# As Streaming Reaches Flood Stage, Does it Stimulate or Depress Music Sales?*

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**Abstract**

Streaming music services have exploded in popularity in the past few years, variously raising optimism and concern about their impacts on recorded music revenue. Even if streaming displace sales, it may still raise overall revenue if the streaming payment is large enough in relation to the extent of sales displacement. We make use of the growth streaming during the years 2013-2015 to measure their collective impact on unpaid consumption and on the sales of recorded music. We are unable to statistically distinguish the distinct impacts of these services, but we reject that their combined impact on sales is zero. We also find that streaming displaces music piracy. Given the current industry's revenue from track sales ($0.82 per sale) and the average payment received per stream between $1.51 and $2.77 per thousand streams or, on average, about $2.14 per thousand streams, our sales displacement estimates show that the losses from displaced sales are roughly outweighed by the gains in streaming revenue.

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# 1 Introduction

Streaming music distribution is growing rapidly around the world, raising questions about its impact on the revenue to rights holders generated by recorded music. Since 2010, the number of active Spotify users has grown from 15 to 100 million worldwide. In the US, volumes of streaming on Pandora and YouTube exceed those for Spotify and have also grown rapidly. By the end of 2015, Pandora was streaming roughly 6 billion songs per week. While some observers hail streaming as the salvation of a recorded music industry dogged by piracy, others raise alarm about low payments from streaming services and displacement of permanent downloads. Musician disclosures of royalty statements from streaming services have led the New York Times to question "whether these micropayments can add up to anything substantial."[1]

Anecdotes aside, economics offers two broad ways to think about streaming. First, streaming offerings are bundles of zero-marginal cost products. Given that different consumers' valuations of songs are not perfectly positively correlated, streaming bundles hold the possibility of raising revenue, consumer surplus, or possibly both, depending on how they are priced.[2] Successful bundling would translate some of the interest in music not generating a la carte sales - unpaid consumption and deadweight loss - into willingness to pay for the bundled offering.[3] Second, streaming potentially displaces sales of digital singles and physical albums.

Determining whether streaming stimulates or displaces the sales of recorded music is vital to our understanding of its impact on the fortunes of the recorded music industry. Some argue that streaming functions as music promotion, much like traditional terrestrial radio. If this is true, then this demand stimulation - combined with greater appropriability made possible by bundling - would give streaming an unambiguously positive impact on recorded music revenue. Others

[1]Sisario, Ben. "As Music Streaming Grows, Royalties Slow to a Trickle." New York Times, Jan. 28, 2013. http://www.nytimes.com/2013/01/29/business/media/streaming-shakes-up-music-industrys-model-for-royalties.html. The article describes the payments to cellist Zoe Keating. Musician David Lowery complained that Pandora paid him $16.89 for playing his famous song "Low" a million times, "less than what [he] make[s] from a single t-shirt sale!" See Hogan (2013) (http://www.spin.com/articles/pandora-david-lowery-cracker-low-royalties-debate-streaming/?fullsite=true). Finally, Radiohead's Thom Yorke has colorfully called Spotify "the last desperate fart of a dying corpse." (http://www.theguardian.com/technology/2013/oct/07/spotify-thom-yorke-dying-corpse). *Rethink Music* - an initiative of the Berklee Institute for Creative Entrepreneurship - has also recently proposed solutions to "increase transparency, accelerate transactions and cash flows, and reduce inefficiencies in the global music industry" (Rethink-Music, 2015).

[2]See the literature on bundling in general (Stigler, 2007; Adams and Yellen, 1976; Schmalensee, 1984) and music bundling in particular (Shiller and Waldfogel, 2011).

[3]Streaming also represents a business strategy of renting, as opposed to selling, access to recorded music, which can be advantageous for producers by eliminating resale, among other mechanisms (Varian, 2000).

believe that streaming functions as a substitute for music purchase, muting the benefits. But even if streaming displaces sales, it does not necessarily depress music revenue; that depends on whether the streaming payment is high enough to offset and potentially overcome the reduction in revenue from forgone permanent sales. Revenue is the sum of revenue from music sales and streams. That is, $rev = p_d q_d + p_s S$, where $q_d$ is the number of track-equivalents sold (e.g. digital downloads from iTunes, etc.), $S$ is the number of streams, and $p_d$ and $p_s$ are the revenues generated per track sale and stream, respectively. If sales depend on streams, then $q_d = q_d(S)$, and the change in revenue with an additional stream is $\frac{\partial rev}{\partial S} = p_d \frac{\partial q_d}{\partial S} + p_s$. An increase in streaming therefore raises revenue if any negative impact of streaming on sales is sufficiently small, i.e. if the additional revenue associated with a stream, $p_s$, exceeds the revenue loss that an additional stream engenders through track sales ($\frac{\partial q_d}{\partial S} p_d$).

Hence, it is of substantial interest to know not only *whether* streaming displaces sales but, if so, at *what rate.* In addition, we need to compare the rate of sales displacement with the relative payments to rights holders for streaming and a la carte permanent sales in order to determine whether streaming raises or reduces recorded music industry revenue. Moreover, the effect of streaming on sales may vary across types of services (on-demand vs non-interactive). If possible, we would like to measure the distinct displacement/stimulation impacts of different types of services.

The goal of this paper is to analyze data on streaming, sales, and unpaid consumption to determine how streaming is affecting revenue to the recorded music industry. The first - and main - empirical task is to measure the impact of streaming on sales, as well as the impact of streaming on piracy. To measure the impact of these services on these consumption outcomes, we might ideally launch services in some countries and not others, then monitor what happens to sales and unpaid downloads. Recent experience bears some resemblance to this experimental ideal. Spotify, founded in 2006, has grown at different rates in different countries and has grown very quickly since 2011. Pandora, founded in the US in 2000, grew rapidly from 2008 to 2012 and has grown more slowly since. Streaming at YouTube has also grown increasingly fast each year since 2012 and particularly fast since late 2015.

To measure the impact of streaming, we would ideally have high frequency song-level data on sales, piracy, and volumes of streaming on all of the major streaming services. We would also need these data for a period covering substantial growth in streaming that we might plausibly view as exogenous to song demand. With song-level data we could ask whether songs that are streamed more in a particular country and week sell or are pirated more or less in those times and places. For both theoretical and econometric reasons detailed below, we might expect different relationships between streaming and sales, and between streaming and piracy, at the song, as opposed to the aggregate (country) level. Still, if we had these ideal data we could address two kinds of questions. First, we could estimate the effects of streaming. Second, we could explore how the level of aggregation - and the associated choice of which variation to exploit for measuring the potentially displacing effect of streaming - influences the identified effect.

Our actual data, while in many ways appealing, deviate from the ideal. Indeed, it is the deviation of our actual data from the ideal that makes up the exercise challenging and, at the same time, makes those details important. We have weekly song-level measures of digital track sales for 21 countries but only for the two years 2012-2013 that include some but not the most rapid growth in streaming to date. We have weekly song-level streaming measures for all of these countries, but only for the top 50 songs (by country and week) and only for one of the major streaming services, Spotify, which began releasing data in April 2013.[4] We also have weekly artist-level piracy measures for the same 21 countries and the entire 2012-2013 time window. We refer to these data collectively as our "international product-level data."[5] We can combine track sales, Spotify streams, and piracy data to undertake song or artist level regressions of sales and piracy on streaming at Spotify. We can also aggregate the data to the country-by-week level to ask how aggregate sales and piracy covary with the growth in Spotify streams.

For the longer period 2012-2015, we also have aggregate US data on weekly digital and physical music sales as well as measures of the volume of streaming at Spotify, Pandora, and YouTube, which are representative of the three broad types of streaming: on-demand audio, non-interactive audio, and on-demand video, respectively. These "aggregate US" data - which we derive from public sources - have the virtues of both including the most prominent streaming services, as well as covering a period of rapid growth in US streaming.

Each of our two broad datasets has advantages and shortcomings. The international product-level data are particularly useful for exploring how levels of aggregation affect displacement

[4] In October, 2014 they extended this list to the top 200 songs.

[5] We use the term "product-level" for rhetorical simplicity even though the piracy data are at the artist and not the song level.

estimates. Because they include a piracy measure, they are also useful for allowing a contrast between streaming's displacement of sales and piracy. These advantages come with two major shortcomings, however. First, they cover a period prior to much of the growth in streaming. Second, the international product-level data include an explicit measure of streaming for only one major service, Spotify. The US aggregate data have three major advantages. First, they cover a context of rapid growth in streaming with some variation in the growth patterns across platforms. Second, we have measures of the major streaming services operating in the US, limiting the extent to which we might over-attribute displacement to a particular included service. Third, identification is driven by aggregate time variation which, as the results from the international product-level data will suggest, is the more promising approach for measuring the impact of streaming on sales and piracy.

Our paper presents several results. Song-level regressions of sales on Spotify streaming yield consistently positive coefficients, consistent with either song-level sales stimulation or unobserved heterogeneity. Likewise, artist-level regressions of unpaid consumption on Spotify streaming also yield positive coefficients, again consistent with either artist-level piracy stimulation or unobserved heterogeneity. Aggregate-level regressions, which treat aggregate use of Spotify over time as exogenous to the demand for music, yield consistently negative coefficients, for both the impacts of streaming on sales and on piracy. The contrast between the estimates from song or artist level approaches and the aggregate approach raises doubts about the ability of the product level approach to identify displacement/stimulation absent an exogenous source of variation. When we turn to our aggregate US data, we find significant negative relationships between volumes of streaming for each of the major streaming types and sales, but we cannot statistically distinguish between them. Hence, we pool them to measure the average impact of streaming on track-equivalent sales in the US. Our estimates indicate that an additional thousand collective streams reduces track-equivalent sales by roughly 2.1, with a 95 percent confidence interval that extends from 1.4 to 2.8. The lack of data transparency on payments to rightsholders unfortunately renders the calculation of the effect of streaming on revenue difficult. Using the best evidence that we are able to assemble, our point estimate suggests that the new streaming revenue more than offsets the reduced revenue through track sales. Yet, given the range of our estimates of $p_s$, we cannot reject the hypothesis that streaming was revenue neutral as of 2015.

This paper proceeds in five sections after the introduction. Section 2 provides background on two issues related to streaming, sales displacement and bundling, as well a description of the recent growth in streaming that we can use to document its impact. Section 3 turns to our data sources, and Section 4 describes our various identification strategies for measuring the effects of streaming on sales and unpaid consumption, given the data at hand. Section 5 presents our results, and Section 6 gathers evidence on on payments to rightholders from track-equivalent sales and streaming to calculate the overall effect of streaming on revenue. Section 7 concludes.

# 2 Background

## 2.1 Streaming, Airplay, and Effects on Sales

There are two distinct types of streaming music services, interactive and non-interactive. The interactive services, such as Spotify, YouTube, and Deezer, allow users to choose which song they will hear. Of Spotify's 100 million users, one quarter pay $10 per month for the service. The others pay nothing except indirectly through their exposure to advertising. Non-interactive services such as Pandora do not allow users to choose the particular songs they hear, but Pandora does allow users to create narrowly tailored stations (consisting of songs similar to a seed song or artist).

Streaming services tend to describe themselves as tools for musical discovery. For example, Pandora has a "mission to reward the musically curious among us with a never-ending experience of music discovery."[6] Similarly, "Spotify makes it easier than ever to discover, manage and share music with your friends, while making sure that artists get a fair deal."[7] Under this conception of streaming services, they resemble terrestrial radio stations, which are widely believed to stimulate sales of recorded music. The basis for this belief is the observation that the particular songs on the radio tend to sell more when they are being aired. Moreover, and related, songs on the radio tend to sell better than those not receiving airplay.[8]

If streaming resembles traditional radio airplay and stimulates demand for recorded music, for

[6] https://www.pandora.com/about.

[7] https://press.spotify.com/us/2013/05/29/hello-music-discovery-spotify-here/.

[8] See Dertouzos (2004), a study undertaken for the National Association of Broadcasters, which found a positive effect of radio airplay on overall music sales.

example through permanent digital downloads, then the recent growth in streaming should raise revenue, all else constant. Yet, even if the analogy to traditional radio is accurate, it is important to note that understanding the impact of airplay on sales is challenging, for both empirical and theoretical reasons. First, documenting the impact is empirically challenging: radio airplay of a song is endogenous, and songs are aired on radio mostly upon release, when consumers are potentially interested in purchasing the recently-released titles for other reasons.

Liebowitz (2004) articulates a second important challenge, a possible "fallacy of compostition." Even if the radio airplay of *particular* songs stimulates their sales, the airplay of songs *generally* need not stimulate overall sales of recorded music. The relevant experiment for measuring the overall impact is growth in the use of the medium, not change in the airplay of particular songs. Liebowitz (2004) studies the period surrounding the diffusion of radio broadcasting and its effect on the already-established recorded music industry in the US during the 1920s. He documents that the diffusion of radio was accompanied by a collapse of the recorded music industry, which he interprets as displacement of recorded music sales by radio.

This interpretation of the experience of the 1920s is intriguing, but it is also true that the experience of the US radio and recorded music industries over the subsequent 50 years suggests a rather different relationship between radio broadcasting and recorded music sales. As Figure 1 shows, while per capita record sales decreased with radio diffusion during the 1920s, both grew between 1930 and 1980, raising questions about whether radio airplay displaces sales.[9] Still, the advent of streaming raises questions analogous to those raised at the dawn of radio.

The impact of airplay on recorded music sales has acquired new importance with the recent growth in Internet radio, or streaming. Unlike traditional radio, which exposes people to a broad selection of generally unfamiliar music, streaming services tend to provide very narrow selections of music. To the extent that Internet radio serves consumers what they want to hear, it may obviate additional purchases (beyond the possible purchase of access to Internet radio). In that case, streaming would serve as a substitute rather than a complement for recorded music purchases.

On-demand services such as Spotify take selection a step further than non-interactive services

[9] The underlying data in Figure 1 is obtained from Gronow (1983) and from the Historical Statistics of the United States, Colonial Times to 1970, Parts 1-2 (see `http://hsus.cambridge.org/HSUSWeb/table/jumpby.do?id=Dg117-130`).

such as Pandora. Users choose exactly which songs they will hear. Premium (paid) users can entirely control what they hear on both fixed and mobile devices. Free users also have full control over what they want to listen to on their fixed devices, but they have less control on their mobile devices, where they can only shuffle among and/or within playlists. Whether Internet radio stimulates or depresses recorded music sales is an open question. The control that users have over what they hear at least raises the possibility that Internet radio would exert a less stimulating impact on sales than terrestrial radio.

Some recent research examines the impact of streaming on recorded music sales. First, Hiller (2016) studies the impact of video availability on YouTube on sales of corresponding albums. Music released by Warner was unavailable on YouTube during a contract dispute. During this period, the excluded music experienced better (higher sales) ranks on the Billboard 200 weekly album ranking, relative to albums from other labels. This evidence indicates that the streaming available at YouTube cannibalizes sales of albums. Second, Kretschmer and Peukert (2014) undertake a similar exercise, studying the impact of videos excluded from YouTube in Germany. They find that availability of an artist's video on YouTube stimulates sales of the artist's albums but not the individual song. Third, data scientists at Pandora have undertaken A/B experiments, turning off songs in random geographic areas, then asking whether sales of those songs are higher or lower in places where the songs continue to play. McBride (2014) finds that song sales are 2 percent lower in DMAs where the songs are not played. It is worth noting, however, that these are all song-level studies, which are therefore potentially vulnerable to Leibowitz's concern about a fallacy of composition that a relationship holding for individual works may not hold for music as a whole.

Another set of papers uses individual-level data to examine the impact of music streaming on sales. Wlömert and Papies (2015) use a survey panel of music consumers to analyze the effect of on-demand streaming services adoption. Their results show that individuals who adopt such services purchase significantly less recorded music. While they find a larger displacement effect for paid compared to free streaming adoption, their results also show a positive net effect of paid streaming services on revenue. They conclude that the overal effect of streaming on the music industry revenue is positive. Aguiar (2017) uses clickstream data on French Internet users and exploits the introduction of a listening cap to document the effect of free streaming through Deezer on digital music purchasing and piracy behavior. His results show a positive effect of free music streaming on visits to digital music purchasing and piracy websites. Finally, Datta et al. (2017) rely on an panel of music consumers to study the effects of Spotify adoption on individual music consumption and discovery. They find that iTunes consumption drops by 28% about six months after Spotify adoption. They also find that the adoption of Spotify increases overall music consumption and discovery.

Spotify has made public statements about its impact on music sales. Founder Daniel Ek has publicly argued that it is a "myth" that "Spotify hurts sales, both download and physical. This is classic correlation without causation."[10] Spotify chief economist Will Page presents evidence from case studies that artists who withhold their music from Spotify do not sell more copies. This suggests that Spotify does not cannibalize sales at the artist level.[11]

### 2.2 Streaming as Bundled Selling

Streaming services present bundled offerings that allow the seller to collect revenue in circumstances that generated no revenue under a la carte selling. It is well known that bundling creates opportunities to raise revenue, particularly when the products have zero marginal costs.[12] Consumers' decisions to purchase a bundle depend on the sum of their valuations across songs. Hence the valuation coming from songs that a consumer values too little to purchase a la carte will not generate revenue under a la carte selling, while it can contribute to revenue under bundling.

The most salient example of this kind of revenue reclamation arises from streaming as an alternative to piracy. Spotify's Daniel Ek argues that while "piracy doesn't pay artists a penny," "Spotify has paid more than two billion dollars. . . that's two billion dollars' worth of listening that would have happened with zero or little compensation to artists. . . if there was no Spotify."[13] Academic studies have also documented that appealing licensed alternatives can depress piracy (Danaher et al., 2010, 2013). Ek's point that bundled sales through Spotify can harvest as revenue interest in music that would otherwise have animated piracy is correct, but that

[10] https://news.spotify.com/us/2014/11/11/2-billion-and-counting/.

[11] See Page (2013) (https://press.spotify.com/us/2013/07/17/adventures-in-netherlands/). But David Lowery is characteristically blunt about the opposite conclusion, arguing that "Spotify doesn't kill music sales like smoking doesn't cause cancer. . . " See https://thetrichordist.com/2014/09/17/spotify-doesnt-kill-music-sales-like-smoking-doesnt-cause-cancer/.

[12] See Bakos and Brynjolfsson (1999).

[13] https://news.spotify.com/us/2014/11/11/2-billion-and-counting/.

possibility alone does not imply that revenue to recorded music would increase since whatever additional revenue is harvested from former pirates must be balanced against potential revenue foregone from former purchasers.

### 2.3 A Simple Model of a la Carte and Bundle Music Purchase

It is helpful to articulate a simple model of music purchase under a la carte and bundled options to characterize the possible impacts of streaming on sales. In the absence of a streaming bundled offering, consumers have three choices with each song(s). They can purchase it at its a la carte price, they can obtain an unauthorized copy without payment (piracy), or they can forgo its consumption ("suffering in silence"). For concreteness, suppose that each consumer $i$ has a valuation of the song $v_i^s$, along with a non-monetary cost of piracy that is specific to the person and song, $g_i^s$. The song has an a la carte price $p$.

The consumer purchases the song if his valuation of the song exceeds the price and the price is lower than the non-monetary cost he would experience from obtaining the song via piracy, i.e. if $v_i^s > p$ and $p < g_i^s$. The consumer pirates the song if his non-monetary cost is lower than the price and his valuation exceeds the non-monetary cost, i.e. if $v_i^s > g_i^s$ and $p > g_i^s$.

There are two ways for a consumer to fail to consume a song he values positively under a la carte. First, if the price is below the individual's non-monetary cost of obtaining the song ($p < g_i^s$), so that purchase would be the preferred mode for obtaining this song, then the individual forgoes consumption if the value falls short of the price. Second, if unpaid consumption would be the individual's preferred mode of acquisition for this song, then the non-monetary cost falls short of the price ($g_i^s < p$), and the individual forgoes consumption if the value falls short of the non-monetary cost of obtaining the song.

With this setup the consumer surplus that individual $i$ experiences from songs $s = 1, \dots, N$ is $v_i^s - p$ for each of the songs he buys and $v_i^s - g_i^s$ for each of the songs he obtains without payment. Formally:

$$CS_i = \sum_s \left[ (v_i^s - p)\mathbf{1}\{\, v_i^s \geq p; p < g_i^s \,\} + (v_i^s - g_i^s)\mathbf{1}\{\, v_i^s \geq g_i^s; p > g_i^s \,\} \right]. \tag{1}$$

The revenue that the sellers derive from the consumer is the number of instances in which he purchases, times the price:

$$Rev_i = p \sum_s \mathbf{1}\{v_i^s \geq p; p < g_i^s\}. \tag{2}$$

The deadweight loss associated with the consumer arises from the instances in which the valuations exceed the (zero) marginal cost but no consumption occurs:

$$dwl_i = \sum_s \left[ v_i^s \mathbf{1}\{\, v_i^s < p; p < g_i^s \,\} + v_i^s \mathbf{1}\{\, v_i^s < g_i^s; p > g_i^s \,\} \right]. \tag{3}$$

The advent of streaming allows different consumption possibilities and, importantly, different revenue opportunities. In particular, streaming allows the possibility of revenue generation from circumstances generating no revenue under a la carte sales. When streaming replaces piracy, this revenue is new; and when streamed consumption replaces situations in which non-pirates would have forgone consumption, the revenue is new. However, when streaming replaces a la carte purchase, the streaming revenue comes at the expense of a previous revenue stream. Hence, generating revenue from instances which formerly did not generate revenue - such as piracy - is not sufficient for streaming to raise revenue.

To see how streaming might affect revenue, it is useful to articulate a model of the decision to purchase the streaming service. Define $p_B$ as the price of the bundle. Consumer $i$ purchases the bundle if the surplus he obtains from the bundle is positive and exceeds the surplus he obtains from his chosen combination of purchase and stealing. $CS$ under streaming is

$$CS_i^{Streaming} = \sum_s v_i^s - p_B. \tag{4}$$

Hence, consumer $i$ purchases the bundle if his surplus under streaming exceeds his surplus under a la carte purchase, or if:

$$\sum_s v_i^s - p_B > \sum_s \left[ (v_i^s - p) \mathbf{1}\{\, v_i^s \geq p; p < g_i^s \,\} + (v_i^s - g_i^s) \mathbf{1}\{\, v_i^s \geq g_i^s; p > g_i^s \,\} \right] > 0. \tag{5}$$

A figure helps to explain this. Figure 2a shows a consumer's valuation of all songs he values positively. We can represent these valuations as a demand curve, where we order the songs from most highly valued to least. The gray area under this demand curve is the consumer surplus he would experience if all songs were free. This area less the bundle price $p_B$ is the surplus experienced under bundling if he chooses the bundled option.

Songs can be divided for this individual into those he would be willing to steal (with $g_i^s < p$) and those he would not steal ($p < g_i^s$). His valuation distributions are represented under the second (Figure 2b) and third (Figure 2c) demand curves (note that the area under the second and third demand curves sums to the area under the first). Revenue under the a la carte regime is the dark gray rectangle under the buy ($p < g_i^s$) curve, while consumer surplus under a la carte is the sum of $CS_1$ for songs with $g_i^s < p$ and the $CS_2$ for songs with $g_i^s > p$.

Suppose that the streaming option were available at a price $p_B$ equal to the amount that the individual formerly spent on a la carte music (the revenue under the "buy" demand curve). Then he would clearly prefer the bundled option because the bundled option would deliver more $CS$ than a la carte (the bundled $CS$ would equal to the full area under the demand curve less the a la carte revenue). Hence, all of the other regions under both demand curves would become consumer surplus.

While the consumer described above - and illustrated in Figure 2 - would prefer the bundle if priced appropriately, not all consumers would prefer the bundle. For example a consumer for whom $g_i^s = 0$ for all songs would obtain the full area under the demand curve in Figure 2a as $CS$ by stealing everything a la carte. This would exceed his surplus from purchasing the bundle.

In our model, if $p_B$ is equal to a la carte revenue, then the consumer chooses the bundle. It's worth noting that revenue from streaming is not literally $p_B$. Instead, rights holders are paid a per-stream rate times the number of times their songs stream.[14]

Assuming that individuals not adopting streaming do not steal different amounts when the bundled option becomes available, whether streaming raises revenue depends entirely on the revenue gains and losses from those adopting streaming. All of the revenue from consumers

[14] We are implicitly assuming that $p_s S$ is related to $p_B$, for example that the streaming payments equal the subscriber revenue less administrative fees. How bundle revenues are shared among rights holders is the topic of a small economic literature. See Ginsburgh and Zang (2003) and Shiller and Waldfogel (2013).

who formerly specialized in piracy is gain. Similarly, the revenue from the units that paying consumers failed to consume (because $v_i^s < p$) is a gain. But the revenue from units formerly purchased at $p$ per unit by a la carte buyers is now gone, replaced by the revenue from the streaming subscription fee.

It is clear from this simple model that the change in revenue under bundled sales comes from four conceptually distinct sources. The first three are gains under streaming, while the fourth is a loss. The first source of revenue is the units that were formerly consumed without payment. The second source consists of units that were formerly not consumed, despite that fact that the non-monetary cost is below the price ($g_i^s < p$), because the valuation falls short of even the non-monetary cost of acquisition ($v_i^s < g_i^s$). A third source of revenue is units that were formerly not purchased, despite the fact that the price falls short of the non-monetary cost ($p < g_i^s$), because the value falls short of the price ($v_i^s < p$). The final source of changed revenue is the reduction in a la carte revenue for units which were formerly purchased at $p$ (where $v_i^s > p$ and $p < g_i^s$), but now generate revenue only as part of the payment for streaming. For revenue to rise, it is necessary that the additional revenue collected for units not formerly generating revenue offset any reduction in revenue from the songs formerly purchased a la carte.

This setup points to various possible impacts of bundled sales through streaming. First, it is possible that streaming would reduce unpaid consumption. Second, it is possible that streaming would reduce the instances of failure to consume songs whose value exceeds zero to their potential users. Finally, it is also possible that streaming would displace paid a la carte sales. Of these three, two are observable to us, the volume of unpaid consumption and the volume of paid track-equivalent sales.

### 2.4 Recent Growth of Internet Radio as a Source of Exogenous Variation

Non-interactive and interactive (on-demand) streaming have grown quickly around the world in recent years. Nielsen publishes some annual aggregates for the US that illustrates this growth. They report US annual on-demand streaming volumes separately for audio and video, from the following services: AOL, Beats, Cricket, Google Play, Medianet, RDIO, Rhapsody, Slacker, Spotify, XBOX Music, and YouTube/Vevo.[15] One can also track volumes of non-interactive US

[15]See http://www.nielsen.com/us/en/press-room/2015/2014-nielsen-music-report.html and http://www.nielsen.com/us/en/insights/reports/2016/2015-music-us-year-end-report.html.

streaming based on disclosures at Pandora's website.

On-demand US audio streaming - from sources such as Spotify - reached 49 billion streams in 2013, 79.1 billion in 2014, and 144.9 billion in 2015, the last year of our study period. On-demand US video streaming - from sources such as YouTube - was 57.1 billion in 2013, 85.4 billion in 2014, and 172.4 billion in 2015. Translating Pandora's hours into streams at 15 songs per hour, Pandora's streaming stood at 207 billion in 2012, rose to 250.2 billion in 2013, then to 298.5 billion in 2014.[16] Streaming at Pandora grew slightly to 303.6 billion in 2015.

The growth of streaming is also visible in the US recorded music industry's revenue data. The Recording Industry Association of America (RIAA) reports data on revenue from the sales of recorded music as well as streaming.[17] In 2010 US streaming revenue stood at $0.5 billion. By 2012 streaming revenue reached $1.0 billion, and by 2013, streaming revenue rose to $1.4 billion. US streaming revenue reached $1.9 billion in 2014 and $2.4 billion in 2015. RIAA breaks streaming revenue into three components, SoundExchange distributions (which are largely payments from Pandora and SiriusXM), revenue from subscription services (such as Spotify), and payments from "on-demand ad supported" streaming services such as YouTube. In 2014, SoundExchange revenue made up 41 percent of total streaming revenue, subscription revenue made up 42 percent, and on-demand ad supported revenue made up the remaining 17 percent. In 2015 US streaming revenue from "paid subscription" services jumped 50 percent from $0.8 billion to $1.2 billion, while SoundExchange distributions rose slightly from $773 million to $803 million. On-demand ad supported revenue grew from $295 million to $385 million.[18]

It is as if the music industry were living through a large-scale "experiment" as streaming diffuses rapidly, particularly during 2014 and 2015 in the US. This raises the possibility of studying the impact of this diffusion on the sales of recorded music; but since the experience is not literally an experiment, documenting its impact is challenging.

[16]See http://waxy.org/2008/05/the_whitburn_project/andhttps://plot.ly/~RhettAllain/131/average-song-length for a reference to 4 minutes as an average song length.

[17]See Joshua P. Friedlander, News and Notes on 2014 RIAA Music Industry Shipment and Revenue Statistics, RIAA http://riaa.com/media/D1F4E3E8-D3E0-FCEE-BB55-FD8B35BC8785.pdf.

[18]See https://www.riaa.com/wp-content/uploads/2016/03/RIAA-2015-Year-End-shipments-memo.pdf.

# 3 Data

Given the timing of streaming's diffusion, we would ideally have high frequency product (song or artist)-level data on streaming via all streaming services, overall music purchases, and piracy for a period covering the strong growth in streaming. In reality, getting data on some of these measures is challenging. The data we are ultimately able to obtain bear some resemblance to the ideal but also embody some shortcomings.

Broadly, we have international product-level datasets for part of 2013, and we have a US aggregate dataset covering 2012-2015. We describe these datasets and their constituent parts in turn. Our international product level datasets are constructed from three separate sources. We describe these separately and then turn to the datasets we construct by combining them.

First, we have data on digital track sales by country and week for 2012-2013 from Nielsen. We have these for 21 countries, including Australia, the US, New-Zealand and 18 European countries, and for all tracks.[19] Second, we have Spotify streams during April-December 2013, for the top 50 songs in each country and week.[20] The Spotify data contain a total of 1,148 distinct songs. Third, we observe pirated consumption aggregated to the artist level for roughly 8,000 artist, by week and country, for 2012-2013. The piracy data are collected by Musicmetric, a company that tracks peer-to-peer activity to develop measures of unpaid consumption by country and week for each of the artists they monitor.[21]

The first resulting dataset links songs by week and country between the Nielsen track sales data and the Spotify streaming dataset. We are able to link 966 tracks out of the 1,148 distinct tracks available in our Spotify data, for a total of 28,186 track-country-week observations. The second resulting dataset links the Musicmetric data (which are at the artist by week by country level) to Spotify data aggregated to the artist by week by country. The dataset contains 279 artists and 21,324 artist by week by country observations, which overall account for 85% of

[19] The European countries include Austria, Belgium, Germany, Greece, Denmark, Finland, France, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

[20] These data are from publicly available charts at https://spotifycharts.com/regional. Beginning October 26, 2014, Spotify began reporting the top 200 songs per country week, for songs with at least 10,000 weekly streams in the country. Prior to 2016, Spotify provided data at a different page: charts.spotify.com. Combining data from the original and more recent Spotify site, the data are weekly with the exception of 5 weeks during 2015.

[21] Apple acquired the firm that creates the Musicmetric data in 2015. See https://www.theguardian.com/technology/2015/jan/21/apple-buys-musicmetric-british-startup-beats.

the streams in our April-December 2013 Spotify data. In addition to using these international product-level dataset at the song/artist levels, we can also aggregate them to the country level by week to conduct aggregate analyses.

The second broad dataset, the "US aggregate data," includes weekly aggregate volumes of both digital and physical recorded music sales, along with measures of streaming on each of the three most prominent streaming services in the US, Pandora, Spotify, and YouTube, for 2012-2015. The sales data, on digital singles, digital albums, and physical albums, are Nielsen data reported weekly in Billboard Magazine.[22] We create a measure of track-equivalent sales by combining sales from these three sources. In particular, we multiply album sales (digital and physical) by 10 and add digital track sales.

While our streaming measures cover some of the most prominent and widely used streaming services, they do not cover all streaming services. Fortunately, we also observe aggregate annual US data on audio and video on-demand streams, respectively, for 2013-2015, from the 2014 and 2015 Nielsen yearly music reports.[23] We treat the two Nielsen measures as comprehensive counts of US track streaming on audio on-demand and video on-demand services, and we inflate the data on Spotify and YouTube streaming to reflect overall US audio and video on-demand streaming.

Before simply scaling up our Spotify index and treating it as a measure of overall on-demand audio streaming, we can empirically assess the assumption that Spotify streams are proportional to overall audio on-demand streaming. Overall audio on-demand streams grew 61 percent from 2013 to 2014. Our Spotify streaming measure grew 76.7 percent. Between 2014 and 2015, overall on-demand audio streams grew 83 percent while our Spotify measure grew by 98 percent. While the growth in Spotify is broadly consistent with the growth in streaming, it is also true that Spotify is growing more quickly that on-demand audio streaming overall. The faster growth of Spotify is also consistent with other information such as the Edison Infinite Dial Study showing that 3 percent of the 12+ US population listened to Spotify during the past week during 2013, while 10 percent listened in early 2016.[24]

[22] The data are reported weekly in the Chart Beat section of Billboard Magazine. Billboard produces 41 issues per year, each of which reports sales data for the current and previous week, so we have data for 48 weeks of each year.

[23] See footnote 15.

[24] See http://www.edisonresearch.com/the-infinite-dial-2016/.

To make our Spotify time series better mimic the overall pattern of on-demand audio streaming, we adjust the weekly growth rate so that the Spotify's growth between 2013 and 2015 mirrors the annual Nielsen on-demand audio growth. Between 2013 and 2015 our Spotify US top-50 index grows by 250.1 percent while the Nielsen figure grows by 195.7 percent. Thus, on a weekly basis, our Spotify index grows 0.24 percent faster.[25] We make two adjustments to the Spotify index to translate it into a measure of aggregate US on-demand audio streams. First, we calculate $S'_t = S_t e^{-0.0024t}$, where $t$ is time. Second, we scale the adjusted index: $S''_t = \theta S'_t$ so that the annual sum of $S''_t$ equals Nielsen's reported total US on-demand audio streaming for 2014.

YouTube data are the hardest to obtain. Although each video at YouTube indicates the number of times it has been streamed, Google provides no historical data on streaming volumes. One third party that provides data on YouTube is Socialblade (www.socialblade.com), which monitors streams at each of the top 500 YouTube music channels.[26] For each of these channels, Socialblade maintains a page with historical data on the daily streams at the channel back as far as 2011.[27] With some effort and cleaning, the information at these pages can be turned into data on weekly streaming volume at YouTube. According to Socialblade, the Justin Bieber Vevo channel[28] was the most heavily viewed as of early 2016. Socialblade reports daily views for this channel back to January 12, 2011. Most of the daily view numbers look reasonable, but some are clearly not. Of the daily viewing totals for this channel between 2011 and late 2015, 8 are large negative numbers. Another handful of numbers are large and positive. For example, on June 5, 2014, Socialblade reports -20,739,310 views for Justin Bieber Vevo. The following day, Socialblade reports 25,455,092. The average for the preceding week was roughly 2.5 million. Many of the large negative daily entries are paired with large positive entries immediately before or after, so much of the suspicious variation cancels in the creation of weekly data. We aggregate views across the top 500 channels. We take the cleaning a step further by smoothing the weekly data using local mean regression.[29] We then scale this time series so that the aggregate 2014 values equals Nielsen's reported video on-demand streaming for the US.

Prominently missing from Nielsen's data are Pandora stream volumes. Fortunately, we can

[25]Note that $(\frac{250.1}{195.7})^{\frac{1}{104}} = 1.002362$, so the weekly growth rate is 0.236 percent too fast.

[26]See http://socialblade.com/youtube/top/category/music/mostviewed.

[27]See, for example, http://socialblade.com/youtube/user/justinbiebervevo/monthly.

[28]https://www.youtube.com/user/JustinBieberVEVO.

[29]We perform this exercise with the lowess command in Stata, using the default bandwidth.

construct measures of Pandora streaming from Pandora's announcements of listening hours. Between 2012 and early 2015, Pandora made monthly disclosures of listener hours. Starting in mid-2015, Pandora moved to quarterly disclosures. Because our sales data are weekly, we convert the Pandora data to weekly in the following way. First, we allocate reported listening hours (for months or quarters) evenly to the days of the period. We then aggregate to weeks. Finally, we translate listening hours to the number of streams assuming 15 songs per hour.[30]

Figure 3 shows the evolution of our streaming measures alongside our track sales measure. The upper-left panel shows the three main types of streaming. Pandora is the highest and shows slowing growth, while on-demand audio and on-demand video have both been growing at an increasing rate, especially since 2014. The remaining panels of Figure 3 compare the evolution of the various streaming measures with the evolution of track-equivalent sales. The figures show a clear decline in permanent sales over the period 2012-2015.

# 4 Estimation Approaches

## 4.1 Song and Artist-level approaches

Using song-level data by country and week, we can attempt to identify the sales displacement coefficients in a variety of ways. We bear in mind even at the outset that the song-level approach faces three substantial challenges. First, streaming of particular songs is endogenous. From that perspective, estimating the impact of streaming on the sales of recorded music or piracy recalls the challenges in measuring the sales-displacing impact of piracy on music sales. Second, even if one were to uncover a credible causal impact at the song level, it would not necessarily reflect the effect of interest, the overall impact of streaming on sales. Third, because we have song-level data on only one of the major streaming services, we face the possibility of getting a misleading estimate of the effect of streaming generally. Still, these data are uniquely well suited to showing the effects of different sources of identification on the estimated displacement effect.

Define $q_{sct}$ as the sales of song $s$ in country $c$ and week $t$. Define streams $s_{sct}$ analogously. It is instructive to consider the sequence of possible approaches, including those with little promise

[30]See http://waxy.org/2008/05/the_whitburn_project/ and https://plot.ly/~RhettAllain/131/average-song-length for evidence that songs are about four minutes long, on average.

of credibly identifying the causal impact of streams on sales, to understand the possible promise of other approaches. The generic endogeneity challenge is that streaming and sales may both be driven by the time-varying interest in a song. Consider, first, the simplest approach:

$$q_{sct} = \alpha_0 + \alpha_1 s_{sct} + \varepsilon_{sct} \tag{6}$$

This approach has little promise of identifying possibly displacing effects of streaming on sales, for three clear reasons. First, streaming and sales will both be higher in larger countries. Second, they will both be higher for songs that are more popular. Third, both may be higher at times of high sales (e.g. shortly after release).

Taking one step at a time, if we add country fixed effects to this specification, yielding: $q_{sct} = \alpha_0 + \alpha_1 s_{sct} + \mu_c + \varepsilon_{sct}$, then we will have dealt with the problem that some countries are larger than others. We can include fixed effects for country, song, and calendar weeks. The identification strategy is then, in words, to ask whether songs that stream more in this country and week, relative to the average levels for this country, song, and week, sell more during this week.

This approach is still vulnerable to the concern that interest in a song has a song-specific temporal component. For example, a few weeks after release, a particular song may be of interest to consumers via both channels (purchase and streaming). We can attempt to address this by including song-specific time effects:

$$q_{sct} = \alpha_0 + \alpha_1 s_{sct} + \mu_c + \theta_{st} + \varepsilon_{sct}. \tag{7}$$

This approach allows for a song-specific time pattern of sales that is common across countries, then asks whether song-country-weeks with more streaming have higher or lower sales.

The song-specific approach recalls the approaches of Oberholzer-Gee and Strumpf (2007) and Blackburn (2004) in the file-sharing literature. Both of those studies relate the volume of unpaid consumption for particular works over time to the volume of recorded music sales for the same works. Oberholzer-Gee and Strumpf (2007) also employ an instrumental variables approach, based on the number of German school children on vacation, to generate exogenous variation in the volume of unpaid activity.

We attempt to identify the piracy displacement using artist-level data on unpaid consumption and streaming by country and week. We can go as far as introducing artist-specific time effects (along with country fixed effects) in a regression of unpaid consumption on streams. We can therefore ask whether artist-country-weeks with more streaming have higher or lower levels of unpaid consumption, after controlling for artist-specific time patterns of piracy.

Beyond the obvious endogeneity challenge discussed above, the product-level data present two main shortcomings. First, the data end prior to a period of substantial growth in streaming, during 2014 and 2015. Second, we observe song or artist level streaming at only Spotify and not at the other major streaming services. We have no direct information on the relationship between the streaming time pattern of a particular song or artist across streaming platforms. To the extent that streams on different services are uncorrelated - which seems implausible - the use of Spotify data would yield an unbiased estimate of Spotify's impact. If streaming is positively correlated across platforms but measures of streaming at other services are omitted from the regressions, then we would likely over-estimate the impact of Spotify on sales and piracy.

As it turns out, our estimates using the product-level data are, in the end, mostly exercises that show the inherent challenges of taking a song or artist level approach to estimating sales or piracy displacement. We will ultimately not rely on song and artist-level coefficients as sales displacement estimates. Instead, we will draw inferences from the change in the estimates as we move from product level approaches to aggregate approaches that employ the same data. We will then use aggregate approaches that combine streaming data across the three major services to estimate sales displacement.

### 4.2 Aggregate Approaches using the International Product-level Data

It is arguable, even a priori, that the aggregate approach holds more promise than the product-level approach. Suppose that streaming is growing because it is new and is in the process of diffusing. Then the change in aggregate streaming is not related to the appeal of music. Rather, the change in streaming is effectively exogenous. We can measure its effect by looking at what happens to sales during the diffusion. Contrast that with the song-level approach. Ideally, the song level approach would be driven by the possibility that some songs are heavily streamed while others are not, for reasons unrelated to the appeal of the songs. This would work, for example, if there some set of songs appealed to consumers who do not use streaming, while another set of songs appealed to consumers who use streaming. Given that we only observe streaming volumes for the most popular songs, we cannot implement this approach, even if we had a notion of which songs do and do not stream extensively. This leaves us with the impression that the aggregate approach holds more promise of identifying the impact of streaming on sales.

Our basic approach to measuring the impact of streaming on sales and piracy is as follows. We first aggregate the international product-level data at the country-week level. Second, we regress weekly measures of sales (and piracy) on country dummies, week dummies, and a measure of streaming in the country:

$$q_{ct} = \gamma_c + \gamma_t + \alpha s_{ct} + \varepsilon_{ct}, \tag{8}$$

where $q_{ct}$ is a measure of consumption (sales or piracy) in country $c$ during week $t$, $s_{ct}$ is a measure of streaming in country $c$ in year $t$ , $\gamma_c$ and $\gamma_t$ are country and week fixed effects, respectively, and $\varepsilon_{ct}$ is an error term. As noted above, however, we only have Spotify data for the European countries, so our country-level streaming measure understates total streaming.

### 4.3 Displacement using the US Aggregate Data

The basic approach to measuring sales displacement in the Billboard US-only data for 2012 through the end of 2015 is slightly different. Rather than a single measure of streams, we have three separate measures: audio on-demand streams ($A_t$), video on-demand ($V_t$), and non-interactive streams at Pandora ($P_t$). Hence we can estimate

$$q_t = \gamma_t + \alpha A_t + \beta V_t + \delta P_t + \varepsilon_t. \tag{9}$$

Since the data are weekly for a single country, we cannot employ an arbitrary week dummy, as above. We can, however, use a week of the year dummy to adjust for seasonality, since we have weekly observations for more than two years. With this approach, we are asking whether US sales this week move with the volumes of US streaming, after accounting for seasonality. Two additional points are in order. First, as emphasized above, we have aggregate US measures of streaming reflective of total streaming, not just one particular audio on-demand service. Hence, we need not mistakenly attribute to Spotify any effects of streaming generated by other services. Second, for the US we observe total music sales - physical and digital - so we can document the impact of streaming on total revenue and not just the revenue derived from digital downloads.

# 5 Results

## 5.1 Song and Artist-level Results

The first panel in Table 1 reports results of sales regressions using the song-level data. Regardless of which set of fixed effects we include, we find a positive coefficient on streams, in the neighborhood of 64, meaning that an additional 1,000 streams is associated with 64 additional track sales. Note that this result obtains even when we use song-specific time dummies. So the result means that after accounting for the temporal popularity of this song (in a common way across countries), as well as the different tendencies to purchase songs in different countries, country weeks in which a song streams more it also sells more.

There are two possible interpretations. One is that streams stimulate sales. A second possibility is that the relationship is contaminated by unobserved heterogeneity. Songs that are popular in particular countries during particular weeks are both streamed and sold at elevated rates. So we are left with something best described as questionable evidence for song-level sales stimulation. And even if streaming stimulates sales at the song level, it is not clear that the overall effect of streaming on sales would be positive.

The second panel in Table 1 reports artist-level piracy regressions, and we obtain results similar to the results on purchase. Artists that are streaming more on Spotify this week tend also to be pirated more this week, after accounting for the various fixed effects.

## 5.2 Aggregate Results using International Product-level Data

To proceed with our aggregate approach, we aggregate our matched data at the country and week level. The top panel of Table 2 reports regressions of matched aggregate sales by country week on matched aggregate streams. When we do not include fixed effects, in column (1), the sales displacement coefficient is positive. When we include a country fixed effect, in column (2), the coefficient becomes negative (-37.0, with a standard error of 5.4). The coefficient in the specification with fixed effects for week as well as country, in column (3), is nearly identical. When we include only US data (and therefore no country nor time fixed effects), the coefficient is -61.8 (29.6) (column (4)). Including a time trend, in column (5), changes the displacement coefficient to -78.6 (35.7).

The bottom panel of Table 2 reports regressions of matched aggregate unpaid consumption activity on matched aggregate Spotify streaming. When no fixed effects are included in column (1), the piracy displacement coefficient is positive and significant. The inclusion of country fixed effects leads to a negative coefficient, and additionally including weekly fixed effects leaves the displacement estimate nearly identical. Using only the US data (therefore without country or week fixed effects), we obtain a much larger coefficient (-123.7, with a standard error of 32.8). Including a weekly time trend nevertheless reduces the coefficient by half (-64.3, standard error of 33.1).

The results derived from the international product-level data clearly highlight the inherent endogeneity challenge of taking a song or artist level approach to estimating sales or piracy displacement. While our song and artist level results present positive coefficients, the more sensible aggregate approach shows that streaming displaces both sales and piracy. The level of aggregation therefore matters to identify displacement. Because we only use streaming data on one type of service (Spotify), it is hard to draw inferences about the overall effect of streaming on the recorded industry revenues. We now turn to the results of our estimations using our more comprehensive US data on the various types of streaming platforms.

### 5.3 Results using Aggregate US Data

Table 3 reports the results of the aggregate analysis using US data and an inclusive "track equivalent" sales measure that treats digital and physical album sales as the equivalent of 10 track sales each. Column (1) reports a regression of weekly sales data on on-demand audio streaming using data for 117 weeks between 2013 and the end of 2015. The on-demand audio coefficient is -5.67 and significant. The second and third columns replace on-demand audio streams with Pandora (non-interactive) and on-demand video, respectively. Each stream volume, included alone gets a negative and significant coefficient. The last column includes all three streaming measures simultaneously. The $p$-value for the hypothesis that the three services' coefficients are equal is 0.093, so we cannot reject the hypothesis that they affect sales equally.[31] We clearly reject the hypothesis that they are all jointly zero, however. These findings suggest that we should sum the streaming measures together to create aggregate streaming.[32]

Table 4 presents regressions of track-equivalent sales on the aggregate stream measure. The first specification regresses sales on total streaming and presents a negative and significant coefficient. The second specifications regresses sales on total streaming along with lagged sales. The corresponding normalized displacement coefficient is displayed at the bottom of columns (2) and is negative and significant. In particular, it is almost identical to the coefficient from the first specification which does not control for lagged sales. Our estimates are -2.142 (with a 95 percent confidence interval running from -2.88 to -1.41) and -2.097 (with a 95 percent confidence interval running from -2.84 to -1.36), respectively.

Summing up, we see the following patterns. First, when we use aggregate data, we find sales and piracy displacement by Spotify. Second, when we use data on the US covering the period of substantial growth in streaming, we find that growth in each type of streaming is negatively related to sales, but we cannot distinguish the impacts. Our best estimate of the overall effect of streaming is -2.1 track equivalent sales per thousand additional streams, with a 95 percent confidence interval that extends from -2.8 to -1.4.

[31]The correlations of the three services are high. The correlation coefficient between Pandora and on-demand audio is 0.75, it is 0.73 between Pandora and on-demand video, and it is 0.98 between on-demand audio and on-demand video.

[32]It is surprising, in our view, that we do not see different impacts for interactive and non-interactive services. We do not take this as strong evidence that the services have similar or identical impacts; rather, we take this as evidence that multicollinearity among the streaming service measures gives rise to a test with low power.

## 6 How Large is the Revenue Displacement?

### 6.1 Impact of Streaming on Rights Holder Revenue

The impact of an additional stream on revenue is $\frac{\partial rev}{\partial S}$, or $p_d\frac{\partial q_d}{\partial S}+p_s$. Hence increased streaming raises music industry revenue if $\frac{\partial rev}{\partial S}>0$, or if $-p_d\frac{\partial q_d}{\partial S}<p_s$. In this section we turn to providing evidence on $p_s$ and $p_d$, which correspond to the revenues generated per track stream and sale, respectively. We can then compare $p_s$ to our estimated ranges on $p_d\frac{\partial q_d}{\partial S}$ to evaluate the impact of streaming on total revenue to right holders.

We can summarize the possible effects of streaming on revenue in a picture with the change in track-equivalent sales revenue ensuing from an additional stream ($p_d\frac{\partial q_d}{\partial S}$) on the horizontal axis and the increase in revenue from an additional stream ($p_s$) on the vertical. Figure 4 graphs the revenue-neutral line, i.e. the combination of sales displacement rates and streaming payments that make bundling revenue-neutral: $\frac{\partial rev}{\partial S}=p_d\frac{\partial q_d}{\partial S}+p_s=0$. Revenue will therefore rise with streaming if $-p_d\frac{\partial q_d}{\partial S}<p_s$. If streaming stimulates permanent sales, then we could classify streaming as promotion, and overall revenue would rise. If streaming displaces sales, but the per-stream rate is sufficiently high relative to the per-sale payment, then streaming is successful (i.e. revenue-increasing) bundling. Finally, if streaming displaces sales but the per-stream rate is relatively low, then streaming is unsuccessful bundling as it decreases overall revenue.

We now turn to providing evidence on $p_s$ and $p_d$, the revenues generated per track stream and sale, respectively.[33]

### 6.2 Music Rights and Revenue Sources in the US Market

For the purpose of determining how the magnitude of $p_d\frac{\partial q_d}{\partial S}$ relates to $p_s$, we need to determine how much revenue rights holders receive for an additional track sale, $p_d$, and how much they receive for an additional stream, $p_s$. While this is a simple task in principle, we note at the outset that data confidentiality makes this a difficult exercise. Any conclusion we draw must

[33] The legal doctrine in the music industry is complex and involves many parties and types of rights. We only describe the main characteristics of the functioning of rights and revenue streams in the recorded music industry and note at the outset that our description is not meant to be exhaustive. It is also limited to music rights in the US, which may differ from other countries. For a more detailed presentation, we refer the reader to Fisher (2004) or Passman (2012).

be tempered by the imprecision of our estimates of these prices, along with the documented statistical imprecision of our estimate of $\frac{\partial q_d}{\partial S}$. The prices $p_d$ and $p_s$ are the payments to rights holders for an additional track sale and an additional stream, respectively. The rights holders of recorded music are some combination of the following entities: record labels, musical performers, song writers, and music publishers. They can in some cases be the same entities, as when a self-released artist performs his or her own compositions. Or they can be different entities, as when a performing artist releases a song written by another person on an album released by a major label.

The calculation of $p_d$ is relatively straightforward, at least for digital tracks. Roughly, rights holders receive 70 percent of the revenue from digital track sales. According to the RIAA, the average revenue per digital track sold was \$1.174 in 2014. Given the 30 percent share that the retailer retains on sales at the Apple iTunes Store, this leaves \$0.822 per track sold to be shared among the rights holders.[34]

The payment per stream $p_s$, which corresponds to the payments per stream for the various kinds of streaming services, is substantially harder to obtain.

Non-interactive streaming services (e.g. Pandora) pay two performance royalties, one - administered through Sound Exchange - for the use of the musical recording and another - administered through ASCAP and BMI - for the songwriter/publisher. Pandora's payment per stream is relatively easy to observe, as the rates they pay for the sound recording royalty is determined by a statutory license administered by the Copyright Royalty Board. During 2014 Pandora's per-stream payment for the sound recording was \$1.4 per thousand streams. They paid an additional 1.85 percent of their revenue to ASCAP, and 2.5 percent to BMI, for song writers. In 2014 Pandora reported revenue of \$921 million, and they streamed roughly 300 billion songs.[35] Adding the payments to ASCAP and BMI would bring their payments to \$1.5 per thousand streams.

Interactive services pay not only the sound recording and song-writing royalties but also a "mechanical" royalty for the reproduction of their recordings in the course of delivering interactive streaming music. The payments from services such as Spotify for sound recordings are determined by negotiation with labels, and terms are in general not known. The payments to song

[34] See https://www.harryfox.com/find_out/rate_charts.html.
[35] See http://investor.pandora.com/phoenix.zhtml?c=227956&p=proxy.

writers - through ASCAP/BMI/SESAC, along with the mechanical royalty - is known. Spotify pays 10.5 percent of its revenue to song writers (and publishers) for these two royalties. Without knowing the payments for the sound recordings, however, knowing the payments to song writers is of limited use.

Spotify reports that it pays between \$6 and \$8.4 to rights holders collectively per thousand streams. Other sources suggest that Spotify's reported average payments may be high relative to their actual average payments to artists. The Berklee report (Rethink-Music, 2015) indicates that Spotify pays \$6.53 per thousand streams on the subscription-based side of their service and an average of \$1.21 on the advertiser-supported part of the service. Given that subscribers make up about a quarter of the users, the Berklee numbers suggest an average Spotify payout in the neighborhood of \$2.54 ($= 0.75 \times 1.21 + 0.25 \times 6.53$). We use Spotify's higher self-reported upper value of \$8.4 as an upper bound and the Berklee value of \$2.54 as a lower bound.

As difficult as it is to determine the average per-stream payout to rights holders at audio on-demand services, ascertain the $p_s$ for the video on-demand service is even more difficult, in the sense that we have only snippets of information from articles in the trade press. For example, Rolling Stone has reported that "music business sources say [YouTube's royalty payment] ranges from \$0.6 to \$2 for every 1,000 views." The Berklee report offers some confirmation of this range, in that it reports a payment of \$1.11 per thousand streams at YouTube.

Table 5 summarizes what we know about $p_s$ at the three types of services. While we are fairly confident that Pandora's non-interactive rate is \$1.5 per thousand streams, we are less confident about point estimates for the other types of services. Accordingly, we report "low" and "high" estimates in the second and third columns. The fourth column reports our estimates of the number of US streams for each type of streaming. The last two columns then report our low and high estimates of $p_s$. The low estimate is \$1.51, and the high estimate is \$2.77.

Where does this leave us on the question of whether streaming raises overall revenue? An additional thousand streams raises the revenue to rights holders by somewhere between \$1.51 and \$2.77, on average. An additional thousand streams reduces track-equivalent sales revenue by \$1.76, with a 95 percent confidence interval between \$2.37 and \$1.16.[36] Figure 5 summarizes this information. The bell curve shows the uncertainty surrounding our estimate of $p_d \frac{\partial q_d}{\partial S}$, while

[36] Recall, this is $0.822 \frac{\partial q_d}{\partial S}$.

the horizontal light blue line shows the range of average $p_s$ estimates. If the true value of $p_s$ is at the top of the range, then streaming appears to raise revenue. If the true value of $p_s$ is at the lower end, then we cannot reject the idea that streaming has been revenue neutral. Hence we cannot conclude that streaming functions as successful bundling, in the terms outlined above.

### 6.3 Bargaining over Licensing Fees in the Shadow of Piracy

Whether the growth in streaming - and the apparent concomitant decline in recorded music sales - would reduce revenue for creators and intermediaries depends on the revenues associated with individual sales and streams. While non-interactive streaming rates as well as royalties for songwriters and publishers are determined by compulsory licenses in the US, payments to the owners of song recordings for interactive services are negotiated individually between labels and services.

Bundled services offer a wide variety of music and potentially high value to consumers, but appropriating this value is challenging. If the labels were to negotiate collectively, they could presumably capture much of consumers' willingness to pay as revenue. Two concerns remain, however. First, even if the labels were to negotiate as a monopolist, they face competition from piracy as an outside good. If the labels were to insist on a fee requiring streaming platforms to charge, say \$25 per month, then perhaps their potential users would revert to piracy.

There is a second concern for the industry arising from the fact that music rights holders do not negotiate royalty rates collectively. Even if piracy were eliminated, the competition among labels would tend to reduce rates. Evidence above is at least suggestive that when particular songs are aired, they sell more than when they do not, even if music as a whole sells less when streaming exists. In such an environment it is easy to envision a prisoner's dilemma in which individual rights holders are better off charging low rates and getting their particular songs aired, even though they would be better off still if they all withheld their music from streaming services. Pandora's recent deal with Merlin, the representative of a large number of independent labels, provides an interesting example. Under the deal, Pandora "will recommend Merlin artists over those not affiliated with the consortium in exchange for paying Merlin's musicians a lower royalty rate."[37]

[37] Laura Sydell. "Pandora's New Deal: Different Pay, Different Play." NPR.org. November 26, 2014. http://www.npr.org/2014/11/26/366339553/pandoras-new-deal-different-pay-different-play.

A third possibility for the industry - exercised by Adele and Taylor Swift - is that rights holders might withhold their music from streaming services during periods of high demand. After an initial burst of a la carte sales around release, artists might make their works available to streaming services, allowing streaming to facilitate inter-temporal price discrimination. The viability of all of these approaches require first some understanding of the relationship between streaming and sales.

## 7 Conclusion

Streaming has risen sharply in popularity over the past few years. While streaming might stimulates or depress permanent sales of recorded music, its impact on overall recorded music revenue depends on the relative sizes of the payments per streams and per permanent track-equivalent sales, as well as on the rate at which additional streams displace sales. In this paper we have attempted to ascertain each and to measure the impact of streams on revenue.

We perform a series of exercises toward this end. First, using week song-level data on track sales and Spotify's top 50 streams, during 2013 in 21 countries - along with analogous data on piracy and streaming - we find positive relationships between streams and sales, and between streams and piracy. Aggregating the data to the country level - and using the temporal variation in streaming for identification - gives very different results. Growth in streaming gives rise to reductions in sales and piracy.

We then turn to an analysis of the US, 2012-2015, where we are able to develop a measure of audio on-demand streaming as well as measures of non-interactive and video on-demand streaming. Using these measures along with a measure of track-equivalent sales, we are unable to statistically distinguish the effects of the distinct types of services; but we reject the hypothesis that they are collectively zero. When we combine them into an aggregate streaming measure, we estimate that an additional thousand streams depress sales revenue by $1.76, with a 95 percent confidence interval between $2.37 and $1.16. At the same time - according the best estimates we can muster using public sources - an additional thousand streams raise streaming revenue by between $1.51 and $2.77. Hence, we cannot confidently rule out the possibility that as of 2015 streaming had been revenue neutral for the recorded music industry.

Revenue generation from recorded music is shifting rapidly from the sales of individual tracks (and albums) to bundled sales of streams. As this transition continues, understanding the relationship between streaming and sales will be crucial to both our understanding, as well as the operation, of the recorded music industry. In 2016, the year following the study period, US revenue from paid streaming rose from paid subscriptions rose to $2.5 billion from $1.2 billion in 2015, supporting a substantial increase in overall US retail music revenue from $6.9 billion in 2015 to $7.7 billion in 2016, suggesting that streaming sales are fulfilling their promise of raising revenue more than they displace revenue.[38] Perhaps not surprisingly, the increase in revenue was driven by a higher per-stream rate.[39]

[38]See http://www.riaa.com/wp-content/uploads/2017/03/RIAA-2016-Year-End-News-Notes.pdf.

[39]See http://www.billboard.com/articles/business/7744268/riaa-us-music-industry-2016-revenue-double-digit-growth.

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# A Figures and Tables

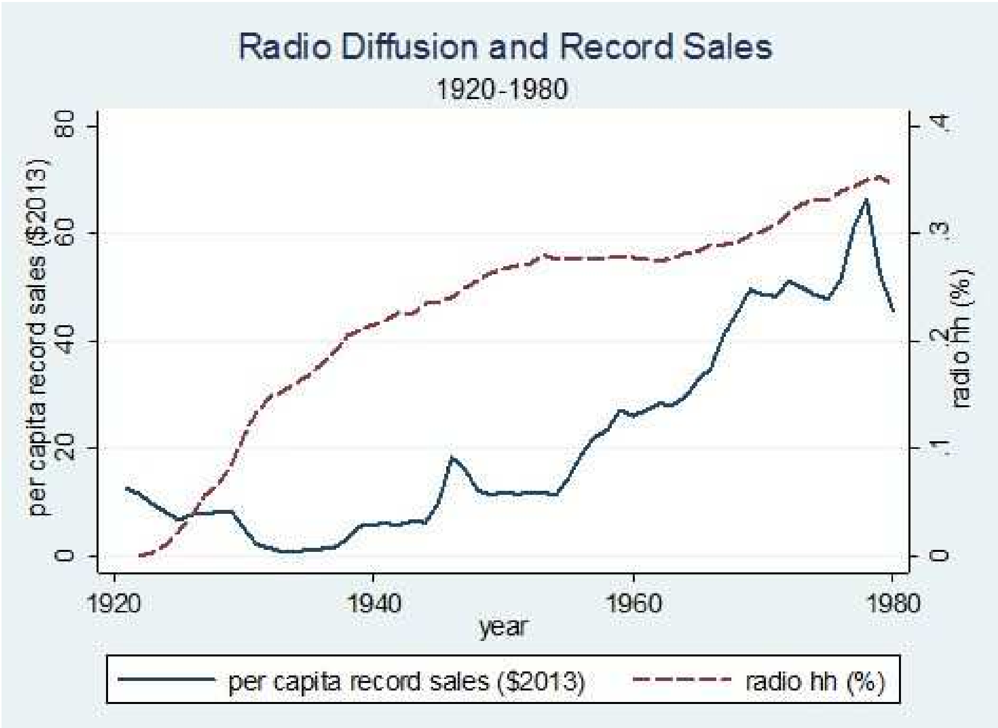
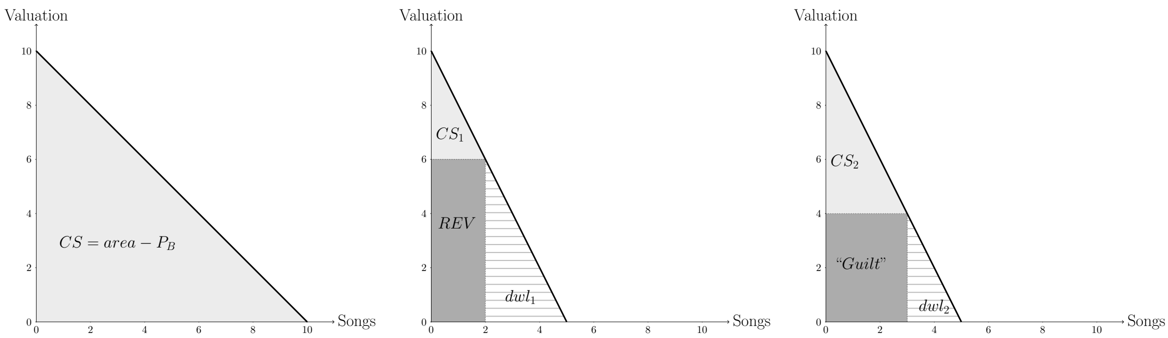



Figure 1: Radio Diffusion and Record Sales.

Figure 2: A Comparison of Bundle Purchase with a la Carte Consumption




(a) Bundle (b) A la Carte Buying: $p < g$ (c) A la Carte Stealing: $p > g$

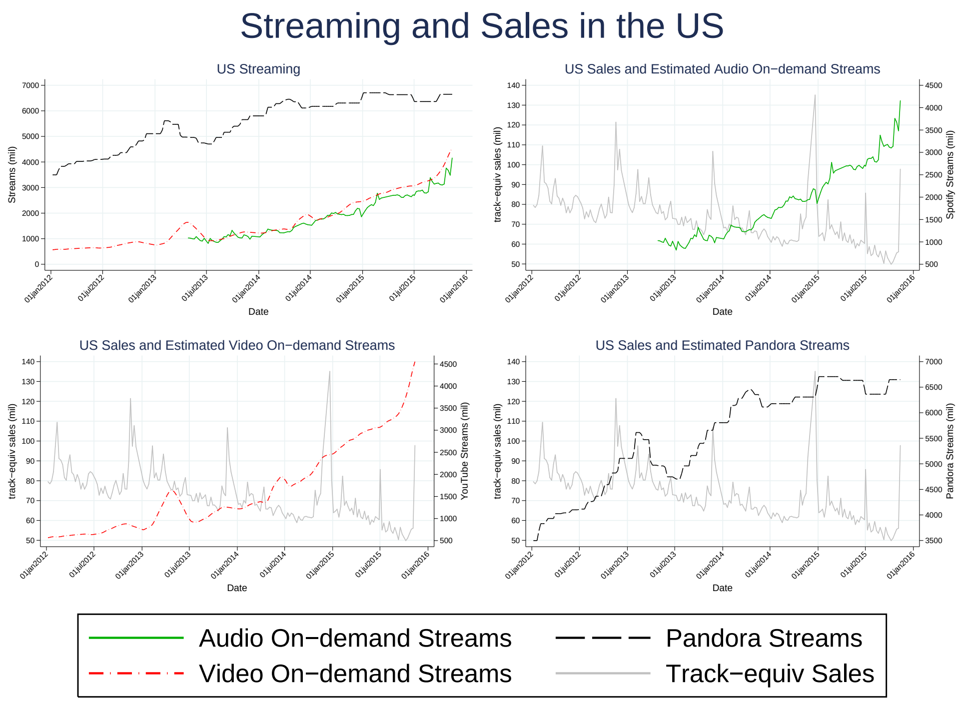
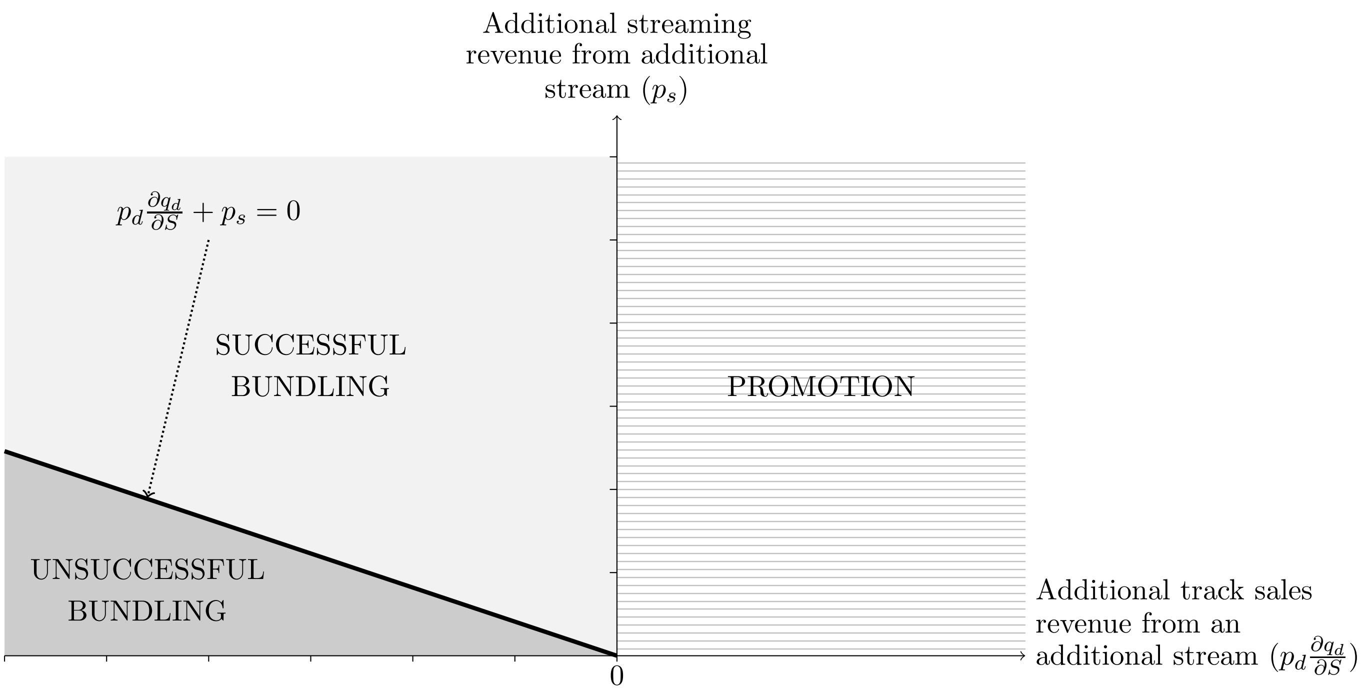



Figure 3: US Streams and Sales, by Format.

Figure 4: Displacement Rate and Price per Stream



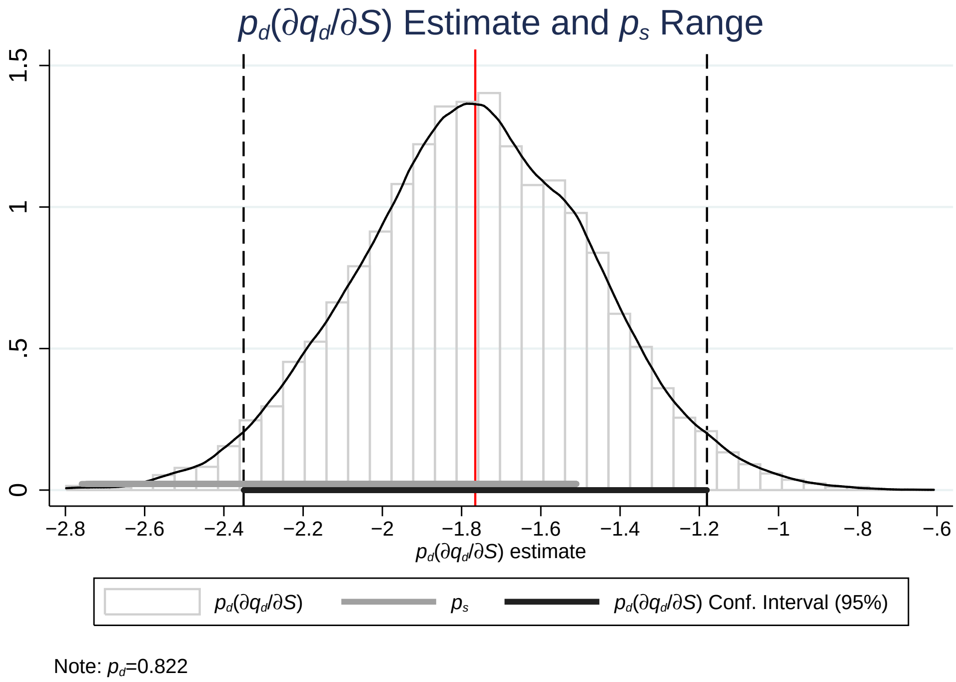



Figure 5: Sales Displacement Estimate and Relative Price Range

Table 1: Song and Artist-level Displacement Estimates.†

| | Dependent Variable: Sales | | | | |
|---|---|---|---|---|---|
| | (1) Coef./s.e. | (2) Coef./s.e. | (3) Coef./s.e. | (4) Coef./s.e. | (5) Coef./s.e. |
| Streams (thousands) | 66.1267*** | 63.6605*** | 64.2270*** | 62.2120*** | 64.3192*** |
| | (0.4836) | (0.6708) | (0.6699) | (0.7299) | (0.8654) |
| Country FE | ✗ | ✓ | ✓ | ✓ | ✓ |
| Week FE | ✗ | ✗ | ✓ | ✓ | - |
| Song FE | ✗ | ✗ | ✗ | ✓ | - |
| Song-Week FE | ✗ | ✗ | ✗ | ✗ | ✓ |
| $R^2$ | 0.399 | 0.560 | 0.564 | 0.650 | 0.719 |
| No. of Obs. | 28186 | 28186 | 28186 | 28186 | 28186 |

| | Dependent Variable: Piracy | | | | |
|---|---|---|---|---|---|
| | (1) Coef./s.e. | (2) Coef./s.e. | (3) Coef./s.e. | (4) Coef./s.e. | (5) Coef./s.e. |
| Streams (thousands) | 24.7935*** | 24.8912*** | 21.0029*** | 21.5989*** | 21.2895*** |
| | (0.3690) | (0.3662) | (0.4349) | (0.4173) | (0.4269) |
| Country FE | ✗ | ✗ | ✓ | ✓ | ✓ |
| Week FE | ✗ | ✓ | ✓ | ✓ | - |
| Artist FE | ✗ | ✗ | ✗ | ✓ | - |
| Artist-Week FE | ✗ | ✗ | ✗ | ✗ | ✓ |
| $R^2$ | 0.175 | 0.190 | 0.255 | 0.403 | 0.550 |
| No. of Obs. | 21324 | 21324 | 21324 | 21324 | 21324 |

† The top panel (sales) reports regressions of weekly sales by track and country on weekly Spotify streams, along with various tracks and country-level fixed effects. We include 21 countries for the period April-December 2013. The bottom panel reports analogous regressions at the artist level and using Musicmetric piracy as the dependent variable. Standard errors are in parenthesis.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

Table 2: Aggregate Displacement Estimates.[†]

| | Dependent Variable: Sales | | | | |
|---|---|---|---|---|---|
| | All | All | All | US only | US only |
| | (1) | (2) | (3) | (4) | (5) |
| | Coef./s.e. | Coef./s.e. | Coef./s.e. | Coef./s.e. | Coef./s.e. |
| Streams (thousands) | 66.0252*** | -36.5918*** | -35.2462*** | -61.8072** | -78.5501** |
| | (2.1511) | (5.4447) | (5.7858) | (29.6397) | (35.6612) |
| Country FE | ✗ | ✓ | ✓ | - | - |
| Week FE | ✗ | ✗ | ✓ | - | Time trend |
| $R^2$ | 0.580 | 0.949 | 0.952 | 0.113 | 0.132 |
| No. of Obs. | 683 | 683 | 683 | 36 | 36 |

| | Dependent Variable: Piracy | | | | |
|---|---|---|---|---|---|
| | All | All | All | US only | US only |
| | (1) | (2) | (3) | (4) | (5) |
| | Coef./s.e. | Coef./s.e. | Coef./s.e. | Coef./s.e. | Coef./s.e. |
| Streams (thousands) | 31.7058*** | -79.0524*** | -76.0528*** | -123.7270*** | -64.2560* |
| | (1.4037) | (6.9082) | (6.8979) | (32.7618) | (33.1009) |
| Country FE | ✗ | ✓ | ✓ | - | - |
| Week FE | ✗ | ✗ | ✓ | - | Time trend |
| $R^2$ | 0.416 | 0.733 | 0.780 | 0.296 | 0.486 |
| No. of Obs. | 719 | 719 | 719 | 36 | 36 |

† The top (bottom) panel reports regressions of country-level track sales (piracy) on country-week Spotify streaming for April-December 2013. The last two columns use only US data for the same period. Standard errors are in parenthesis.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 3: US Streaming and Aggregate Track-equivalent Sales, 2013-2015.†

| | (1) Coef./s.e. | (2) Coef./s.e. | (3) Coef./s.e. | (4) Coef./s.e. |
|---|---|---|---|---|
| Audio on-demand Streams (thousands) | -5.672*** | | | 6.043 |
| | (1.15) | | | (8.87) |
| Pandora Streams (thousands) | | -7.648*** | | -7.636*** |
| | | (0.51) | | (2.70) |
| Video on-demand Streams (thousands) | | | -7.133*** | -6.116 |
| | | | (0.74) | (6.12) |
| Constant | 78261.594*** | 115148.802*** | 84640.673*** | 115236.418*** |
| | (2155.14) | (2848.37) | (1367.16) | (12148.95) |
| $R^2$ | 0.835 | 0.879 | 0.829 | 0.872 |
| No. of Obs. | 117 | 184 | 183 | 115 |
| F-test: Equal coeff | | | | 2.57 |
| P-value | | | | 0.093 |
| F-test: Coeff zero | | | | 28.60 |
| P-value | | | | 0.000 |

† The table reports regressions of US weekly track-equivalent sales on measures of US weekly streaming. All specifications include week-of-the-year effects. Standard errors are in parenthesis and clustered at the month level. Track-equivalent sales are digital track sales + (10 × album sales).

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

Table 4: Combined US Streaming and Aggregate Track-equivalent Sales, 2013-2015.†

| | (1) Coef./s.e. | (2) Coef./s.e. |
|---|---|---|
| Combined streams (thousands) | -2.142*** | -1.798*** |
| | (0.36) | (0.34) |
| track equivalent (-1) | | 0.142 |
| | | (0.14) |
| Constant | 89100.692*** | 75505.088*** |
| | (3495.84) | (11349.65) |
| Normalized | | -2.097*** |
| | | (0.378) |
| $R^2$ | 0.852 | 0.787 |
| No. of Obs. | 115 | 113 |

† All specifications include week-of-the-year effects. Standard errors are in parenthesis and clustered at the month level. Track-equivalent sales are digital track sales + (10 × album sales).

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

Table 5: US Payments per 1,000 Streams†

| | Low | High | Streams (bil) | low | high |
|---|---|---|---|---|---|
| Pandora | 1.5 | 1.5 | 298.5 | 1.51 | 2.77 |
| On-Demand Audio | 2.54 | 8.4 | 79.1 | | |
| On-Demand Video | 0.6 | 2 | 85.4 | | |

† Pandora is based on their content acquisition costs divided by our estimate of their streams. It is close to the statutory 1.4, along with the payments for ASCAP and BMI. On-Demand audio is based on Spotify's reported payments and figures reported by Rethink-Music (2015) of between 2.54 and 8.4 per thousand streams. On-Demand video payments are based on figures reported in Billboard for YouTube of between 0.6 and 2 per thousand streams. These are substantiated in Rethink-Music (2015), which reports 1.11 per thousand streams.