Digitization of Music: Consumer Adoption Amidst Piracy, Unbundling, and Rebundling

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Appendix A

Notations

Notation	Definition
$S_i(t)$	The demand for music format $i \in \{CD, DA, DS, UM, SM\}$ in time period t
$N_I(t)$	The number of (broadband) Internet subscribers in time period t
$N_C(t)$	The number of consumer complaints received by Internet Crime Complaint Center (IC3)
$F_i(t)$	The cumulative adoption probability of music format $i \in \{CD, DA, DS, UM, SM\}$ by time t
m_i	The unique market potential for music format $i \in \{CD, DA, DS, UM, SM\}$
p_i	The innovation coefficient for music format $i \in \{CD, DA, DS, UM, SM\}$
q_i	The imitation coefficient for music format $i \in \{CD, DA, DS, UM, SM\}$
λ_i	The sampling effect on music format $i \in \{DA, DS\}$
$\Phi_{GS}(t)$	Generation substitution (the demand migration from CDs to digital albums) in time period t
$\Phi_{UB}(t)$	Unbundling (the demand migration from CDs to digital singles) in time period t
$\Phi_{A_{CD}}(t)$	Attrition from CDs (the demand migration from CDs to unlicensed digital music) in time period t
$\Phi_{A_{DA}}(t)$	Attrition from digital albums (the demand migration from digital albums to unlicensed digital music) in time period t
$\Phi_{A_{DS}}(t)$	Attrition from digital singles (the demand migration from digital singles to unlicensed digital music) in time period t
$\Phi_{S_{DA}}(t)$	The streaming effect on digital albums (the demand migration from digital albums to streaming music) in time period t
$\Phi_{S_{DS}}(t)$	The streaming effect on digital singles (the demand migration from digital singles to streaming music) in time period t
$v_i(t)$	The real price of music format $i \in \{CD, DA, DS, UM\}$ in time period t
$\beta_{DS}(t)$	The set of parameters that accounts for the differential impact of album and single formats on the demand migration from CDs to digital singles

β_{UM}	The parameter that accounts for the differential impact of album and single formats on the demand migration from CDs and digital albums to unlicensed digital music
ζ_i	The parameter that accounts for the differential impact of downloading and streaming formats on the demand migration from music format $i \in \{DA, DS\}$ to streaming music
$\alpha(t)$	The set of parameters that measures consumers' relative preference for an individual song (digital single) over an album (digital album) formats
γ	The decrease in rate of piracy effect on the demand for CDs after licensed digital downloads were introduced in the market
η	The decrease in rate of piracy effect on the demand for licensed digital downloads after streaming music was introduced in the market
δ	Per Internet subscriber consumption of unlicensed digital music
δ'	Per pirate consumption of unlicensed digital music
δ''	Per complaint consumption of unlicensed digital music
$\psi(t)$	The piracy rate in time period t

Appendix B

The Prices of CD, Digital Album, and Digital Single

Bass et al. (1994) show that if the percentage changes of decision variables (e.g., price) over time are approximately constant, then the estimation results of the Bass model without decision variables are observationally identical to that with decision variables. Hence, in order to verify if there is statistical evidence to believe that the estimation results of the Bass model parameters in our model without prices of each music formats are identical to those with prices of each music formats, we estimate

$$v_i(t) = c \cdot v_i(t-1)$$

where $v_i(t)$ is the real price of music format $i \in \{CD, DA, DS\}$ in time period t. The following table shows the parameter estimates and model fit.

Table B1. Parameter Estimates and Model Fit: The Trend of Real Prices of Music Formats

	CD	Digital album	Digital single
c	0.9271^{***}	0.9769^{***}	0.9933^{***}
	(0.0122)	(0.0071)	(0.0113)
n	31	10	10
Adj. R^2	0.9947	0.9995	0.9987

Note: Standard error in parentheses; *** $p \leq 0.001$

Adjusted R-squares are noticeably high and c for all music formats are significant at the 1 percent level, suggesting that the percentage changes of prices of each music format over time are approximately constant. The rear prices of CDs, digital albums, and digital singles have decreased by 7 percent, 2 percent, and 0.7 percent every year respectively.

Appendix C

The Forecasting Performance of Our Model

Although the focus of our study is not on forecasting, because the diffusion models are often used for forecasting, we evaluate the forecasting performance of our base model using simultaneous simulation (*ex post* forecasting). Using the parameter estimates (reported in Table 1), we derive the *mean absolute error* (MAE) and the *root mean squared error* (RMSE) and compare them with those from the NB model. In order to apply the NB model to our data, we adjust our data into the album level (by defining the demand for licensed digital downloads in time period t as $S_{LM}(t) = S_{DA}(t) + \frac{S_{DS}(t)}{12}$) and consider licensed digital downloads as a successive generation of unlicensed digital music. For comparison, we compute MAE and RMSE for licensed digital downloads from our base model using the same approach, that is, compute the estimated demand for licensed digital downloads from the estimated demand for digital albums and digital singles (i.e., $\widehat{S_{LM}(t)} = \widehat{S_{DA}(t)} + \frac{\widehat{S_{DS}(t)}}{12}$), and compute MAE and RMSE for licensed digital downloads using the following: MAE for licensed digital downloads = $\frac{1}{n}\sum_t \left|\widehat{S_{LM}(t)} - S_{LM}(t)\right|$ and RMSE for licensed digital downloads = $\sqrt{\frac{1}{n}\sum_t \left[\widehat{S_{LM}(t)} - S_{LM}(t)\right]^2}$.

Table C1. The Evaluation of Forecasting Performance

	Our Base Model	Our Base Model with Adjustment	The NB Model
Mean absolute error (MAE)			
CD	0.0247	0.0247	0.0556
Unlicensed digital music	0.0481	0.0481	0.0888
Licensed digital downloads	-	0.0068	0.0069
Digital album	0.0058	-	-
Digital single	0.0140	-	-
Root mean squared error (RMSE)			
CD	0.0317	0.0317	0.0671
Unlicensed digital music	0.0829	0.0829	0.1450
Licensed digital downloads	-	0.0144	0.0141
Digital album	0.0119	-	-
Digital single	0.0391	-	-

Both MAE and RMSE for CDs from our base model are less than a half (44% and 47% respectively) of those from the NB model, and both MAE and RMSE for unlicensed digital music are about a half (54% and 57% respectively) of those from the NB model. Both MAE and RMSE for licensed digital downloads from our base model are almost identical to those from the NB model. This suggests that our base model significantly improves the forecasting performance for CDs and unlicensed digital music and provides as good forecasting performance as the NB model for licensed digital downloads.

Appendix D

Interpolation of Missing Data

Some of the data in our dataset, not used for the estimation of our base (main) model, have some missing observations. We interpolate these missing observations using a linear time trend as shown in Figure D1 and explained below.

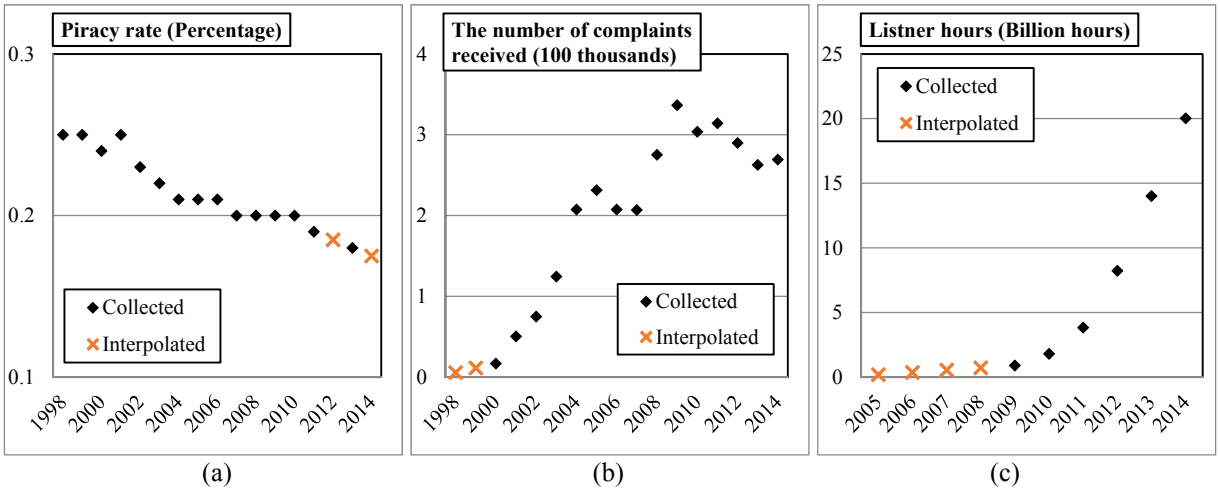


Figure D1. Collected and Interpolated Data for (a) Piracy Rate Estimated by BSA (b) Number of Consumer Complaints Received by IC3, and (c) Pandora's Listener Hours

Piracy rate. BSA (The Software Alliance) did not report the piracy rate for 2012 and 2014. Hence, we use the mean value of 2011 and 2013 data for 2012 data, and impute the 2014 data assuming the piracy rate had decreased linearly since 2010.

Consumer complaints received by Internet Crime Complaint Center (IC3). IC3 began to report the number of complaints received from 2000, whereas the (broadband) Internet connection became available in the United States in 1997. Assuming Internet crime and thereby the complaints received was negligible until (broadband) Internet became available, we interpolate 1998 and 1999 data using a linear time trend (i.e., the number of complaints received had increased linearly during the time period 1998–2000).

Listener hours. While Pandora was launched in 2005, listener hours are available only from 2009 in Pandora's annual report. We interpolate the missing observations assuming listener hours had increased linearly during the time period 2005–2009. We also interpolate the missing observations assuming listener hours during this time period had increased at a constant rate. The estimation results of our extended model are rather insensitive to the assumption.

Appendix E

Robustness Checks

The Price of Unlicensed Digital Music

Table E1 reports the estimation results and model fit for the cases $\beta_{UM} = 10$ and 8.

Table E1. Parameter Estimates and Model Fit: Relaxing the Assumption that $\beta_{UM} = 12$

	Base model		$\beta_{UM} = 10$		$\beta_{UM} = 8$	
	Est.	**Std. Err.**	**Est.**	**Std. Err.**	**Est.**	**Std. Err.**
Market potential						
CD (m_{CD})	1.0084***	0.0573	1.0153***	0.0585	1.0246***	0.0596
Unlicensed digital music (m_{UM})	0[a]	-	0[a]	-	0[a]	-
Digital album (m_{DA})	0.6081***	0.1446	0.6165***	0.1497	0.6281***	0.1578
Digital single (m_{DS})	0.8799†	0.4447	0.8366†	0.4307	0.7820†	0.4089
Innovation						
CD (p_{CD})	0.0085***	0.0014	0.0086***	0.0014	0.0088***	0.0014
Unlicensed digital music (p_{UM})	0.0057*	0.0021	0.0060**	0.0021	0.0063**	0.0021
Digital album (p_{DA})	0.0085[a]	-	0.0086[a]	-	0.0086[a]	-
Digital single (p_{DS})	0.0085[a]	-	0.0086[a]	-	0.0086[a]	-
Imitation (world-of mouth effect)						
CD (q_{CD})	0.3386***	0.0381	0.3345***	0.0382	0.3292***	0.0381
Unlicensed digital music (q_{UM})	0.4805***	0.0493	0.4781***	0.0491	0.4743***	0.0485
Digital album (q_{DA})	0.3023*	0.1450	0.3068*	0.1384	0.3126*	0.1309
Digital single (q_{DS})	0[c]	-	0[c]	-	0[c]	-
Sampling effect						
Digital album (λ_{DA})	0.0037	0.0203	0.0026	0.0188	0.0012	0.0170
Digital single (λ_{DS})	0.7441*	0.3156	0.7646*	0.3324	0.7940*	0.3539
Adjustment for difference in units between						
Digital single and CD (b_{DS})	0.8043**	0.2225	0.8042**	0.2274	0.8044**	0.2348
Unlicensed digital music and CD / digital album (β_{UM})	12[a]	-	10[a]	-	8[a]	-
Proportion of digital single (a)	0.1968***	0.0237	0.1962***	0.0239	0.1955***	0.0242
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1452*	0.0576	0.1440*	0.0575	0.1424*	0.0572
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853***	0.1806	0.5885***	0.1506	0.4901***	0.1186
Adj. R-Square						
CD	0.9888		0.9884		0.9878	

Unlicensed digital music	0.9994	0.9994	0.9994
Digital album	0.9115	0.9087	0.9051
Digital single	0.9935	0.9935	0.9934
Number of observations	33×4	33×4	33×4

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; † $p \leq 0.1$; [c] boundary condition; [a] technical assumption

The Market Potential for Unlicensed Digital Music

Table E2 reports the estimation results and model fit for the cases $m_{UM} = 0.5m_{CD}$ and m_{CD}.

Table E2. Parameter Estimates and Model Fit: Relaxing the Assumption that $m_{UM} = 0$

	Base model		$m_{UM} = 0.5m_{CD}$		$m_{UM} = m_{CD}$	
	Est.	**Std. Err.**	**Est.**	**Std. Err.**	**Est.**	**Std. Err.**
Market potential						
CD (m_{CD})	1.0084***	0.0573	1.0127***	0.0587	1.0172***	0.0599
Unlicensed digital music (m_{UM})	0[a]	-	0.5064[a]	-	1.0172[a]	-
Digital album (m_{DA})	0.6081***	0.1446	0.6189***	0.1514	0.6301***	0.1597
Digital single (m_{DS})	0.8799†	0.4447	0.8940*	0.4196	0.9068*	0.3991
Innovation						
CD (p_{CD})	0.0085***	0.0014	0.0086***	0.0014	0.0087***	0.0014
Unlicensed digital music (p_{UM})	0.0057*	0.0021	0.0058*	0.0021	0.0059*	0.0022
Digital album (p_{DA})	0.0085[a]	-	0.0086[a]	-	0.0087[a]	-
Digital single (p_{DS})	0.0085[a]	-	0.0086[a]	-	0.0087[a]	-
Imitation (world-of mouth effect)						
CD (q_{CD})	0.3386***	0.0381	0.3358***	0.0382	0.3330***	0.0382
Unlicensed digital music (q_{UM})	0.4805***	0.0493	0.4829***	0.0492	0.4851***	0.0491
Digital album (q_{DA})	0.3023*	0.1450	0.3006*	0.1452	0.2986*	0.1454
Digital single (q_{DS})	0[c]	-	0[c]	0	0[c]	0
Sampling effect						
Digital album (λ_{DA})	0.0037	0.0203	0.0036	0.0202	0.0036	0.0201
Digital single (λ_{DS})	0.7441*	0.3156	0.7219*	0.2887	0.7019*	0.2668
Adjustment for difference in units between						
Digital single and CD (b_{DS})	0.8043**	0.2225	0.7828***	0.2080	0.7633***	0.1953
Unlicensed digital music and CD / digital album (β_{UM})	12[a]	-	12[a]	-	12[a]	-
Proportion of digital single (a)	0.1968***	0.0237	0.1986***	0.0230	0.2004***	0.0224
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1452*	0.0576	0.1502*	0.0598	0.1551*	0.0620
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853***	0.1806	0.7311***	0.1919	0.7787***	0.2027
Adj. R-Square						

CD	0.9888	0.9887	0.9886
Unlicensed digital music	0.9994	0.9994	0.9994
Digital album	0.9115	0.9126	0.9139
Digital single	0.9935	0.9936	0.9937
Number of observations	33×4	33×4	33×4

$^{***}\ p \leq 0.001$; $^{**}\ p \leq 0.01$; $^{*}\ p \leq 0.05$; $^{\dagger}\ p \leq 0.1$; [c] boundary condition; [a] technical assumption

Other Proxy Measures for the Demand for Unlicensed Digital Music

Table E3 reports the estimation results and model fit for different proxy measures for $S_{UM}(t)$.

Table E3. Parameter Estimates and Model Fit: Different Proxy Measures for $S_{UM}(t)$

	Base model		Weighted Internet penetration		Complaints received by IC3	
	Est.	**Std. Err.**	**Est.**	**Std. Err.**	**Est.**	**Std. Err.**
Market potential						
CD (m_{CD})	1.0084***	0.0573	1.0172***	0.0637	1.0084[a]	-
Unlicensed digital music (m_{UM})	0[a]	-			0[a]	-
Digital album (m_{DA})	0.6081***	0.1446	0.4884**	0.1396	0.6081[a]	-
Digital single (m_{DS})	0.8799†	0.4447	0.9445	0.6277	0.8799[a]	-
Innovation						
CD (p_{CD})	0.0085***	0.0014	0.0083***	0.0015	0.0081***	0.0014
Unlicensed digital music (p_{UM})	0.0057*	0.0021	0.0069*	0.0030	0.0080*	0.0039
Digital album (p_{DA})	0.0085[a]	-	0.0083[a]	-	0.0081[a]	-
Digital single (p_{DS})	0.0085[a]	-	0.0083[a]	-	0.0081[a]	-
Imitation (world-of mouth effect)						
CD (q_{CD})	0.3386***	0.0381	0.3376***	0.0414	0.3441***	0.0240
Unlicensed digital music (q_{UM})	0.4805***	0.0493	0.4502***	0.0702	0.4214***	0.1102
Digital album (q_{DA})	0.3023*	0.1450	0.1498	0.2487	0[c]	-
Digital single (q_{DS})	0[c]	-	0[c]	-	0.0840	0.3449
Sampling effect						
Digital album (λ_{DA})	0.0037	0.0203	0.0319	0.0550	0.0287	0.0234
Digital single (λ_{DS})	0.7441*	0.3156	0.7063†	0.4061	0.5810**	0.1635
Adjustment for difference in units between						
Digital single and CD (b_{DS})	0.8043**	0.2225	0.7479**	0.2207	0.5977***	0.0767
Unlicensed digital music and CD / digital album (β_{UM})	12[a]	-	12[a]	-	12[a]	-
Proportion of digital single (a)	0.1968***	0.0237	0.2029***	0.0261	0.2296***	0.0160
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1452*	0.0576	0.1548*	0.0756	0.2064**	0.0732
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853***	0.1806				
Per pirate consumption of unlicensed digital music (δ')			3.2865***	0.8800		

Per complain consumption of unlicensed digital music (δ'')			7.0943*** 1.1971
Adj. R-Square			
CD	0.9888	0.9895	0.9896
Unlicensed digital music	0.9994	0.9990	0.9722
Digital album	0.9115	0.9584	0.6905
Digital single	0.9935	0.9942	0.9953
Number of observations	33×4	33×4	33×4

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; † $p \leq 0.1$; [c] boundary condition; [a] technical assumption

Appendix F

The Extended Model

Our extended model that includes streaming effects (given in equations (3), (6) – (11), (14) – (16), and (17) – (23)) can be summarized as the following. We write the demand (units shipped) for each music format i in time period t as

$$
\begin{aligned}
S_{CD}(t) &= m_{CD}F_{CD}(t) - \Phi_{GS}(t) - \Phi_{UB}(t) - \Phi_{A_{CD}}(t) \\
S_{UM}(t) &= \delta N_I(t) = m_{UM}F_{UM}(t-\tau_{UM}) + \beta_{UM}\Phi_{A_{CD}}(t) + \beta_{UM}\Phi_{A_{DA}}(t) + \Phi_{A_{DS}}(t) \\
S_{DA}(t) &= m_{DA}F_{DA}(t-\tau_{LM}) + \Phi_{GS}(t) - \Phi_{A_{DA}}(t) - \Phi_{S_{DA}}(t) \\
S_{DS}(t) &= m_{DS}F_{DS}(t-\tau_{LM}) + \beta_{DS}(t)\Phi_{UB}(t) - \Phi_{A_{DS}}(t) - \Phi_{S_{DS}}(t) \\
S_{SM}(t) &= m_{SM}F_{SM}(t-\tau_{SM}) + \zeta_{DA}\Phi_{S_{DA}}(t) + \zeta_{DS}\Phi_{S_{DS}}(t)
\end{aligned}
$$

where $\beta_{DS}(t) = b_{DS}\left[1 - \log\left[\frac{v_{DS}(t)}{v_{CD}(t)}\right]\right]$ and $F_i(t)$ are derived from

$$
\begin{aligned}
\frac{\partial F_i(t)}{\partial t} &= [p_i + q_i F_i(t)][1 - F_i(t)] \text{ for } i = CD, UM, \text{ and } SM \\
\frac{\partial F_i(t)}{\partial t} &= [p_i + q_i F_i(t) + \lambda_i F_{UM}(t-\tau_{UM})][1 - F_i(t)] \text{ for } i = DA \text{ and } DS
\end{aligned}
$$

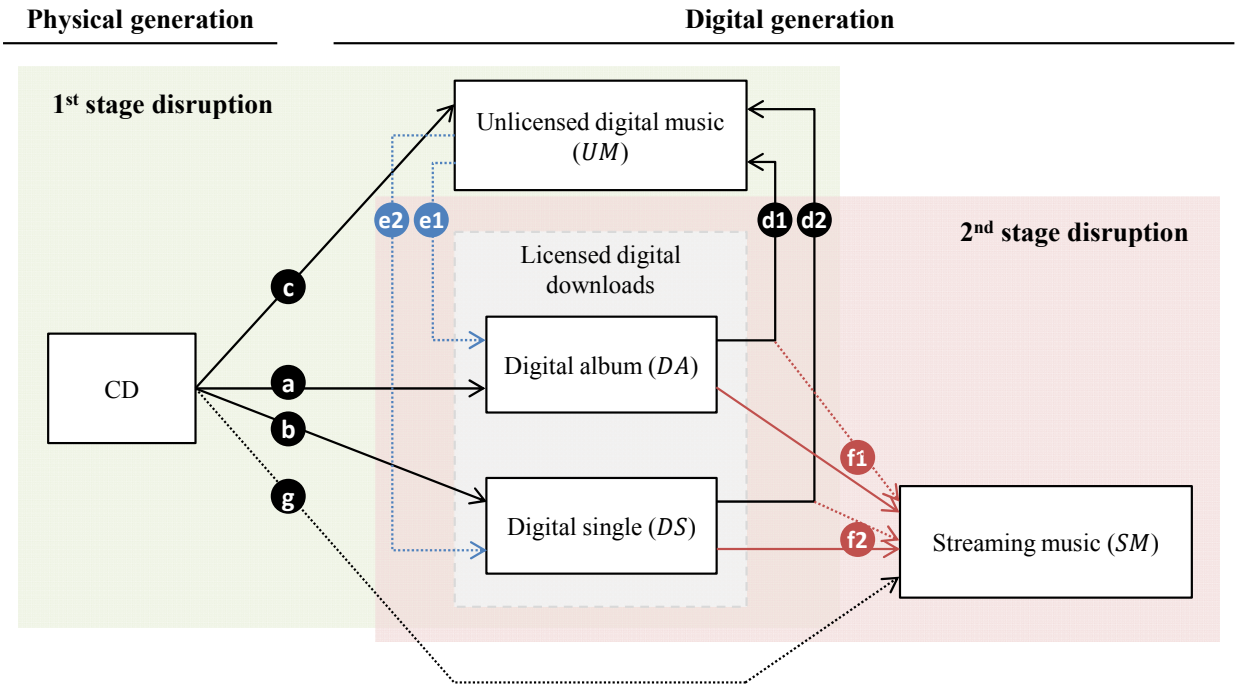
We define each demand migration type as

$$
\begin{aligned}
\Phi_{A_{CD}}(t) &= e^{-\gamma \cdot I_{LM}(t)} m_{CD}F_{CD}(t)F_{UM}(t-\tau_{UM}) \\
\Phi_{GS}(t) &= [1-\alpha(t)]\left[1 - e^{-\gamma \cdot I_{LM}(t)}\right] m_{CD}F_{CD}(t)F_{DA}(t-\tau_{LM}) \\
\Phi_{UB}(t) &= \alpha(t)\left[1 - e^{-\gamma \cdot I_{LM}(t)}\right] m_{CD}F_{CD}(t)F_{DS}(t-\tau_{LM}) \\
\Phi_{A_{DA}}(t) &= e^{-\eta \cdot I_{SM}(t)} m_{DA}F_{DA}(t-\tau_{LM})F_{UM}(t-\tau_{UM}) \\
\Phi_{A_{DS}}(t) &= e^{-\eta \cdot I_{SM}(t)} m_{DS}F_{DS}(t-\tau_{LM})F_{UM}(t-\tau_{UM}) \\
\Phi_{S_{DA}}(t) &= \left[1 - e^{-\eta \cdot I_{SM}(t)}\right] m_{DA}F_{DA}(t-\tau_{LM})F_{UM}(t-\tau_{UM}) + \Phi_{GS}(t)F_{SM}(t-\tau_{SM}) \\
\Phi_{S_{DS}}(t) &= \left[1 - e^{-\eta \cdot I_{SM}(t)}\right] m_{DS}F_{DS}(t-\tau_{LM})F_{UM}(t-\tau_{UM}) + \beta_{DS}(t)\Phi_{UB}(t)F_{SM}(t-\tau_{SM})
\end{aligned}
$$

where $\alpha(t) = a\left[1 - \log\left[\frac{v_{DS}(t)}{v_{DA}(t)}\right]\right]$, $I_{LM}(t) = t - \tau_{LM}$ if $t \geq \tau_{LM}$ and 0 otherwise, and $I_{SM}(t) = t - \tau_{SM}$ if $t \geq \tau_{SM}$ and 0 otherwise.

Appendix G

An Alternative Model: The Direct Demand Migration from CDs to Streaming Music



Note: a. Generational substitution; b. Unbundling; c. Attrition from CDs; d1&d2. Attrition from digital albums and digital singles; e1&e2. Sampling effects on digital albums and digital singles; f1&f2. Streaming effects on digital albums and digital singles; g. Streaming effect on CDs

Figure G1. An Alternative Model Including the Direct Demand Migration from CDs to Streaming Music

In order to test if there was the direct demand migration from CDs to streaming music (arrow labeled "g" in Figure G1), we revise our extended model (given in equations (3), (6)–(11), (14)–(16), and (17)–(23)) as the following. We first revise the demand for CDs in time period t (given in equation (3)) as

$$S_{CD}(t) = m_{CD}F_{CD}(t) - \Phi_{GS}(t) - \Phi_{UB}(t) - \Phi_{A_{CD}}(t) - \Phi_{S_{CD}}(t)$$

and the demand for streaming music in time period t (given in equation (19)) as

$$S_{SM}(t) = m_{SM}F_{SM}(t - \tau_{SM}) + \zeta_{CD}\Phi_{S_{CD}}(t) + \zeta_{DA}\Phi_{S_{DA}}(t) + \zeta_{DS}\Phi_{S_{DS}}(t)$$

We then revise the attrition from CDs, $\Phi_{A_{CD}}(t)$ (given in equation (8)), the generational substitution, $\Phi_{GS}(t)$ (given in equation (9)), and the unbundling, $\Phi_{UB}(t)$ (given in equation (10)) as

$$\Phi_{A_{CD}}(t) = e^{-\gamma \cdot I_{LM}(t)} m_{CD}F_{CD}(t)F_{UM}(t - \tau_{UM})$$
$$\Phi_{GS}(t) = [1 - \alpha(t)][1 - \theta D_{SM}(t)]\left[1 - e^{-\gamma \cdot I_{LM}(t)}\right]m_{CD}F_{CD}(t)F_{DA}(t - \tau_{LM})$$

$$\Phi_{UB}(t) = \alpha(t)[1 - \theta D_{SM}(t)]\left[1 - e^{-\gamma \cdot I_{LM}(t)}\right] m_{CD} F_{CD}(t) F_{DS}(t - \tau_{LM})$$

and define the streaming effect on CDs, $\Phi_{S_{CD}}(t)$, as

$$\Phi_{S_{CD}}(t) = \theta D_{SM}(t)\left[1 - e^{-\gamma \cdot I_{LM}(t)}\right] m_{CD} F_{CD}(t) F_{SM}(t - \tau_{SM})$$

where $D_{SM}(t) = 1$ if $t \geq \tau_{SM}$ and 0 otherwise.

If $t < \tau_{SM}$ (i.e., when streaming music was unavailable), we have: $\Phi_{S_{CD}}(t) = 0$ and the alternative model (that incorporates the direct demand migration from CDs to streaming music) becomes identical to our extended model (that does not). If $t \geq \tau_{SM}$ (i.e., when streaming music was available), in the alternative model, θ fraction of demand for CDs that would have gone to unlicensed digital music switched to streaming music instead. Analogous to the extended model, a part of the remaining (weighted $\alpha(t)$ fraction of $(1 - \theta)$ fraction) switched to digital singles and the rest switched to digital albums. All other aspects of the model remain the same as in our extended model.

We first estimate the alternative model assuming there was demand migration from CDs to streaming music (arrow labeled "g") but not from licensed digital downloads (digital album and digital single) to streaming music (arrows labeled "f1" and "f2") (Model A1). We then estimate the model assuming there were both types of demand migration (i.e., both from CDs and licensed digital downloads to streaming music) (Model A2). Analogous to what we did for the estimation of our extended model, we assume the market potential for streaming music is exogenously given (feed m_{SM} that we obtained from the extended model into the estimation) and estimate the other parameters of the alternative model. For the rest of the estimation, we use the same strategy that we used for the estimation of our extended model. We present the estimation results and model fit from Model A1 and Model A2 along with that from our extended model in Table G1.

Table G1. Parameter Estimates and Model Fit: The Streaming Effect on CDs

	Extended model (without "g", with "f1" and "f2")		Model A1 (with "g", without "f1" and "f2")		Model A2 (with "g", "f1", and "f2")	
	Est.	**Std. Err.**	**Est.**	**Std. Err.**	**Est.**	**Std. Err.**
Market potential						
CD (m_{CD})	1.0084[a]	-	1.0084[a]	-	1.0084[a]	-
Unlicensed digital music (m_{UM})	0[a]	-	0[a]	-	0[a]	-
Digital album (m_{DA})	0.6081[a]	-	0.6081[a]	-	0.6081[a]	-
Digital single (m_{DS})	0.8799[a]	-	0.8799[a]	-	0.8799[a]	-
Streaming music (m_{SM})	0.4054*	0.1820	0.4054[a]	-	0.4054[a]	-
Innovation						
CD (p_{CD})	0.0090***	0.0201	0.0065***	0.0012	0.0087***	0.0012
Unlicensed digital music (p_{UM})	0.0066***	0.0007	0.0059***	0.0007	0.0066***	0.0007
Digital album (p_{DA})	0.0090[a]	-	0.0065[a]	-	0.0087[a]	-
Digital single (p_{DS})	0.0090[a]	-	0.0065[a]	-	0.0087[a]	-
Streaming music (p_{SM})	0.0090[a]	-	0.0065[a]	-	0.0087[a]	-
Imitation (world-of mouth effect)						
CD (q_{CD})	0.3311***	0.0201	0.3691***	0.0237	0.3346***	0.0204
Unlicensed digital music (q_{UM})	0.4436***	0.0236	0.4708***	0.0296	0.4426***	0.0233
Digital album (q_{DA})	0.8118***	0.1755	0.3110***	0.0598	0.8509***	0.1944
Digital single (q_{DS})	0[c]	-	0[c]	-	0[c]	-
Streaming music (q_{SM})	0.2526***	0.0436	0.3868	0.3513	0.2581***	0.0440
Sampling effect						
Digital album (λ_{DA})	-0.031***	0.0070	0.0050	0.0126	-0.031***	0.0068
Digital single (λ_{DS})	0.6223***	0.0584	0.7612***	0.0779	0.6185***	0.0604
Adjustment for difference in units between						
Digital single and CD (b_{DS})	1.2801***	0.1669	0.7971***	0.0607	1.3191***	0.1847
Unlicensed digital music and CD / digital album (β_{UM})	12[a]	-	12[a]	-	12[a]	-
Streaming music and CD (ζ_{CD})			-9.3036	40.9161	-24.2030	42.4553
Streaming music and digital album (ζ_{DA})	1.1897*	0.4312			1.4573**	0.5003
Streaming music and digital single (ζ_{DS})	-0.1186	0.1029			0.0809	0.2112
Proportion of digital single (a)	0.1880***	0.0135	0.1946***	0.0222	0.1951***	0.0185
Proportion of streaming music (θ)			-0.0325	0.1298	0.0551	0.0536
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1063***	0.0125	0.1385***	0.0184	0.1047***	0.0123
The effect of streaming on the attrition from licensed digital music (η)	0.0686**	0.0208			0.0726**	0.0216
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853[a]	-	0.6853[a]	-	0.6853[a]	-
Adj. R-Square						
CD	0.9876		0.9883		0.9876	
Unlicensed digital music	0.9996		0.9995		0.9996	
Digital album	0.7414		0.8959		0.7207	
Digital single	0.9971		0.9933		0.9971	
Streaming music	0.9994		0.9359		0.9996	
Number of observations	33×5		33×5		33×5	

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; † $p \leq 0.1$; [c] boundary condition; [a] technical assumption

In both Model A1 and Model A2, the proportion of streaming music θ is insignificant, suggesting that there was likely no direct demand migration from CDs to streaming music. Consistent with the estimation results of our extended model, on the other hand, the estimation results of Model A2 suggest that there was likely demand migration from digital albums to streaming music (significant ζ_{DA}) and the introduction of streaming music has weakened the piracy effect by about 7 percent every year ($\eta = 0.0726$). These results are consistent with the theory that streaming music is a subsequent generation of digital music format and the disruption of digitization of music has indeed come in two stages (i.e., the demand for music migrated from physical to digital download formats first and from digital download to streaming formats in the second stage).

Appendix H

The Differential Impact on the Demand Migration from CDs to Digital Albums

Because both the CD and the digital album are album formats, we assume there is no differential impact on the demand migration from CDs to digital albums; that is, one unit demand for CDs migrates to one unit demand for digital albums. In order to verify this assumption, analogous to what we did to control for the differential impact of single and album formats on the demand migration from CDs to digital singles, we revise the demand for digital albums in time period t for our base model (given in equation (4)) as

$$S_{DA}(t) = m_{DA}F_{DA}(t - \tau_{LM}) + \beta_{DA}(t)\Phi_{GS}(t) - \Phi_{A_{DA}}(t)$$

for our extended model (given in equation (17)) as

$$S_{DA}(t) = m_{DA}F_{DA}(t - \tau_{LM}) + \beta_{DA}(t)\Phi_{GS}(t) - \Phi_{A_{DA}}(t) - \Phi_{S_{DA}}(t)$$

and controlling for the price effect, we define

$$\beta_{DA}(t) = b_{DA}\left[1 - \log\left[\frac{v_{DA}(t)}{v_{CD}(t)}\right]\right] \tag{H1}$$

The revised models (the revised base model (Model B1) and the revised extended model (Model B2)) allow that one unit demand for CDs migrates to $\beta_{DA}(t)$ units demand for digital albums. In contrast, $\beta_{DA}(t)$ is assumed to be one in our base model and the extended model. All other aspects of the models remain the same as in our base model and the extended model. We use the same estimation strategy that we used for the estimation of our base model and the extended model. We present the estimation results and model fit from the revised models along with that from our base model and the extended model in Tables H1 and H2.

Table H1. Parameter Estimates and Model Fit: The Differential Impact on the Demand Migration from CDs to Digital Albums in the Base Model

	Base model (assuming $\beta_{DA}(t) = 1$)			Model B1 (estimating $\beta_{DA}(t)$)		
	Est.	Std. Err.	Sig.	Est.	Std. Err.	Sig.
Market potential						
CD (m_{CD})	1.0084	0.0573	***	1.0090	0.0562	***
Unlicensed digital music (m_{UM})	0	-	a	0	-	a
Digital album (m_{DA})	0.6081	0.1446	***	0.5731	0.2100	*
Digital single (m_{DS})	0.8799	0.4447	†	0.8411	0.6324	
Innovation						
CD (p_{CD})	0.0085	0.0014	***	0.0085	0.0014	***
Unlicensed digital music (p_{UM})	0.0057	0.0021	*	0.0056	0.0021	*
Digital album (p_{DA})	0.0085	-	a	0.0085	-	a
Digital single (p_{DS})	0.0085	-	a	0.0085	-	a
Imitation (word-of mouth effect)						
CD (q_{CD})	0.3386	0.0381	***	0.3378	0.0376	***
Unlicensed digital music (q_{UM})	0.4805	0.0493	***	0.4851	0.0524	***
Digital album (q_{DA})	0.3023	0.1450	*	0.3011	0.1918	
Digital single (q_{DS})	0	-	c	0	-	c
Sampling effect						
Digital album (λ_{DA})	0.0037	0.0203		0.0075	0.0247	
Digital single (λ_{DS})	0.7441	0.3156	*	0.7654	0.4581	
Adjustment for difference in units between						
Digital single and CD (b_{DS})	0.8043	0.2225	**	0.8372	0.3077	*
Digital album and CD (b_{DA})				0.6767	0.3426	†
Unlicensed digital music and CD / digital album (β_{UM})	12	-	a	12	-	a
Proportion of digital single (a)	0.1968	0.0237	***	0.1873	0.0420	***
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1452	0.0576	*	0.1481	0.0622	*
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853	0.1806	***	0.6853	0.1728	***
Adj. R-Square						
CD		0.9888			0.9888	
Unlicensed digital music		0.9994			0.9994	
Digital album		0.9115			0.9208	
Digital single		0.9935			0.9937	
Number of observations		33×4			33×4	

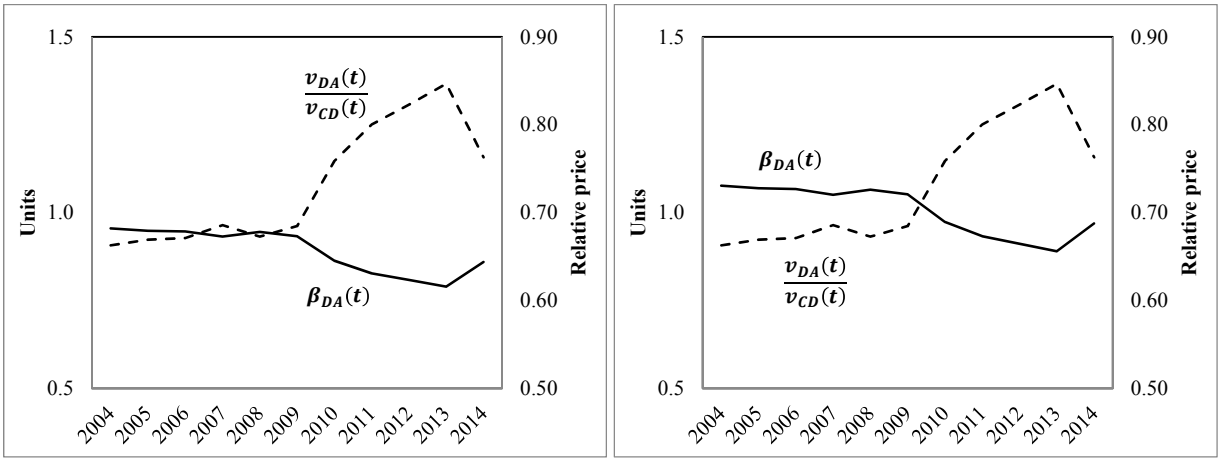
*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; † $p \leq 0.1$; [c] boundary condition; [a] technical assumption

Table H2. Parameter Estimates and Model Fit: The Differential Impact on the Demand Migration from CDs to Digital Albums in the Extended Model

	Extended model (assuming $\beta_{DA}(t) = 1$)			Model B2 (estimating $\beta_{DA}(t)$)		
	Est.	**Std. Err.**	**Sig.**	**Est.**	**Std. Err.**	**Sig.**
Market potential						
CD (m_{CD})	1.0084	-	a	1.0084	-	a
Unlicensed digital music (m_{UM})	0	-	a	0	-	a
Digital album (m_{DA})	0.6081	-	a	0.6081	-	a
Digital single (m_{DS})	0.8799	-	a	0.8799	-	a
Streaming music (m_{SM})	0.4054	0.1820	*	0.4110	0.2005	†
Innovation						
CD (p_{CD})	0.0090	0.0201	***	0.0089	0.0012	***
Unlicensed digital music (p_{UM})	0.0066	0.0007	***	0.0065	0.0007	***
Digital album (p_{DA})	0.0090	-	a	0.0089	-	a
Digital single (p_{DS})	0.0090	-	a	0.0089	-	a
Streaming music (p_{SM})	0.0090	-	a	0.0089	-	a
Imitation (word-of mouth effect)						
CD (q_{CD})	0.3311	0.0201	***	0.3321	0.0201	***
Unlicensed digital music (q_{UM})	0.4436	0.0236	***	0.4443	0.0241	***
Digital album (q_{DA})	0.8118	0.1755	***	0.8126	0.1748	***
Digital single (q_{DS})	0	-	c	0	-	c
Streaming music (q_{SM})	0.2526	0.0436	***	0.2467	0.0452	***
Sampling effect						
Digital album (λ_{DA})	-0.0313	0.0070	***	-0.0311	0.0069	***
Digital single (λ_{DS})	0.6223	0.0584	***	0.6298	0.0600	***
Adjustment for difference in units between						
Digital single and CD (b_{DS})	1.2801	0.1669	***	1.2393	0.1710	***
Digital album and CD (b_{DA})				0.7630	0.1237	***
Unlicensed digital music and CD / digital album (β_{UM})	12	-	a	12	-	a
Streaming music and digital album (ζ_{DA})	1.1897	0.4312	*	1.1956	0.4338	*
Streaming music and digital single (ζ_{DS})	-0.1186	0.1029		-0.1204	0.1073	
Proportion of digital single (α)	0.1880	0.0135	***	0.1838	0.0138	***
The effect of licensed digital downloads on the attrition from CDs (γ)	0.1063	0.0125	***	0.1064	0.0127	***
The effect of streaming on the attrition from licensed digital music (η)	0.0686	0.0208	**	0.0686	0.0207	**
Per Internet subscriber consumption of unlicensed digital music (δ)	0.6853	-	a	0.6853	-	a
Adj. R-Square						
CD		0.9876			0.9874	
Unlicensed digital music		0.9996			0.9996	
Digital album		0.7414			0.7302	
Digital single		0.9971			0.9971	
Streaming music		0.9994			0.9994	
Number of observations		33×5			33×5	

*** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; † $p \leq 0.1$; [c] boundary condition; [a] technical assumption

The estimation results from the revised models (that estimate $\beta_{DA}(t)$) and that from our base model and the extended model (that assume $\beta_{DA}(t) = 1$) are very consistent. Furthermore, from equation (H1), $b_{DA} = 0.6767$ (from Model B1) and 0.7630 (from Model B2) suggest that, given the prices of CDs and digital albums, during the time period 2004–2014, on average one unit demand for CDs migrates to about 0.89 units and 1.01 units demand for digital albums respectively (Figure H1). These results are consistent with our assumption that one unit demand for CDs migrates to one unit demand for digital albums.



(a) Model B1 – revised base model (b) Model B2 – revised extended model

Figure H1. The Unit Conversion between the Demand for CDs and that for Digital Albums