Digitization, Unbundling, and Piracy: 
Consumer Adoption amidst Disruptive Innovations in the Music Industry

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Abstract

In the music industry, the Internet and digital music formats have fundamentally altered the way music is packaged, distributed and consumed. The Internet and digital music formats have enabled music to be purchased as an individual song (digital single) or as an album (digital album), or to be enjoyed without paying for it (unlicensed music). Building on multi-generation diffusion models, we identify, and quantify the demand migration patterns among these various consumption options: (i) from CD to digital album (generation substitution), (ii) from CD to digital single (unbundling), (iii) attrition from CD to unlicensed music, (iv) attrition from digital album to unlicensed music, and (v) attrition from digital single to unlicensed music. We find that the introduction of purchased digital music – digital album and digital single – option has weakened the attrition effect of online music piracy (unlicensed music) on the demand for CD. Since digital single and digital album were introduced, about 7 billion units of the demand for CD that would have migrated to unlicensed music has migrated to either digital single or digital album. Cannibalization due to unbundling, rather than attrition due to piracy, is now the dominant factor that leads the migration of demand for CD to digital music formats and the decline in industry revenue. However, attrition is emerging as a challenge for digital single and digital album. Especially, in recent years, while the rate of increase of attrition effect of online music piracy on digital single is decreasing, that on digital album is increasing. Although we focus on the demand migration patterns in the music industry, our model can be easily extended and used to shed some light on the complicated migration of demand in the industries where ‘tipping across markets’ or ‘platform envelopment’ phenomenon occurs.

Keywords: Disruptive innovation, technology substitution, generation substitution, attrition of demand, unbundling, multi-generation diffusion, music sales, digital music.
1. Introduction

The phenomenon of new technologies replacing old ones is ubiquitous in many industries. Products based on new technologies often have higher quality or lower cost than those based on the old technologies, which induces consumers to migrate from the earlier generation products to the successive generation ones. Sometimes, the new technology can be disruptive in the sense that it can fundamentally redefine the characteristics of the industry or the market (Christensen 1997).

One often-cited example of such a disruptive force is the Internet along with digital music formats in the music industry (Cellan-Jones 2013). It has fundamentally changed the way music is packaged, distributed to, and consumed by consumers. Before the introduction of the Internet, music was distributed primarily using physical media such as LP (Long Play), cassette, and later CD (Compact Disc). The Internet, assisted by the development of digital sound recording formats (e.g., MP3), has made digital music that is distributed without a physical medium the consumers’ preferred choice in recent years.\(^1\) While the digital formats and the Internet as a distribution may seem innocuous, it had a drastic impact on the music industry.\(^2\) First, digital music has transformed the industry from one that predominantly distributed and sold music as a bundle of songs in a single medium (i.e., an album) to one that distributed music also as an individual song (i.e., single). On the supply side, the negligible marginal cost of distribution in the case of digital music as compared to significant marginal cost of distribution for earlier formats such as LP, tape, and CD, has made such unbundling of music viable. On the demand side, with the consumers rapidly adopting distribution channels such as peer-to-peer (P2P) networks, the labels’ move to unbundling of music has allowed consumers to acquire and consume specific songs they prefer thereby foregoing seller-determined bundles which may contain songs they do not prefer. This has

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\(^1\) In this paper, by digital music, we are referring to music in digital format that can be downloaded from the Internet. On the other hand, the CD music, though it is stored digitally, is physical in the sense that it is available for purchase as a physical disc.

\(^2\) The Internet has disrupted other industries also in a similar way. Newspapers, magazines, movies, television, and software are some other examples where a similar phenomenon is observed.
significantly altered the music industry’s market structure. Second, the Internet facilitates sharing of
digital contents at minimal cost and provides consumers with various options to consume music without
paying for it though many of those are illegal. Consumers download music from P2P and Torrent
networks and rip music from various Internet radio channels. Altogether, the Internet has substantially
changed the way music is consumed by enabling digital music to be purchased as an individual song
(digital single) or as an album (digital album), or to be enjoyed without paying for it (unlicensed music). A key difference between purchased digital music – digital single and digital album – and unlicensed
music is that the former is a direct revenue source for the music industry but the latter is not.

It is imperative to understand the dynamics of consumption of music as consumers migrate from
the CD format to digital music formats. The dynamics is especially important because unlike the typical
migration of demand, where a product of a successive generation replaces a product of the previous
generation, digital music formats have given rise to a phenomenon where several new products replace
the old one (i.e., CD). For instance, after the introduction of digital music formats, the demand for music
has migrated (i) from CD to digital album, (ii) from CD to digital single, and (iii) from CD to unlicensed
music. Furthermore, demand also has migrated (iv) from purchased digital music (digital album and
digital single) to unlicensed music. For the music industry, the implications of the various migration
patterns are rather different. While the migration from CD to purchased digital music (digital album and
digital single) has implications in terms of product design, the migration to unlicensed music has
implications pertaining to piracy mitigation and conversion of non-paying consumers to paying
consumers.

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3 Industry experts discussed “single vs. albums” issue at New Music Seminar 2013. Some of their views are
4 We note that while consumers do not pay for unlicensed music, they may still incur costs to consume such music.
For example, when music is shared through a P2P network, consumers face the risk of being caught for piracy, and
downloading a virus. Please see Danaher at al. (2010, page 1141) for a discussion of different categories of costs
that a pirate may incur.
5 The Internet also enables streaming of digital contents and introduces streaming music channels such as YouTube,
Pandora and Spotify; hence, streaming digital music is clearly another available music consumption option.
However, in our study, we model the demand migration patterns from CD to digital music formats, and hence, for
consistency with the CD format, we focus on the digital music formats that consumers can possess. In our model,
streaming music channels indirectly affect the music industry through ripped music files from these channels.
There is considerable research on the impact of the Internet on the music industry. Most studies examined the effect of online file sharing on music sales (e.g., Zentner 2005, 2006; Michel 2006; Rob and Waldfogel 2006; Hong 2007, 2011; Oberholzer-Gee and Strumpf 2007; Liebowitz 2008; Andersen and Frenz 2010). These studies mainly focused on the association between CD sales and online file sharing. Chellappa and Chen (2009) and Dewan and Ramaprasad (2014) included digital music sales in their models, but like previous studies, they also focused on the association between (aggregate) music sales and online file sharing. Koh et al. (2013) and Waldfogel (2010) explored how the availability of purchased digital music option affected the association between music sales and online file sharing. In summary, the prior literature in this stream of research provided insights into the aggregate association between online file sharing and music sales. Closest to our paper (in terms of the overall research question addressed) would be Danaher et al. (2010) that investigate the impact of legitimate digital media distribution channel on physical sales and digital piracy channels in the DVD market. They used the removal of NBC content from Apple’s iTunes store in December 2007 and its subsequent restoration in September 2008 as natural experiments to estimate the short-term effect of the availability of legitimate digital distribution channel on piracy. In contrast to prior literature, we examine the demand migration patterns among various music consumption options (i.e., CD, digital album, digital single, and unlicensed music) available to a consumer, and quantify various migrations at a micro level not found in the existing literature. We do this by taking a product diffusion point of view and by developing a multi-generation diffusion model that is able to capture and quantify the multiple migration dynamics. We discuss why a multi-generation diffusion model is an appropriate model for our context in section 2.

This paper also contributes to the literature on diffusion models. Diffusion models of single product formulate the bell-shaped growth of product sales using innovation (which represents the communication of product through mass media) and imitation (which represents the word-of-mouth) parameters (e.g., Fourt and Woodlock 1960; Mansfield 1961; Floyd 1962; Rogers 1962; Chow 1967; Bass 1969). Studies have extended the single product diffusion models to multiple products by including complements (Peterson and Mahajan 1978; Bucklin and Sengupta 1993; Jun and Park 1999; Dewan et al.
2010; Niculescu and Whang 2011), generation substitutions (Norton and Bass 1987; Mahajan and Muller 1996; Islam and Meade 1997; Jun and Park 1999; Kim et al. 2000; Danaher et al. 2001; Chu and Pan 2008; Michalakelis et al. 2010; Jiang and Jain 2012), competition (Givon et al. 1995; Libai et al. 2010), and network effects (Goldenberg et al. 2010; Hann et al. 2013). Unlike other multi-generational diffusion models, in which the demand from a previous generation product migrates to a single new generation product, our model allows the demand from a previous generation to migrate to multiple new generation products (e.g., from CD to digital album, digital single, and unlicensed music). In addition, our model allows individual diffusion characteristics and the migration patterns to vary across these new generation products, whereas prior studies in this stream make restrictive assumptions about individual diffusion parameters.

One of the main advantages of using the diffusion model approach (over other empirical techniques) is that the model works well with relatively small number of data points (Moutinho and Hutcheson 2011) and without decision variables such as price and advertising (Bass et al. 1994). It has been noted that the Bass model (Bass 1969) can be applied even when as few as four data points are available. Furthermore, if the percentage changes of decision variables (e.g., price) over time are approximately constant, then the estimation results without decision variables are observationally identical to that with decision variables.

The remainder of the paper is organized as follows. In the next section, we develop our model that allows us to analyze and estimate the generation substitution, unbundling, and attrition effects. In Section 3, we estimate our model using two estimation approaches; nonlinear seemingly unrelated regression (NLSUR) and nonlinear system GMM (generalized method of moments). We discuss and compare the various migration effects and the impact they had on the music industry in Section 4.

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6 However, Heeler and Hustad (1980) show that the estimation quality is improved when the data includes the peak.
7 The trends of prices of music formats over time have been relatively stable. The average suggested list price of CD went down significantly immediately after CD was introduced in 1983 and steadily decreased afterwards (Recording Industry Association of America 2007). CD prices were surprisingly unresponsive to the diffusion of unlicensed music (Mortimer et al. 2012). Furthermore, most songs at iTunes have been sold consistently at $.99 per song since iTunes was launched in 2003.
Section 5 summarizes our findings and discusses the implication for the music industry. We conclude in Section 6 with limitations and future research opportunities.

2. Model Development

In this section, we develop a model for the migration of demand for music – from CD to digital music formats – and attrition of demand from purchased music (CD, digital album and digital single) to unlicensed music by extending the standard multi-generation diffusion model (Norton and Bass 1987). We first briefly review the Norton and Bass model. Then, we describe the music industry context we study in this paper, and illustrate why the standard multi-generation model is inadequate to model this context. Finally, we describe the model we use in this paper.

2.1. Review of the Norton and Bass Multi-generation Diffusion Model

Let there be two successive generations, G1 and G2, of a product which are introduced in the market at time 0 and \( \tau_2 > 0 \) respectively. Let \( F_i(t) \) be the cumulative adoption probability of generation \( i \) by time \( t \). In the Norton and Bass model, the sales (in terms of number of units) of generation \( i \) in time period \( t \), \( S_i(t) \), is given by the following:

\[
S_1(t) = m_1 F_1(t) - \Phi(t),
\]

\[
S_2(t) = m_2 F_1(t - \tau_2) + \Phi(t),
\]

where

\[
\Phi(t) = m_i F_i(t) F_2(t - \tau_2),
\]

\[
F_i(t) = \begin{cases} 
1 - e^{-\frac{p_i + q_i}{\tau_2}} & \text{if } t \geq 0, \\
1 + \frac{q_i}{p_i} e^{-\frac{p_i + q_i}{\tau_2}} & \text{otherwise}. 
\end{cases} 
\]

In equation (1), the expression for \( F_i(t) \) provided on the right hand side models the S-shaped curve of cumulative sales over the life time observed for many products. In this expression \( p_i \) is referred
to as the coefficient of innovation and \( q_i \) is referred to as the coefficient of imitation of generation \( i \). \( m_1 \) is the market potential of G1 and \( m_2 \) is the increase in (or unique) market potential for G2 over and above that of G1. That is, the market potential for G2 is \( m_1 + m_2 \). \( \Phi(t) \) is the decrease in demand for G1 and increase in demand for G2 in time period \( t \) due to the generation substitution (i.e., migration from G1 to G2 in time period \( t \)). As G2 diffuses, more of the demand for G1 migrates to G2, and the demand for G1 becomes zero when the demand for G2 is saturated (i.e., \( F_2(t - \tau) = 1 \).

2.2. Our Context: Music Industry

Since its introduction in 1983, the CD had been the dominant music recording and distribution format. Starting late 90s, when residential broadband Internet access started to become mainstream, digital music began to spread on the Internet. However, the music industry did not start selling digital music until 2003. Please note that while the proliferation of the (broadband) Internet\(^8\) and various unlicensed music options (i.e., online music piracy channels such as Napster) began in late 90s, digital music for purchase (e.g., iTunes) became available only in 2003. During the period 1997 – 2003, there was no option to “purchase” digital music. When the music industry started selling digital music, it offered digital music in two forms: digital album, which is a bundle of songs similar to CD, and digital single, which is an individual song.

As a consequence, the demand for music has migrated in different ways, as illustrated in Figure 1.

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\(^8\) In this paper, we refer to the broadband Internet simply as the Internet. The broadband Internet enables various online music piracy channels (unlicensed music options) by providing high-speed data transactions and interactive delivery services. The broadband Internet connection became available in 1996 and began to grow in 2000.
a. Although initial sound quality of digital music was inferior to that of CD, there is now little difference between the two (Atkinson 2008). Further, digital music provides several benefits over CD. A consumer can instantly get (download) digital music from online stores, can store more songs in a smaller device, and play them on a number of different devices. Therefore, a part of the demand for CD has migrated to digital album. This migration can be characterized as the generation substitution (or technology substitution), which is similar to that defined in the multi-generation diffusion literature (e.g., Norton and Bass 1987; Mahajan and Muller 1996; Islam and Meade 1997; Jun and Park 1999; Kim et al. 2000; Danaher et al. 2001; Chu and Pan 2008; Michalakelis et al. 2010; Jiang and Jain 2012).

b. The digital music format allows consumers to purchase an individual song, as opposed to an album, which is a bundle of several songs. It is commonly known that a significant portion of
consumers in the music market prefer to consume only a subset of the songs that are bundled as part of an album (Elberse 2010). Therefore, some of these consumers may hesitate to buy an entire album for the sake of consuming only one or two songs they like. According to a survey conducted by Amberg and Schröder (2007), 69.4 percent of interviewed persons indeed preferred to buy an individual song over buying an entire album. Therefore, another part of demand for CD has migrated to digital single due to this unbundling on top of benefits of digital music that we discussed above. We call this migration from CD to digital single as the *unbundling*.

c. The remaining part of demand for CD has migrated to unlicensed music. Although, as stated in footnote 4, there may be some cognitive/annoyance costs associated with consuming unlicensed music, some consumers may prefer to consume it rather than buy CD. In general, a direct monetary payment is not required to consume unlicensed music. Therefore, unlicensed music is not a direct revenue source for the music industry. We call the migration from CD to unlicensed music as the *attrition of demand from CD to unlicensed music*.

d. Unlicensed music has affected not only the demand for CD but also the demand for purchased digital music – digital album and digital single. That is, some demand for purchased digital music has migrated to unlicensed music.⁹ Therefore, similar to the relationship between CD and unlicensed music, we call the migration from purchased digital music to unlicensed music as the *attrition of demand from purchased digital music to unlicensed music*.

As seen from the above description of the music industry we study in this paper, there are multiple types of migration (and attrition) that occur simultaneously – not only there is migration from one generation (i.e., CD format) to the next generation (i.e., digital music formats), but also there is attrition from products (e.g., digital album or digital single) to another product (i.e., unlicensed music).

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⁹ As it is shown in Danaher et al. (2010), there might be a sampling effect, and some demand for unlicensed music has migrated to digital music. However, we follow a multi-generation diffusion approach, and cannot measure the attrition effect and sampling effect of unlicensed music separately. In our model, the attrition of demand from purchased digital music to unlicensed music captures the net effect of these two.
within the same generation. Furthermore, not all migrations are equivalent. For instance, migration from CD to digital album is different from CD to digital single in the sense that the former is from album to album formats whereas the latter is from album to single formats. Such distinctions in the products themselves, which have a significant effect on industry’s revenue, are not considered in existing multi-generational models. Therefore, there is a need to formulate a diffusion model that captures the migration patterns in the music industry context.

2.3. Our Diffusion Model

We extend the standard multi-generation diffusion model (Norton and Bass 1987) in order to study the generation substitution, unbundling, and attrition effects. We use subscripts CD, DA, DS, and FM to denote, respectively, CD, digital album, digital single, and unlicensed music. CD represents the old generation and DA, DS, and FM represent the new generation of technologies. We adjust the timeline such that CD is introduced at time zero. Both digital album and digital single are introduced at time $\tau_D$, and unlicensed music is introduced at time $\tau_{FM} < \tau_D$. Building on the Norton and Bass model, we write sales (in number of units) in time period $t$ for music in each of the formats as the following:

$$S_{CD}(t) = m_{CD}F_{CD}(t) - \Phi_{O-CD}(t), \quad (2)$$

$$S_{DA}(t) = m_{DA}F_{DA}(t - \tau_D) + \Phi_{GS}(t) - \Phi_{ADA}(t), \quad (3)$$

$$S_{DS}(t) = m_{DS}F_{DS}(t - \tau_D) + \beta\Phi_{UB}(t) - \Phi_{ADS}(t), \quad (4)$$

$$S_{FM}(t) = m_{FM}F_{FM}(t - \tau_{FM}) + \beta\Phi_{ACD}(t) + \beta\Phi_{ADA}(t) + \Phi_{ADS}(t), \quad (5)$$

$F_{i}(t)$ is identical to that defined in equation (1). $m_{CD}$ is the market potential (peak sales) of CD, and $m_{DS}$, $m_{DA}$, and $m_{FM}$ are the increase in market potential (peak sales) for digital single, digital album, and unlicensed music. The demand for CD migrates to digital album, digital single, and unlicensed music (i.e., $\Phi_{O-CD}(t) = \Phi_{GS}(t) + \Phi_{UB}(t) + \Phi_{ACD}(t)$). $\Phi_{O-CD}(t)$ is the overall decrease in demand for CD due to the introduction of digital music formats (indexed by $O-CD$), and $\Phi_{GS}(t)$, $\Phi_{UB}(t)$, and $\Phi_{ACD}(t)$, respectively, capture the generation substitution ($GS$), unbundling ($UB$), and attrition of demand from CD to unlicensed
music (ACD). $\Phi_{ADA}(t)$ and $\Phi_{ADS}(t)$ capture the attrition of demand from digital album (ADA) and digital single (ADS) to unlicensed music respectively. $\beta$ is the parameter that adjusts for the difference in units between album and single formats; that is, one-unit demand of CD migrates to $\beta$-unit demand of individual songs (i.e., digital single and unlicensed music). Similarly, one-unit attrition of demand from digital album is equivalent to $\beta$-unit of additional demand for unlicensed music. A CD album has on average of 12 songs.\(^\text{10}\) Thus, if unbundling does not affect the consumption behavior of consumers, we would likely have $\beta = 12$ (i.e., one-unit demand for CD migrates to 12-unit of individual songs), whereas if it does, we would likely have $\beta < 12$.

We develop the migration parameters, $\Phi_{GS}(t)$, $\Phi_{UB}(t)$, $\Phi_{ACD}(t)$, $\Phi_{ADA}(t)$, and $\Phi_{ADS}(t)$ in the following manner. Until digital music became available for purchase, (i.e., $\tau_{FM} \leq t < \tau_D$), unlicensed music had been the only digital music consumption option for consumers; hence, when $\tau_{FM} \leq t < \tau_D$, we have: $\Phi_{GS}(t)=\Phi_{UB}(t)=0$, and we model $\Phi_{O-CD}(t)$ in the same way as Norton and Bass. That is, when $\tau_{FM} \leq t < \tau_D$, $\Phi_{O-CD}(t)=\Phi_{ACD}(t)=m_{CD}F_{CD}(t)F_{FM}(t-\tau_{FM})$.

After purchased digital music – digital album and digital single – option became available (i.e., $t \geq \tau_D$), some demand for CD that would have migrated to unlicensed music in the absence of digital album and digital single migrated to digital album and digital single instead; hence, we hypothesize (and later empirically test) that the attrition from CD to unlicensed music, $\Phi_{ACD}(t)$, reduces over time. We use an exponential function to model the decrease of this attrition over time and have the following to model for $\Phi_{ACD}(t)$ when $t \geq \tau_D$.

$$\Phi_{ACD}(t) = e^{-\gamma_{CD}(t)} \cdot m_{CD} F_{CD}(t) F_{FM}(t-\tau_{FM})$$ \hspace{1cm} (6)

\(^{10}\) Dave Taylor, a self-proclaimed industry veteran, analyzed 428 CD albums and found that on average a music CD has 12.54 songs. Details are available at: http://www.askdavetaylor.com/do_most_music_cds_have_12_tracks.html.
A portion of the reduction in attrition from CD to unlicensed music becomes $\Phi_{GS}(t)$ and the remaining becomes $\Phi_{UB}(t)$. We conjecture (and later empirically test) that, $\alpha$ fraction of the demand that migrates from CD to purchased digital music chooses digital single, and $[1-\alpha]$ fraction chooses digital album. Therefore, we derive the following models for $\Phi_{GS}(t)$ and $\Phi_{UB}(t)$ when $t \geq \tau_D$.

$$\Phi_{GS}(t) = [1-\alpha]\cdot [1-e^{-\zeta(t)}] \cdot m_{CD}F_{CD}(t)F_{DA}(t-\tau_D)$$

$$\Phi_{UB}(t) = \alpha[1-e^{-\zeta(t)}] \cdot m_{CD}F_{CD}(t)F_{DS}(t-\tau_D)$$

where $\zeta(t) = t-\tau_D$ if $t \geq \tau_D$; and 0 otherwise.

The attrition from purchased digital music to unlicensed music is modeled similar to the Norton and Bass model, and the model we have for the attrition from CD to unlicensed music prior to the introduction of purchased digital music as the following.

$$\Phi_{ADA}(t) = m_{DA}F_{DA}(t-\tau_D)F_{FM}(t-\tau_{FM})$$

$$\Phi_{ADS}(t) = m_{DS}F_{DS}(t-\tau_D)F_{FM}(t-\tau_{FM})$$

A consumer generally does not pay to consume unlicensed music. Hence, it is difficult to track the transactions of unlicensed music, and a direct measure for demand for unlicensed music, $S_{FM}(t)$, is not readily available. Prior studies, therefore, have used a proxy measure such as the Internet penetration (Zentner 2005; Liebowitz 2008; Bender and Wang 2009), Internet use or access (Zentner 2006; Hong 2007, 2011), and computer ownership (Michel 2006). Following this prior literature, we use the (broadband) Internet penetration as a proxy measure for the demand for unlicensed music. We assume

$$S_{FM}(t) = \delta \cdot N_{Int}(t)$$

where $N_{Int}(t)$ is the number of Internet subscribers by time $t$ and $\delta$ is the parameter for the average per subscriber consumption of unlicensed music. Using this assumption and equations (6), (9), and (10), we rewrite equation (5) as:

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1 Similarly, the Internet penetration is used as a proxy measure for unlicensed movie consumption in Smith and Telang (2010).
\[ \delta \cdot N_{\text{int}}(t) = \left[ m_{FM} + e^{-\gamma(t)} \cdot m_{CD} F_{\text{CD}}(t) + m_{DS} F_{\text{DS}}(t - \tau_D) + m_{DA} F_{\text{DA}}(t - \tau_D) \right] \cdot F_{FM}(t - \tau_{FM}). \] (11)

Unfortunately, we cannot estimate both \( m_{FM} \) and \( \delta \) in one model. Hence, we assume that \( m_{FM} = 0 \) and focus on \( \delta \). \( m_{FM} = 0 \) implies that there is no “new” demand for unlicensed music; that is, the entire demand for unlicensed music is from CD. The assumption that \( m_{FM} = 0 \), therefore, captures the upper limit of attrition of demand from CD to unlicensed music.

In summary, the diffusion model we use for the music industry is given by equations (1) – (11) collectively. These equations reduce to the standard Norton and Bass model if we consider only CD and unlicensed music or only CD and digital album.

3. Data and Model Estimation

3.1. Data

As a measure of sales for CD, digital album, and digital single, we collect annual units shipped of these three for the time period 1982 – 2012 from RIAA (Recording Industry Association of America) year-end industry shipment and revenue statistics reports. As a measure of Internet penetration, which is a proxy measure of demand for unlicensed music, we collect the number of (broadband) Internet subscribers on a yearly basis for the time period 1997 – 2012 from Word Bank Databank. We show the time series of units shipped of CD, digital album, and digital single, and Internet penetration in Figure 2.

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12 \( m_{FM} \neq 0 \) implies that some demand for unlicensed music is new; that is, some consumers who did not purchase any CD when CD was the only option now consume unlicensed music. Hence, if \( m_{FM} \neq 0 \), not all demand for unlicensed music would have been the demand for CD.

13 Note that equation (5) is replaced with equation (11) when we use \( N_{\text{int}}(t) \) as the proxy to estimate \( S_{FM}(t) \).

14 The first music CD was released in 1983, and the digital option (iTunes) was introduced in the market in 2003. The sales (units shipped) of music CD in 1982, and sales of digital music in the time period 1982 – 2003 are zero.

15 Word Bank Databank reports per 100 people (broadband) Internet subscribers. Since other data (sales of each music format) is not weighted by the population size, for consistency, we collected the population data also from Word Bank Databank, and converted per 100 people subscribers to the total number of subscribers.
3.2. Model Estimation

The multi-generation diffusion literature (e.g., Norton and Bass 1987) argues that the behavioral process for the adoption of successive generations is expected to be similar; hence, the literature assumes that coefficients of innovation and imitation are constant across generations (i.e., \( p_i = p \) and \( q_i = q \ \forall i \)). However, in the context of the diffusion of music formats, the adoption processes for digital single and unlicensed music are likely to be different from that for CD and digital album because the characteristics of digital single and unlicensed music are substantially different from that of CD and digital album (e.g., an individual song vs. an album). Therefore, we relax the assumption of constant imitation and innovation factors and assume that \( p_{CD} = p_{DA} \neq p_{DS} \neq p_{OM} \) and \( q_i \neq q \) for all \( i \).\(^{16}\)

Following prior studies (e.g., Libai et al. 2009; Dewan et al. 2010), we estimate equations (1) – (4) and (6) – (11) simultaneously using nonlinear seemingly unrelated (NLSUR) regression. Seemingly unrelated (SUR) regression is substantially more efficient than ordinary least square (OLS) regression when estimating multiple time-series equations simultaneously (Creel and Farell 1996). Further, the result

\(^{16}\) For the cell phone industry, Islam and Meade (1997) and Danaher et al. (2001) showed that the assumption of constant imitation factor can be rejected.
of White’s general test for heteroscedasticity rejects the null hypothesis of homoscedasticity, and hence, we use heteroscedasticity-consistent estimates (White 1980).

Generalized Method of Moments (GMM) estimation is another method for improving efficiency when heteroscedasticity is present in the model (Wooldridge 2001). Hence, to check the robustness of our results, we also estimate the model using nonlinear system GMM.17 Following Suarez et al. (2013), we use lagged dependent variables as well as non-GMM exogenous variables as instruments. For non-GMM exogenous variables, we collect the units shipped (sales) of other physical music (other than CD such as LP, cassette and DVD audio) (denoted as \( S_{OP}(t) \)) and mobile music (denoted as \( S_{M}(t) \)) in time period \( t \) from RIAA year-end industry shipment and revenue statistics report, and for each dependent variable, we impose moment conditions instrumenting the sales of (i) different products in the same technology generation and (ii) products in the different technology generation as illustrated in Table 1. The validity of instruments is tested using Hansen’s J test statistics (Hansen 1982).

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Instruments</th>
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<tbody>
<tr>
<td>( S_{CD}(t) )</td>
<td>( S_{CD}(t-1) )</td>
</tr>
<tr>
<td>( S_{DA}(t) )</td>
<td>( S_{DA}(t-1) )</td>
</tr>
<tr>
<td>( S_{DS}(t) )</td>
<td>( S_{DS}(t-1) )</td>
</tr>
<tr>
<td>( S_{FM}(t) )</td>
<td>( S_{FM}(t-1) )</td>
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We report estimation results and model fit from NLSUR along with nonlinear system GMM in Table 2. The adjusted R-squares from both NLSUR and nonlinear system GMM are noticeably high and all parameter estimates are significant at one percent level. The insignificant Hansen’s J statistics suggests that the instruments for nonlinear system GMM estimation are valid; that is, instruments are uncorrelated

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17 By using non-linear system GMM, we control for heteroscedasticity of unknown forms as well as endogeneity and serial correlation in the error terms.
with the error terms. The results shown in Table 2 suggest that there is a strong overall statistical support for our model to capture the demand migration dynamics in the music industry context. Figure 3 illustrates the model fit visually, and the figure also lends support to the strong model fit to the data.

Table 2. Parameter estimates and model fit

<table>
<thead>
<tr>
<th></th>
<th>NLSUR</th>
<th>Nonlinear system GMM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Est.</td>
<td>Std. Err.</td>
</tr>
<tr>
<td><strong>Market potential</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD (m_CD)</td>
<td>2.0738</td>
<td>0.5367</td>
</tr>
<tr>
<td>Digital album (m_DA)</td>
<td>1.9189</td>
<td>0.5661</td>
</tr>
<tr>
<td>Digital single (m_DS)</td>
<td>1.1264</td>
<td>0.2851</td>
</tr>
<tr>
<td><strong>Innovation effect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Album (p_CD &amp; p_DA)</td>
<td>0.0092</td>
<td>0.0017</td>
</tr>
<tr>
<td>Digital single (p_DS)</td>
<td>0.1794</td>
<td>0.0351</td>
</tr>
<tr>
<td>Unlicensed music (p_FM)</td>
<td>0.0131</td>
<td>0.0027</td>
</tr>
<tr>
<td><strong>Imitation effect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD (q_CD)</td>
<td>0.1649</td>
<td>0.0282</td>
</tr>
<tr>
<td>Digital album (q_DA)</td>
<td>0.3231</td>
<td>0.0462</td>
</tr>
<tr>
<td>Digital single (q_DS)</td>
<td>0.6023</td>
<td>0.1233</td>
</tr>
<tr>
<td>Unlicensed music (q_FM)</td>
<td>0.4793</td>
<td>0.0313</td>
</tr>
<tr>
<td><strong>Consumption behavior change due to unbundling (β)</strong></td>
<td>1.1067</td>
<td>0.3018</td>
</tr>
<tr>
<td>per Sub. consumption of unlicensed music (δ)</td>
<td>0.2406</td>
<td>0.0360</td>
</tr>
<tr>
<td>Proportion of digital single (α)</td>
<td>0.7739</td>
<td>0.0477</td>
</tr>
<tr>
<td>Control for time effects (γ)</td>
<td>0.2159</td>
<td>0.0345</td>
</tr>
<tr>
<td><strong>Adj. R-Square</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>0.9766</td>
<td></td>
</tr>
<tr>
<td>Digital album</td>
<td>0.9669</td>
<td></td>
</tr>
<tr>
<td>Digital single</td>
<td>0.9989</td>
<td></td>
</tr>
<tr>
<td>Unlicensed music</td>
<td>0.9997</td>
<td></td>
</tr>
<tr>
<td><strong>Number of observation</strong></td>
<td>31</td>
<td></td>
</tr>
<tr>
<td><strong>Number of instruments</strong></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hansen’s J statistic</td>
<td>-</td>
<td>12.71</td>
</tr>
<tr>
<td>Degree of Freedom</td>
<td>-</td>
<td>26</td>
</tr>
<tr>
<td>P-value</td>
<td>-</td>
<td>0.9864</td>
</tr>
</tbody>
</table>

*** p<0.001; ** p<0.01
A detailed examination of the model parameters provided in Table 2 reveals the following interesting observations.

(i) Our model estimates that if there was no digital music (i.e., digital single, digital album, and unlicensed music were unavailable), the market potential (peak sales) of CD ($m_{CD}$) could have reached 2.07 billion (2.06 billion in the nonlinear system GMM estimation) units, approximately twice the true peak of CD sales, which were 0.94 billion units in 2000. Similarly, if there is no unlicensed music, the market potentials of digital single ($\alpha m_{CD} + m_{DS}$) and digital album ($[1-\alpha]m_{CD} + m_{DA}$) would reach 2.79 billion (2.98 billion in the nonlinear system GMM estimation) and 2.33 billion (1.88 billion in the nonlinear system GMM estimation) units respectively. The digital single and digital album sales are apparently still growing and have not reached the peak yet.

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18 Recall that $m_{DA}$ and $m_{DS}$ reported in Table 3 are the increase in the market potential of digital album and digital single respectively over the market potential of CD.
(ii) Our estimation results confirm that innovation and imitation factors are indeed not identical across different music formats. All $p_i$ and $q_i$ are significant at 0.1 percent level, and significantly different across each different format. The comparison of innovation and imitation factors between different music formats provides several interesting results. First, the innovation and imitation effects for all forms of digital music (i.e., digital album, digital single, and unlicensed music) are estimated to be stronger than those for CD. This result is plausible because of the following reasons. Digital music generally has a lower transaction cost, and thereby, has a lower barrier for diffusion compared to CD. Also, since digital music is distributed through the Internet, the potentially stronger word-of-mouth effect on the Internet may favor better diffusion of digital music compared to CD. Second, due to a smaller unit size (i.e., individual song), digital single would incur a lower opportunity cost than digital album, and hence, has a stronger innovation and imitation effects. Third, given that unlicensed music is also distributed/shared over the Internet and consumers do not “pay” for it, it is somewhat surprising to find that the innovation and imitation effects for unlicensed music are estimated to be weaker than that for digital single. We believe that the inconvenience and risks associated with consuming unlicensed music (e.g., consumers are often asked to register at the website and install multiple software programs to consume unlicensed music, and unlicensed music listeners face various risks such as risks of being caught as well as privacy breaches and computer virus) might cause the weaker innovation and imitation effects.

(iii) We scale the data and use billion as a unit for sales (units shipped) of music and 10 million as a unit for the Internet subscribers. Hence, $\delta = 0.2406 \ (0.2441 \text{ in the nonlinear system GMM estimation})$

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19 The literature (e.g., Norton and Bass 1987) argues that the assumption of constant $p_i$ and $q_i$ can be easily verified using the model fit. If the model without the assumption fits better than with the assumption, it suggests that the assumption needs to be relaxed.

20 While some industry experts argue that iTunes’ price (99 cents) for an individual song (download digital single) is attractive enough to stop people consuming unlicensed music (see http://online.wsj.com/article/SB10001424052970204002304576629463753783594.html), some others argue that compared to the costs to consume unlicensed music, 99 cents might be still too high (e.g., Sandy Pearlman’s 5-cent solution).
implies that each Internet subscriber consumes, on average, about 24 units of unlicensed music every year. This estimate is of the same magnitude as some other estimates made using different approaches. For instance, Institute for Policy Innovation (IPI) estimated that 2.64 billion songs were consumed illegally in 2005 (Siwek 2005). The number of (broadband) Internet subscribers in 2005 was 51 million; hence, this is equivalent to 52 units of unlicensed music consumption per Internet subscriber a year. Although, IPI’s estimate was greater than ours, we would like to note that the estimation of IPI was based on the assumption that 20 percent of illegal music consumption could have been converted to music sales if unlicensed music was unavailable. In contrast, IFPI (International Federation of the Phonographic) noted that only 10 percent of illegal downloads is a loss to the industry (Lindvall 2011). If we follow the assumption of IFPI, the estimated magnitude (26 units) of unlicensed music consumption per Internet subscriber of IPI is similar with ours.

(iv) Our model estimates that the attrition of demand for music from CD to unlicensed music diminishes by about 20 percent every year ($\gamma = 0.2156$ in the NLSUR and 0.2343 in the nonlinear system GMM estimations) with the introduction of purchased digital music – digital album and digital single. This suggests that the option of purchasing digital music indeed replaces some of the attrition of demand from CD; that is, the purchased digital music option converts some non-paying music consumers to paying music consumers. In fact, the report of NPD group shows that overall illegal consumption of music dropped by 26 percent in 2012 (Whitney 2013).

(v) The model estimates that about 80 percent ($\alpha = 0.7739$ in the NLSUR and 0.7880 in the nonlinear system GMM estimations) of the demand that migrates from CD to purchased digital music chooses digital single and the remaining 20 percent chooses digital album. That is, the unbundling effect dominates the generation substitution effect in the music industry. Our estimate is somewhat consistent with a survey that Amberg and Schröder (2007) report in their paper. They state that 69.4 percent of their interview respondents express a preference for purchasing an individual song over an entire album.
Finally, the model reveals that one unit demand for CD converts to about 1.1 units demand for digital single (\( \beta = 1.1067 \) in the NLSUR and 1.0429 in the nonlinear system GMM estimations). Again, this result supports the view that most of the (bundled) songs in a CD album are not preferred by consumers, and that when they have the option of purchasing individual songs, they are more likely to buy only their preferred songs. Our estimate is somewhat similar with that in Elberse (2010) that estimates an overall reduction of one-third of the music sales due to the unbundling.

In summary, the overall model fit, statistical significance of model parameters, and the remarkable closeness of our estimates of various parameters to others’ estimates derived using different methodologies offer a significant level of confidence regarding the findings and implications derived from the model.

4. Quantification of Migration Patterns and Impact on the Music Industry

In this section, we quantify the impact of the Internet and digital music formats on the music industry by computing how the demand for music migrates (i) from CD to various digital music formats and (ii) from purchased digital music to unlicensed music over time. Since the estimation results from NLSUR and nonlinear system GMM are not significantly different,\(^{21}\) for convenience sake, we use the estimation results from NLSUR to present our analysis.

Using equations (6) – (10), we compute the generation substitution, \( \Phi_{GS}(t) \), unbundling, \( \Phi_{UB}(t) \), attrition of demand from CD to unlicensed music, \( \Phi_{ACD}(t) \), attrition of demand from digital album to unlicensed music, \( \Phi_{ADA}(t) \), and attrition of demand from digital single to unlicensed music, \( \Phi_{ADS}(t) \), in each time period \( t \). Figure 4 shows these migration patterns over the study period. We make the following interesting observations from the observed migration patterns.

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\(^{21}\) The result of t-test suggests that the differences in parameter estimates are not significant at 5 percent level.
(i) Over the 1997 – 2012 period, an estimated 13.04 billion units of demand for CD has migrated to digital music – digital album, digital single, and unlicensed music. That is, if digital music was unavailable, by end of 2012, 13.04 billion more units of CD could have been sold. Overall, 50 percent of this “loss in CD sales” is due to the unbundling (i.e., migration to digital single) and 47 percent is due to the attrition to unlicensed music. Only 3 percent of the loss is due to the generation substitution (i.e., migration to digital album). In our estimates, the unbundling effect and the attrition effect dominate the generation substitution effect. This implies that the effects of unbundling and piracy dominate the pure effect of “digital” music. Furthermore, during the period 1997-2012, the unbundling effect slightly exceeds the attrition effect, suggesting that the “loss in CD sales” is caused slightly more by the “unbundling” of the album than by the “free” digital music.

(ii) Figure 4(a) shows how the relative migration patterns from CD to different digital music formats have changed over time. After the introduction of digital album and digital single, the attrition of demand from CD to unlicensed music has steadily decreased each year. Out of a total of 6.16 billion units of

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22 14.11 billion units of CD were sold in about 30 years, from 1983 to 2012.
attrition from CD to unlicensed music during 1997–2012 period, 26 percent (1.60 billion units) occurred before 2004 when purchased digital music option became available. Migration of demand from CD to digital album and digital single, on the other hand, has increased steadily since 2004. This indicates that the music industry’s strategy of providing consumers with an option to purchase music in digital format was successful in stemming the attrition of demand for music from CD to unlicensed music. The rate of increase is clearly higher for migration to digital single than digital album. In 2012, 72 percent of migration from CD was to digital single, 16 percent was to unlicensed music, and the rest was to digital album. Please note that this is an estimate for year 2012. As we discussed above, overall, 47 percent of “loss in CD sales” was due to online music piracy.

(iii) While Figure 4(a) shows that the attrition effect of unlicensed music on CD has decreased since the introduction of purchased digital music, Figure 4(b) demonstrates that the attrition effect of unlicensed music on digital album and digital single has increased. Over the 2004–2012 period, unlicensed music has caused the attrition of 7.13 billion units (an average of 0.79 billion units per year) of digital single and 2.21 billion units (an average of 0.25 billion units per year) of digital album. These numbers suggest that the average attrition effect of unlicensed music on digital single (0.79 billion units per year) is stronger than that on CD (0.39 billion units per year) and digital album (0.25 billion units per year). This result is plausible since unlicensed music would be a more direct substitute for digital single than CD and digital album.

(iv) Between digital single and digital album, the rate of increase of attrition effect of unlicensed music on the former has decreased but on the latter has increased (Figure 4(b)). In fact, the attrition effect of unlicensed music on digital single has remained almost flat during the period 2010–12. This suggests that unlicensed music poses more challenge for digital album in recent years analogous to the challenge it posed to CD before the introduction of purchased digital music option.

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23 By end of 2012, 7.13 billion units of digital single and 0.53 billion units of digital album were sold.
In summary, the magnitudes of the different migration effects suggest that while the unlicensed music (i.e., online music piracy) was a huge factor in the reduction in demand for CD, after the introduction of purchased digital music, it is the unbundling effect that has contributed the most to the decline in demand for CD. However, the attrition effect of unlicensed music on the music industry has not been gone away. Instead of luring demand away from CD, the unlicensed music has been taking more consumers away from digital single, and especially, digital album, and the rate of increase on the digital album has increased in recent years.

5. Implications and Discussion
A few implications for the music industry emerge from our estimation results. First, our result confirms that the attrition effect of unlicensed music on the music industry is substantial. However, we would like to emphasize that it could have been worse if the industry did not provide consumers with the purchased digital music – digital single and digital album – option and focused only on stopping people from consuming unlicensed music. Since the purchased digital music option was introduced, about 7 billion units of demand for CD that would have migrated to unlicensed music has migrated to either digital single (6.5 billion units) or digital album (0.5 billion units). Further, digital album and digital single have created “new” demand for (digital) music. In 2012, 1.4 billion and 117 million units of digital single and digital album were sold respectively. This is already larger than CD sales in 2000 (943 million unites) when it reached the peak and apparently digital single and digital album sales are still growing. It is estimated that the peak sales of purchased digital music would be greater than that of CD by about 3 billion units. These findings support the view that the industry’s strategy needs to be focused on converting the attrition of the demand to profitable migration, rather than stopping the attrition, by offering a new product.

Second, it is widely recognized that consumers prefer only a small fraction of songs bundled in an album. In fact, in our estimation, one unit demand of CD has converted only to 1.1 unit demand of digital single, and about 80 percent of the demand that migrates from CD to purchased digital music chooses digital single – the remaining 20 percent chooses digital album. Further, it was online music piracy when
purchased digital music was unavailable, but in the presence of purchased digital music, unbundling is the dominant factor that leads the decline in CD sales. In 2012, 72 percent of migration from CD was to digital single, 16 percent was to unlicensed music, and the rest was to digital album. Due to this dominance of (digital) single format, although consumers are purchasing more (digital) music than ever, the music industry’s revenue is still down from when the revenue reached the peak in 2000. In 2012, the industry generated $1.2 billion of revenue from 117 million units of digital album sales whereas $1.6 billion of revenue from 1.4 billion units of digital single sales.24 The revenue from digital single and digital album together in 2012 was only about 20 percent of the peak revenue from CD in 2000 ($13.2 billion). Cannibalization due to unbundling, rather than attrition due to online music piracy, is now the dominant factor that leads the decline in industry revenue. These findings suggest that the music industry likely benefitted tremendously by implementing the (seller-defined) bundling strategy though this bundling strategy does not seem to be a good strategy anymore. The music industry may need to exploit the benefits offered by an album format (i.e., higher revenue) by adopting a new product design strategy. One possible strategy could be to allow consumers to create their own customized (digital) bundles. Although Apple dropped it from iTunes in late 2012, iMix might be an example. iMix allowed any users to create a digital bundle (playlist) and make it available for purchase at iTunes.

Third, while purchased digital music option has reduced the attrition of demand from CD to unlicensed music, attrition to unlicensed music is emerging as a challenge for purchased digital music. On average, every year, there are attrition of 0.79 billion units of digital single and 0.25 billion units of digital album to unlicensed music. Especially, compared to 2011, in 2012, while the attrition effect of unlicensed music on digital single increased only by 1.4 percent, that on digital album increased by 29 percent. These findings support the notion that the industry may have to move away from offering seller-defined bundles and move towards a new product design strategy such as a hybrid of album and single formats.

24 The average prices of CD, digital album, and digital single, respectively, are $14.41, $10.07, and $1.05.
6. Conclusion

Many industries have been disrupted by technological innovations and not all disruptive technologies improve the industry’s (or firm’s) profitability (Adner and Zemsky 2005). In the music industry, the Internet and digital music formats have fundamentally altered the way music is packaged, distributed and consumed. The major contribution of our research lies in identifying, isolating, and quantifying the different components of the disruption caused by the Internet and digital music formats. The different components have different implications for the music industry.

Despite the strong statistical results that we obtained in our study, it has a few limitations. First, following prior literature, we used the Internet penetration as a proxy measure for the demand for unlicensed music by assuming that on average, Internet subscribers consume the same amount of unlicensed music. Although the direct measure for the demand for unlicensed music is nearly unavailable, it would be worthwhile to look at a direct measure and verify the results. Second, we assumed that there is no “new” demand for unlicensed music (i.e., \( m_{om} = 0 \)) and measure the upper limit of the impact of online music piracy. Once a direct measure for the demand for unlicensed music becomes available, we can relax the assumption and measure more precise impact of unlicensed music. Third, as many diffusion studies (e.g., Bass 1969, 1995; Mahajan and Peterson 1978; Bucklin and Sengupta 1993; Mahajan and Muller 1996), we estimated the model using relatively fewer number of data points. However, we would like to note that our data covers the full lifecycle of each music format. Lastly, despite its advantage, the diffusion model approach has some limitations. Since the model uses aggregate market-level data, the model does not consider user heterogeneity (Van den Bulte and Stremersch 2004; Susarla et al. 2012) and provides limited individual-level implications (Mahajan et al. 1990). In addition, the model does not capture the direct effects of decision variables such as price and advertising (Chandrasekaran and Tellis 2007). Alternatively, prior studies have used a log-logistic distribution accelerated failure time model (Xue et al. 2011) and the decomposed diffusion model (Susarla et al. 2012). Nonetheless, the diffusion model has been successfully applied to estimate the sales in many different industries including retail.
service, telecom, information technology, agriculture, pharmaceutical, and consumer durable goods (see Mahajan et al. 1990, Bass 2004, and Meade and Islam 2006 for the review of diffusion models). In particular, Bass (1995), Bewley and Griffiths (2003), Pae and Lehmann (2003), and Boswijk and Franses (2005) apply the model and estimate the sales of recording formats (e.g., LP, tape, and CD). As it is shown in Chen et al. (2013), given that “communication” is a significant factor that derives music sales, the diffusion model might be a good technique to measure the diffusion of and demand migration patterns among different music consumption options.

Although we focus on the demand migration patterns in the music industry, we would like to note that our model can be easily extended and used to shed some light on the complicated migration of demand and competition landscape in the industry, where ‘tipping across markets’ or ‘platform envelopment’ phenomenon occurs (Eisenmann et al. 2011). In many industries, a company has moved into an adjacent industry (or market) by bundling new features into its existing product (Gawer and Cusumano 2008). For instance, Apple has moved into portable PC market by adding new features to its “tablet” device. This tablet device has complicated the competition landscape in the portable PC market and fragmented the demand for the portable PC. For the portable PC industry, it would be important to understand the migration patterns of the demand from an old portable PC (e.g., an older version laptop PC) to new portable PCs (e.g., a newer version laptop PC and tablet PC) as well as the competition between the tablet device and laptop PCs to make a good strategic decision for the future. The model presented in this paper can be used to analyze such decisions.
References


