggregate decline of each song individually so identifying the initial set as discussed in the theory section is unnecessary.

[28] We estimate the average rate (ρ) of decline over time. Similarly, we estimate the average (ρ) for a traditional format more directly using radio data.

set of songs in one period is:

$$\left[U_r \left(X_R \right) e^{-\overline{\rho}t} \right]_0^1 - RP_r \tag{11}$$

Using the number of listens for individual songs the average depreciation rate can be estimated with the following equation:

$$streams_{rjn+t} = \beta_r peak_{rjt} + \alpha_{n+t} + \lambda_j + \epsilon_{jn+t} \tag{12}$$

Where β_r captures the average depreciation rate ($\beta_r = e^{-\overline{\rho}(n)}$). 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. We explore this possibility in the next section. With our current model we can test whether:

Remark 3 *The song usage declines at a faster rate for streaming versions than retail versions.*

4 Empirical model

In our 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 depreciation, substitution, and fixed effects such that:[29]

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

[29] For this section we remove the s and r subscripts, and assume general estimation can be done for both with the same specification as we cannot identify ρ and ξ separately.

Where $\gamma = e^{-(\psi_I + \xi_I)(t)}$ for streams and $\gamma = e^{-(\rho_I)(t)}$ 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. We do that by dividing both sides by the individual song's peak number of listens, generating

$$PercentageofPeak_{jn+t} = \gamma_{n+t} + \phi_{jn+t} + \tau_j + \sigma_{jn+t} \tag{14}$$

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 14 would transform γ to $-(\overline{\psi} + \overline{\xi})(t)$, providing identification for $\overline{\psi}$ and $\overline{\xi}$ jointly in streaming music and radio, and $\overline{\rho}$ individually for sales.

Empirical estimation differs slightly from the theory result. In order to bound the probability while allowing for fixed effects, we take a log transformation of the percentage, ln(P/1-P), before performing a least squares regression. 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. Where appropriate, we convert the coefficient of the variables of interest explained in the theory section.

4.1 Estimation

As we have shown above, the discount and substitution rates of an information good are crucial in the decision to subscribe or purchase. The quicker the consumer discounts or substitutes a song, the more attractive a streaming subscription becomes. We can observe an approximation of that decline 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 and substitution we are interested in, but also potentially the addition of new listeners each week, even post-peak. The estimated combined discount and substitution 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.

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.[30] 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:

$$ln(P_{jt}/(1 - P_{jt})) = \delta_0 + \gamma WeeksAfter_{jt} + \delta' z_{jl} + \alpha_t + \lambda_j + \epsilon_{jl} \quad (15)$$

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 and substitution, $-(\overline{\rho} + \overline{\xi})$. 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, interacting indicators for debuting in the top of the charts with $WeeksAfter$ variables 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.[31]

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.

[30]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.

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

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.

Given that 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.[32]

4.2 Data

We use several sources for data on song consumption. First, 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 sample includes the top 200 songs sold each week 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 songs that do not reach that top. The exclusion is only important if the rate of decline differs between top 200 songs and other, less popular songs. The dataset includes digital sales from 2009 to 2017.

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. The charts run from July of 2015 to June of

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

2018. Again, as the dataset only includes the top 200 songs this is not necessarily representative of the entire library. However, 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.

We also analyze the weekly Hot 200 US radio airplay datasets for two time periods.[33] 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 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.[34] 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.

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.[35] 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.

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

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

[35] 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.

4.3 Discount and substitution 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 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 the combined $\overline{\psi}$ and $\overline{\xi}$ values, which we use to calculate the decline in streams by using equation 9. This result implies a 9.1 percent decline in a song's consumption each week past the peak on the Spotify platform. We cannot further delineate the decline in utility and substitution effects, and the substitution effect may be of increased importance given the ease of change on the streaming platform. Although it would be preferable to identify these effects separately, the combined rate of change is most important for the consumer choosing format. We also test the significance of peak position and the period when a song peaks, however, both are insignificant in this specification.

Table 3 displays results for the specification using Nielsen 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 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.

Given that sales data is only useful for comparing time periods, we consider another traditional method of music consumption, 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 4 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 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.[36] 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.

5 Consumption decision

Our empirical analysis shows how consumer preferences greatly impact which format to choose. In this section, we compare a user's simulated utility from enrolling in a streaming subscription and making retail purchases. We consider the characteristics that attract consumers to streaming services: access to new music (price per song), broader song

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

access (scope), platform features, or discounting. While external factors can also affect consumption, we focus on how users' preferences influence their music format choices.

5.1 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 users 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 (or $\xi_i = 0$) but have a uniform deprecation rate across formats ($\rho_i = \psi_i$).[37] We first examine a consumer that is only considering a streaming music subscription, optimizing her utility requires solving:

$$\max_S \int_0^{T_s} u_{is}\left(X_{iS}\right) e^{-\rho_i t} dt + \sum_{i=1}^{M} E(y_{it}) + T_s(F_S - P_s) \tag{16}$$

where M is the expected number of future songs with value to the user.[38] $\sum_{i=1}^{M} E(y_{it})$ (or simply, $E(Y_i)$) represents the total expected value for the set of songs that will enter the bundle in future periods when they have a subscription.[39]

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: $\int_0^{T_r} u_{ir}\left(X_{iR}\right) e^{-\rho t} dt - RP_r$. Therefore, if a consumer utilizes only one format, her decision requires identifying the sign for the following expression:

$$\int_0^{T_r} u_{ir}\left(X_{iR}\right) e^{-\rho_i t} dt - RP_r - \left[\int_0^{T_s} u_{is}\left(X_{iS}\right) e^{-\rho_i t} dt + E(Y_i) + T_s(F_S - P_s)\right] \tag{17}$$

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

[38]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.

[39]We assume that expected value for each periods is identical.

Comparing the utility received from each format, we identify the size of a user's consumption set, specifically, if $|X_{iS}| \leq |X_{iR}|$ or $|X_{iS}| \geq |X_{iR}|$ (or equivalently $S \leq R$ or $S \geq R$). To determine 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 user's opportunity cost, so 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 $\int_0^{T_r} u_{ir}(x_j) e^{-\rho_i t} dt - P_r = 0$ for song j and $\int_0^{T_s} u_{is}(x_k) e^{-\rho_i t} dt + T_s(F_k) = 0$ for some song k, where $j < k$. From this, we can conclude:

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

Proof. Because of the ordering we've employed, it must be that $u_{im}(x_j) > u_{im}(x_{j+1})$ for any format m ($m \in \{r, s\}$). This implies that $\int_0^{T_r} u_{ir}(x_{j+1}) e^{-\rho_i t} dt < P_r$, so x_{j+1} will not be purchased. However, for song $j+1$ it may be that $\int_0^{T_s} u_{is}(x_{j+1}) e^{-\rho_i t} dt + T_s(F_{j+1}) \geq 0$. 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 (because of the retail price) may still provide utility and be consumed by users with a streaming subscription. Using this relationship, the expression from 17 can be rewritten as:

$$\int_{T_s}^{T_r} u_{ir}(X_{iR}) e^{-\rho_i t} dt - \int_0^{T_s} u_{is}(X_{i,x \in S-R}) e^{-\rho_i t} dt - E(Y_i) - T_s F_S + T_s P_s - R P_r \quad (18)$$

This expression can be separated into several components: the additional stream of utility from owning that extends beyond the subscription subscription ($\int_{T_s}^{T_r} u_{ir}(X_{iR}) e^{-\rho_i t} dt$), the additional utility from songs with insufficient utility to purchase accessible from a streaming subscription ($\int_0^{T_s} u_{is}(X_{i,x\in S-R})e^{-\rho_i t}dt$), expected value from access to future songs ($E(Y_i)$), platform benefits (T_sF_S), and price differential ($T_sP_s - RP_r$). 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 consumers decision if they are forward-looking.

Rearranging equation 17 allows the consumer to choose between formats. If a consumer is to choose a durable purchase the following inequality must hold:

$$\int_{T_s}^{T_r} u_{ir}\left(X_{iR}\right)e^{-\rho_i t}dt - RP_r > \int_0^{T_s} u_{is}\left(X_{i,x\in S-R}\right)e^{-\rho_i t}dt + E(Y_i) + T_s(F_S - P_s) \quad (19)$$

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 (relevant) music ($E(Y_i)$).

Using 19, the ideal format can be identified for any consumer with a specific set of preferences. This allows us to conclude the following:

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.*

Proof. In this scenario, 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 $\int_{T_s}^{T_r} u_j\left(X_{iR}\right) e^{-\rho_i t} dt > RP_r - T_s P_s$. 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, $\int_{T_s}^{T_r} u_i\left(X_{iR}\right) e^{-\rho_i t} dt > 0$. Therefore, we can conclude that $\int_{T_s}^{T_r} u_j\left(X_{iR}\right) e^{-\rho_i t} dt > RP_r - T_s P_s$. ■

Next we examine the utility from utilizing both formats. In our representation we assume that the songs with the highest utility are purchased in the first period and consumed using the retail format.[40] Using equation 17 and adding the overlapping usage from each source ($\int_0^{T_s} u_{is}\left(X_{i,x\in R}\right) e^{-\rho_i t} dt$), allows us to represent the utility from using both formats as:

$$\int_0^{T_r} u_{ir}\left(X_{iR}\right) e^{-\rho_i t} dt + \int_0^{T_s} u_{is}\left(X_{i,x\in S-R}\right) e^{-\rho_i t} dt + E(Y_i) + T_s(F_{|S|-|R|} - P_s) - RP_r \quad (20)$$

Comparing the use of both formats to benefits of only purchasing (equation 6) shows that users that select both formats must satisfy: $\int_0^{T_s} u_{is}\left(X_{i,x\in S-R}\right) e^{-\rho_i t} dt + E(Y_i) + T_s F_{S-R} > T_s P_s$ 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.

5.2 Ideal format

In this section we use the estimated consumption habits for the average user to identify the ideal music format based on a consumer's idiosyncratic preferences. Using estimates

[40]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.

for depreciation, intensity, and scope of music interest we compare the benefits for each format.[41]

We begin by assuming that the user's time spent listening to music and scope (size of her consumption bundle) are relatively consistent in each time period but differ for each format.[42]. The user's first period consumption where the amount of music that user i utilizes satisfies a time constraint: $B_{i0} = a_1x_1 + a_2x_2 + ... + a_Mx_M = \sum_{j=1}^{M} a_jx_j$, where $M \in [R, S]$. If we assume the initial value of a song, along with the 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: $B_{i1} = (a\,|X_{iM}|)\,e^{-\rho_i} + aY_{iM}$, where Y represents the number of new additions to the user's consumption bundle or, equivalently, the replacement rate of songs for user i on format M per period.

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 user's listening habits (number of songs or $|X_{iM}|$) and the user'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 user's time budget and scope are relatively stable (but still differ by format), we would expect that the deprecation 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. As a result, the differing depreciation rates that occur across formats can indirectly be captured by evaluating the user'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

[41]Continuing a simple choice we focus on the decision to make retail purchases or enroll in a streaming subscription.

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

less favored songs, specifically those that are only in the streaming consumption bundle.[43] 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. Furthermore, the ideal format depends on how a user's utility differs with each format.

Comparing a user'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 user's utility from each format as the consumer surplus stemming from their 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 $u_{iS}(X_{iS}) - u_{iR}(X_{iR})$, 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 define the demand for unique songs for both formats, as shown in figure 1.

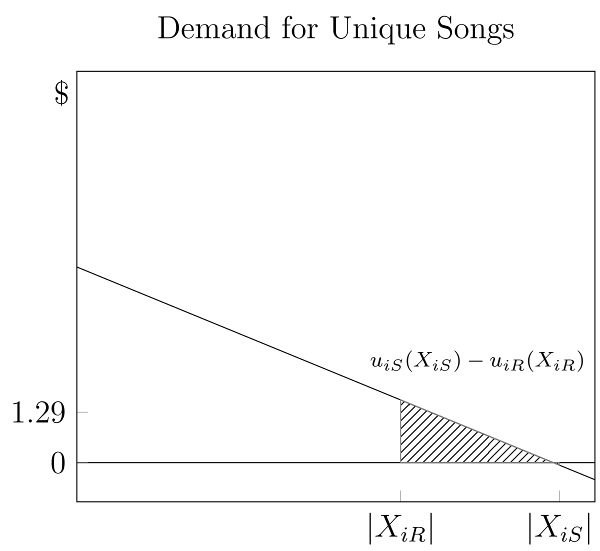

Fig. 1 Consumer surplus from songs

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

We consider that all users have access to music in some form whether it be older songs, radio, or free streaming with shuffled playback.[44] Therefore, a representative user'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 user's benefit per period and identify the user's optimal format for music consumption. For streaming, the maintenance costs are straightforward as adding new songs to a user's bundle is free, therefore the "average" cost per period is just P_s. The user's net benefit from the streaming format (per period) can therefore be represented as: $u_{iS}(X_{iS}) - P_s$. 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: $u_{iR}(X_{iR}) - P_r Y_{iR}$ or equivalently, $u_{iR}(X_{iR}) - P_r(1 - e^{-\rho_i})|X_{iR}|$.

Using these results, the representative user's optimal format can be identified by signing the following equation:

$$u_{iS}(X_{iS}) - P_s - \left[u_{iR}(X_{iR}) - P_r\left(1 - e^{-\rho_i}\right)|X_{iR}|\right] \tag{21}$$

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

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 give plausible examples of song expansion. Specifically, we first use the finding that the adoption of Spotify increases a user's overall music consumption by 49% and the quantity of unique songs they listen to by 31% on average,[45] relative to similar users that do not utilize streaming methods. As a low end value, we take the result that the number

[44] 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.

[45] 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. This provides empirical evidence of our result from proposition 4.

of new songs is increased by 3.4 percent for streaming adopters versus non-streamers.[46] These findings allow us to calculate song expansion from a user'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 user'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.[47] Substituting these values in 21 yields:

$$\underbrace{\$1.29\left(\frac{\delta_i}{2}\right)|X_{iR}|}_{[u_{iS}(X_{iS})-u_{iR}(X_{iR})]/\text{wk}} \; -\underbrace{\$2.30}_{P_S/\text{wk}}+\underbrace{\$1.29\left(1-e^{-\rho_i}\right)|X_{iR}|}_{\text{Price of retail/wk}} \tag{22}$$

We illustrate the effect of each component by using two simulations of different consumer characteristics. The deprecation rate we use in both are based off our previous weekly estimations (4.3%, 5.3%, and 9.1%) and an additional lower rate of 1.5% (so we examine 5.3%±3.8%). If we assume a user'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 user's song-expansion constant with either value, we can identify a user's ideal format, which depends on their scope of listening habits (number of songs or $|X_M|$) and the user's depreciation rate (ρ_i). Figure 2 illustrates the ideal format based on user's depreciation and scope of listening habits based on two levels of song-expansion (31% and 3.4%).

[46] 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.

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

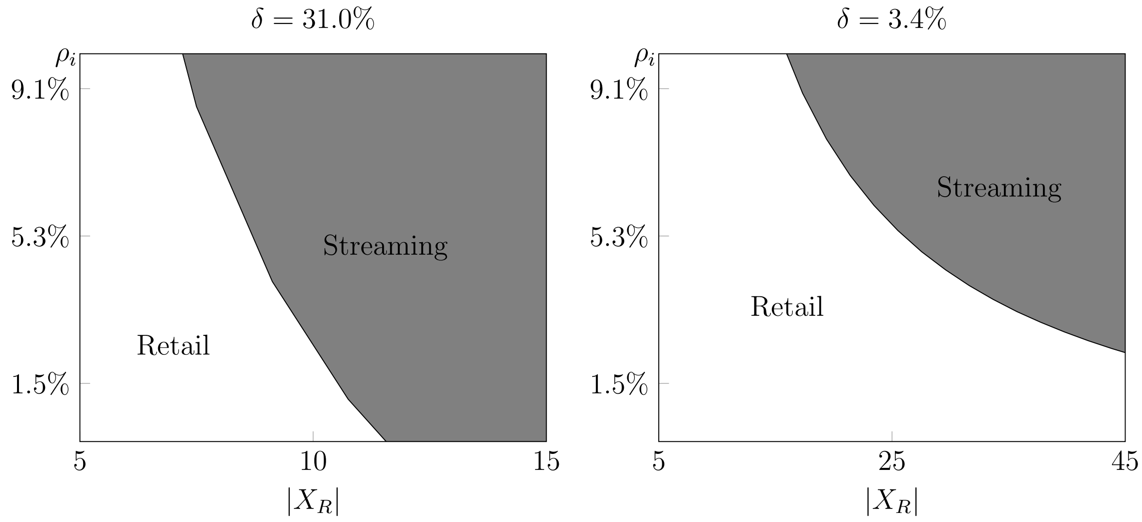

Fig. 2 Optimal Music Format

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 very sensitive to depreciation. The size 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. Conversely, if the utility from an individual songs declines quicker the consumer would need to rely on new music, which is a benefit of streaming.

We can also find the value to the typical consumer. Using Datta et al. (2018), we consider a starting value of 34 plays which we use for the consumer's initial retail consumption set.[48] 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

[48] Datta et al. (2018) reports that when consumers adopt a streaming subscription, iTunes playcounts decreases 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.

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% yields 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 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 examined based on a user's scope of listening of 34 songs (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 the 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.

Our results also come with a few caveats. First, we assume that the consumer is somewhat myopic, and thus discounts the future implications of their current consumption 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. 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 (44%), laptop/PC (37%), television (23%), and tablet/e-readers (20%) being the most common devices (Neilsen.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.[49] Retail or subscription prices could change in the future, as a result of streaming adoption, which would alter the relative value of each format.

Our simulation illustrates how the extent of how format differences impact a user'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. First, 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. Second, 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. Finally, 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.

6 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. Con-

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

sumers 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 consumers of streaming music experience a swifter decline in value of music relative to a peak than the traditional distribution channel of radio. Additionally, song sales and radio airplay decline slower in the streaming era as 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 theory of decline is 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. 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. These ideas may also apply to the publishing industry, the news industry, video games, 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 the diffusion of this method of distribution may be limited by these factors, expansion seems all but guaranteed as our simulations indicate that the average serious 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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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 propietary.

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: 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 4: 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 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

“Value” represents the additional benefit of using streaming format over retail. Any values below 0.0 indicate that the user would prefer the retail option.