Effect of Piracy on Adoption of Technological Innovation in the Entertainment Industry

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Abstract

Advances in technology have enabled producers of entertainment goods to reach customers in new and innovative ways. However, new technologies also make it easier for users to infringe on the content. Producers want to protect their content and argue that piracy hurts their ability to innovate. Critics argue that piracy acts as a leveler in mostly monopolistic industries and encourages consumer friendly innovation. In this paper, we explore the interplay of piracy and technology adoption. We build a dynamic model of horizontal differentiation where users are heterogeneous in taste. Some users are technologically savvy and prefer newer technological (digital) versions while others consumers prefer traditional (physical) versions. The firm always releases a physical product initially and has to make a decision on whether and when to adopt the newer digital platform, which will facilitate digital release. We assume that the physical version itself lead to piracy and consumers who have a strong preference for digital might choose to pirate in the absence of a legal digital version. First, we show that, when the cost for innovation adoption is small, the piracy has no effect of technology adoption. The monopolist always adopts the digital platform simultaneously with the release of the physical version. Secondly, when the cost of digital adoption is sufficiently high, piracy acts as a competing force and leads to an earlier release of the digital version only if a large number of users are willing to move to the legal version at a full price. If not, piracy discourages and delays adoption. When the release of digital platform induces additional piracy, the monopolist always delays product release. Thus, only under specific conditions, does piracy create incentives to adopt innovations. In most case, piracy discourages the adoption of innovation. We find that while some level of piracy is beneficial to consumers, higher level of piracy delays adoption of the digital platform hurting overall consumer welfare. Furthermore, our model provides specific empirically measurable conditions that would suggest a productive or a damaging role of piracy on technology adoption.

Key words: Piracy, information goods, entertainment goods, multi-channel distribution, product differentiation

1. Introduction

The last few decades have witnessed immense technological progress with the emergence of new and innovative technologies. This phenomenal technological growth has affected various industries, but in particular this growth has had a profound effect on the content distribution industry. In approximately the last two decades, distribution of content like movies and music has continued to shift from physical formats to a myriad of digital platforms. For example, movie producers relied heavily on theatrical release for generating revenues from movies, but now they can use various digital technologies like DVDs and online streaming to distribute the content to their consumers. This shift has been enabled by two dominant factors – (i) the ease of digitization of content and (ii) the ease of distribution of the digitized content due to the exponential growth of the Internet. The technological changes have also lead to a change in consumer preferences and an increasing number of customers have a preference for more advanced digital technologies. For example, in the past years, mobile device gains great popularity among consumers. In 2008, the average number of hours American spent on mobile computers is around 46 hours. In 2012, this number has soared to 208 hours{Short, 2013 #37}.

Growth of the Internet and broadband has led to the availability and adoption of content distribution platforms significantly. These new digital platforms allow producers to distribute their content more efficiently and to reach a much larger market. At the same time, increasing consumer proclivity for these newer technologies would have predicted an enthusiastic adoption of these platforms by the producers. However, producers of entertainment goods such as movies and music have been historically reluctant to adopt these technologies. For a very long time, music labels were reluctant to adopt online distribution of music via MP3 and more recently movie producers have been wary of adopting digital distribution formats like online streaming and downloads. An important reason that most producers cite for their reluctance to adopt the new digital platforms is piracy. Adopting a digital platform and releasing a digital version of the physical product has one additional important challenge, which is often ignored, in that the digitization also makes it much easier to copy and share the content. Once the effect of piracy due to digitization is accounted for, then it is not entirely clear what the right release decisions should be: not only at the studio level, but also socially. In the presence of rampant piracy, the benefit of reaching a broader audience or efficiency might be surpassed by the threat of piracy.[1]

On the other hand, several critics of the media industry argue that much of the piracy occurs because studios are unwilling to either adopt newer distribution channels or unwilling to make their content available in a timely fashion. The delay in adoption of online music by record labels was an important factor in the rise of Napster and music piracy (Goldman, 2010). The critics argue that it is the monopolistic nature of these industries that create little incentives for accelerated adoption and release in new channels. The following quote sums us these feelings: "companies are upset that digital tools and platforms are making it possible for companies to invade their customer relationships, (and) upset their traditional economics" (McQuivey April 8, 2013). They also argue that piracy proliferates due to lack of availability of digital versions in a timely fashion (Doctorow Dec 20, 2012, Filloux Nov 26, 2012). When no viable digital alternative is legally available, consumers are forced to pirate content (Ernesto 2013). It is believed that releasing the digital version early might help in curbing piracy and lead to higher profits for the producer (Harmon 2003).

To demonstrate the monopolistic nature of media companies, critics point to the "windowing" strategy commonly used by the entertainment industry to inflate profits. Windowing refers to the common practice of releasing the same product at different times in different formats in different geographic areas. For example, movies are first released in theatres and then licensed for DVD release only a few months later. Only after several months it might be available on cable television and in other formats. The windowing strategy helps the producers in capturing the impatient customer and prevents cannibalization between the different versions of the product available in the market. The delay in adoption of digital platforms is seen by many as a way to way to prevent cannibalization of sales in the traditional channels.

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[1] There is an analog of this phenomenon in the physical world too. Many developing counties have weak intellectual property protection. Studios may be reluctant to release movies in counties like Russia, India, China where release of the movie leads to growth in piracy sources. For example, even a theatrical release in these counties lead to widespread camcording (video recording of movies playing in theatrical screens). These camcorder versions are then uploaded to the Internet for widespread distribution worldwide. Producers thus may be reluctant to screen movies in such places.

In summary, the producers defend their reluctance to adopt digital distribution platforms by suggesting that adoption of these platforms can lead to increased piracy and in that sense *piracy hurts innovation in the entertainment industry*. On the other hand, studios are accused of not responding to customer needs by delaying adopting newer innovations in a timely fashion. The critics of the recording industry also argued that the monopolistic nature of the industry meant that labels were unwilling to adopt new innovations in a timely fashion. They believe that more competition in the form of *piracy would force firms to adopt innovations quickly*. Thus the overall effect of piracy might be beneficial as it makes content available to end-users quickly and cheaply by forcing firms to respond by adopting innovations in distribution platforms.

The prior discussion illustrates the conflicting viewpoints about the effect of piracy on innovation in the entertainment industry. It remains unclear whether piracy would act a competing force and hasten the adoption of new technology platforms or if it would deter the adoption of these platforms. From the ensuing discussion it is not clear why a monopolist might be unwilling to adopt new platforms and innovations when they are more efficient and can reach a broader audience. Prior economic theory also suggests that large incumbent are more likely to invest and adopt innovations (Tirole, p 101). This departure from common intuition and economic theory poses not only a managerially relevant question but also an answered academic question about the dynamics of the entertainment industry and the effect of piracy on the adoption of new digital platforms. In this research, we focus on the following questions:

1. Under what conditions does piracy impede the adoption of new digital platforms and when does it accelerate the adoption of such platforms?
2. How does the additional piracy introduced by the new digital platform affect the decision to adopt the platform?
3. What is the effect of piracy on consumer welfare – when does piracy help or harm consumers?

Our research has important implication for business and public policy. First, we want to examine the commonly held view that piracy can act as competition and force firms to respond in welfare enhancing way.

Indeed, if piracy can act as a competitive tool, then the need for regulatory action is not as strong. Second, if piracy reduces producers' incentives to release the product in timely fashion and reduces consumer welfare then protection of intellectual property has implications for firm innovation. In short, merely adopting technological platforms in a timely fashion is not an optimal answer to respond to a growing threat of piracy, as commonly believed in press.

In this paper, we use an analytical model to study producer's decision of adopting and releasing a digital version of the product. We build a model of horizontal differentiation where consumers are heterogeneous in taste and enter the market over time. Some users prefer digital version while others prefer physical version. A monopolistic firm always chooses the traditional platform for releasing the product at time t = 0 and has to make a decision about when to adopt the new digital platform and release digital versions of their products. A delay in the adoption of the digital platform negatively affects the consumers that have a preference for the digital version. This decision depends on the cost of adopting the new platform and the level of piracy in the market. We first assume that a product release in *any* channel might lead to piracy that evolve dynamically and study how this base level of piracy affection the adoption of the digital channel. Subsequently, we assume that the digital platform might increase the level of piracy in the market and again compare the firm's adoption decision.

Our analysis presents several interesting results. First, we show that when costs of adopting the new platform are small, the monopolist always adopts the digital platform immediately even in the presence of piracy. Thus presence or absence of piracy has not effect on the adoption decision when the adoption costs are low. When the adoption costs are sufficiently high, monopolist will delay the release irrespective of the level of piracy in the market. However, for moderate adoption costs, under most conditions piracy leads to a delay in the adoption of the digital platform. Piracy lead to an earlier adoption of the digital platform *only if* a significant fraction of users have a preference for the digital version and are willing to purchase a legal version even in the presence of piracy. Thus, the role of piracy on firm choices is a nuanced one. Only under very specific conditions, does the piracy create an incentive to adopt the digital platform. In most case, it discourages it. We also show that, while some level of piracy is beneficial to consumers, higher level of piracy causes the firms to delay products excessively hurting overall consumer welfare. Most importantly, our model provides clear hypothesis for testing the implications of the role of piracy in an empirical setting. Our model provides specific conditions that would suggest a productive or a damaging role on piracy. Empirically, one can potentially measure those conditions to infer whether presence of piracy indeed causes welfare gains or losses.

Our paper makes several managerial and academic contributions. This paper builds on the extensive and important literature that discusses the effects of piracy and its control on market outcomes. However, this literature is silent on the effect of piracy on innovation and the adoption of new digital distribution platforms, an important topic of debate in the media industry. To the best of our knowledge, this paper proposed the first dynamic model of channel adoption in the media industry and explicitly modeling the dynamic decision-making process helps us generate new insights that are very relevant both from an academic and managerial perspective. Rest of the paper is organized as follows. In Section 2, we present the extant literature on piracy, highlight existing results and position this research in the literature. We introduce the dynamic model of channel adoption in Section 3. The general model presented in Section 3 is used to perform welfare analysis in Section 4. We explicitly model customer heterogeneity in Section 5 to extend our analysis and derive further interesting results. Finally, we summarize the paper and conclude in Section 6.

2. Literature Review

Our research is very closely related to two main streams of research. The first stream focuses on the impact of piracy on firm profitability, while the other stream focuses on the pricing and quality decision under piracy.

On the profitability issue, much empirical evidence suggests that piracy hurts firm profitability. For example, Hui and Png (2003) study the impact of piracy on CD sales and estimate that the upper bound of loss in revenue due to piracy in music industry is 6.6%. Using European individual-level cross section data, Zentner (2006) finds that peer-to-peer networks reduce the probability of purchasing music by 30%. De Vany and Walls (2007) estimate that a major studio movie can suffer acceleration in box-office revenue decay and potentially lose about $40 million in the presence of pre-release and contemporaneous Internet downloads. Danaher, Smith et al. (2012) measure the impact of HADOPI law on music sales and find that HADOPI law caused iTunes song and album sales to increase by 22.5% and 25%, respectively, comparing with control groups. In contrast to the empirical evidence, some analytical studies suggest that piracy can possibly lead to higher firm profitability. Conner and Rumelt (1991) use an analytical model to show that piracy can help monopolists generate higher profit in the presence of high network externalities, due to enlarged total consumer base from piracy downloads, increasing consumer utility from purchasing. Similarly, Slive and Bernhardt (1998) consider the software market with home users and business users in the existence of network externalities. They find that when network externalities are high enough, monopolists can generate more profit when home users are allowed to pirate. Chellappa and Shivendu (2005) show that sampling can help producers internalize the benefit of piracy when consumers with heterogeneous preferences for quality might first pirate the product and then purchase the legal version in the second stage.

On the aspect of pricing and quality decision, researchers focus on the change in optimal price and quality in the presence of piracy and recommendations of pricing and quality strategies. Belleflamme (2002) builds up a model based on vertical differentiation in which consumers have heterogeneous tastes for quality and incur reproduction cost and degradation cost when pirating. He finds that piracy will lower the optimal price below the monopolistic level without piracy. Bae and Choi (2006) build a similar but more general model to study the decision making of price and quality in the face of the threat of piracy. Similarly, they also find that piracy will cause monopolists to charge lower price. In addition, they find that piracy will lead to higher usage compared to the monopolistic level without piracy. However, the impact of piracy on quality can be either positive or negative depending on whether quality degradation dominates reproduction cost or vice versa. Based on a framework very similar to that by Bae and Choi (2006), Lahiri and Dey (2013) argue that although quality will generally be lower than a market without piracy, the relationship between cost of piracy and quality is not monotonic. Producers will try to differentiate their product from the pirated version by adopting higher quality when the cost of piracy is low. There have also been studies that focused on pricing and quality strategies in the face of piracy. For example, on the pricing side, Sundararajan (2004) suggests that producers can adopt a combination of the zero-piracy pricing schedule and a piracy-indifferent pricing schedule to fight against piracy. Sinha, Machado et al. (2010) suggest that the music industry should lower the price than the current level in the face of music piracy. On the quality side, some researchers suggest that versioning strategy can sometimes be a good strategy to combat piracy (Alvisi, Argentesi et al. 2002, Wu and Chen 2008, Lahiri and Dey 2013).

3. A Dynamic Model of Channel Adoption

In this section we outline our basic model that captures a producer's decision to adopt a new distribution platform. We first begin by outlining the components of our model and then proceed to present the analysis on the generalized model of channel adoption in the absence of piracy. We then extend our model to examine the effects of piracy on the adoption decision.

3.1 Channel Adoption in the Absence of Piracy

3.1.1. Distribution Channels

Traditionally producers have relied on physical channels like theaters, CD/DVD etc. for the distribution of their content. Increasingly, newer digital platforms like online streaming and mobile downloads are can be used by producers for content distribution. For the sake of simplicity we assume two types of distribution platforms in our analysis – the traditional platform and the digital platform. Without loss of generality we assume that a physical product is released in the traditional version, whereas a digital version is made available when the digital platform is adopted. Not that the physical and digital nomenclature does not pose any restriction from a modeling perspective apart from the intuitive difference that digital or newer formats are easier to reproduce in an illegal manner. We would also like to emphasize that we are not modeling a short-term strategy for a product release. Instead, we try to build a long-term model from the producer's perspective of adopting the new distribution platform that will affect the future release decision of all subsequent product releases.

Assumption 1: We normalize the cost of using the traditional platform to zero but assume that adopting the new digital platform costs $C(t)$ where t is the time since release of the new platform. We further assume that these costs decrease over time. There are several factors due to which costs decrease over time, e.g. as times goes by most technologies becomes cheaper, it is easier to hire employees that understand the newer technology and the uncertainties associated with any technology get resolved. We further assume that the costs decrease with a decreasing rate over time. These assumptions can be formalized as follows: $C'(t) < 0$ and $C''(t) > 0$.

We consider a dynamic model with T time periods during which a producer sells a physical product and might sell a digital version of the product if he adopts the digital platform. At $t = 0$, the new digital platform becomes available to the producer. Based on the costs of adoption, he decides when to adopt the digital platform. In Section 3.2 we also consider the manner in which piracy further affect this decision. We restrict our analysis to T time periods for simplicity. However, without loss of generality, T can be arbitrarily large in our analysis. In the following analysis, we call the market where only the physical version exists single channel market, while the market where both physical version and digital version compete a multi-channel market.

Assumption 2: To focus on impact of costs and piracy on release choices, we assume that prices for digital version and physical version are exogenous and set equal to p. This is fairly typical in the entertainment industry, which has well-established reference prices for theater tickets, DVDs or online movie purchase and prices are not determined for individual products.

3.1.2. Consumer Demand

We use a very general model of consumer behavior in this section. In each time period, a fraction $q(t)$ of utility maximizing consumers arrive in the market. Based on the products available in the market, they can choose either the physical or the digital version of the product or completely forego consumption. Consumers who do not choose the product upon their arrival exit the market and do not return. This is fairly typical for most entertainment products where consumers have very attractive outside options and once their entertainment needs at time t are satisfied, it is a lost opportunity for the firm. Although we assume customer heterogeneity in the preference for the two channels, we use reduced form functions to capture this demand. The notation for demands under different market conditions and their relationships are shown in Table 1.

Table 1 Demand under different market conditions

	Single Channel	Multi-Channel
No Piracy Condition	D_S^{NP} Demand from physical version	D_M^{NP} $(D_M^{NP} \geq D_S^{NP})$ Demand from physical and digital versions

Subscripts: S – Single Channel, M – Multi-channel, NP – No Piracy

We assume that $D_M^{NP} \geq D_S^{NP}$ because adopting the digital platform might help attract more consumers who would otherwise not purchase the physical version of the products. Thus, the per-period market expansion effect due to the adoption of the digital platform is given by $D_S^{NP} - D_M^{NP}$.

3.1.3 Firm's Decision

The producer maximizes his profit by adopting the digital platform at time t_r such that the following profit function is maximized,

$$\pi_1 = \underbrace{\int_{t=0}^{t_r} \mathrm{q}(t) p D_S^{NP}\, pdt}_{Profits\ before\ release\ of\ digital\ version} + \underbrace{\int_{t=t_r}^{T} q(t) p D_M^{NP}\, pdt}_{Profits\ after\ release\ of\ digital\ version} - \underbrace{C(t_r)}_{Adoption\ \ Cost}. \quad (1)$$

In this case, the producer tries to balance the additional revenues obtained from adoption the digital platform and adoption costs incurred by an early adoption of the platform. If the benefit from adopting the platform is not sufficiently high, the producer always delays the adoption of the platform, which is formalized in the following proposition:

Proposition 1: *If the adoption of the digital platform is sufficiently costly and the cost structure follows Assumption 1, then the producer delays channel adoption if* $\frac{C'(t)}{q(t)}$ *is lower than* $p(D_S^{NP} - D_M^{NP})$ *at* $t = 0$ *and higher than* $p(D_S^{NP} - D_M^{NP})$ *at* $t = T$.

All proofs are presented in the Appendix.

Here $\frac{C'(t)}{q(t)}$ captures the relative relationship between the decrease of innovation cost and arrival rate. It is easy to see that both low $C'(t)$ and $q(t)$ will provide incentive to producer to push back the release date the former helps the producer to save on the cost of digital adoption, while the latter will scale down the market expansion effect. It is the relative relationship between $C'(t)$ and $q(t)$ that determines the optimal release time.

Based on Proposition 1, we can put forward **Corollary 1:**

Corollary 1: *If the adoption costs associated with the digital platform are sufficiently low, the producer will adopt the digital platform when it becomes available.*

Proof can be found in appendix. Corollary 1 presented here shows that a monopolistic firm would adopt a new distribution platform if the adoption costs are sufficiently low. This is a very general result that runs contrary to the claims made by several critics that producers do not adopt new technologies because it is not in their incentive to adopt new technologies. In the next section, we present some explanations for why producers might be willing to delay the adoption of new technologies and distribution platforms.

3.2 Channel Adoption with Piracy

In the previous discussion, we analyzed a producer's adoption decision based on the cost of technology adoption. Here, we incorporate another factor, which plays a very significant role in this decision – piracy.

3.2.2 Incorporating Piracy

The physical version itself leads to availability of piracy (for example as noted earlier, Camcording of theatrical movies, or TV shows piracy is very common). We assume that in each time period, there is probability $\mathrm{G(t)}$ that piracy occurs in the market, which means when a consumer arrives at the market at time t, the probability that he finds a pirated version is $\mathrm{G(t)}$. We also assume that the pirated version is only available digitally. We assume that digital version of the product might induce additional piracy. The piracy level when both physical and digital versions are available is captured by distribution $\mathrm{F(t)}$. We assume that probability of a pirated version being available may increase from $\mathrm{G(t)}$ to $\mathrm{F(t)}$ when the firm releases the digital version of the product at time t, because it might be easier for pirates to create a pirated version from digital version, or that the quality of the pirated version would be much higher in digital channel. We assume that the piracy level will be continuously increasing with time, i.e. $G'(t) > 0$ and $F'(t) > 0$. Due to the fact that consumer could pirate and share the digital version immediately after the digital version is available, we assume probability of piracy instantly jumps from $G(t)$ to $F(t)$ upon the release of digital version and remains at $F(t)$ afterwards.

The notation for demands under different market conditions in the presence of piracy and their relationships are shown in Table 2.

Table 2: Demand under different market conditions

	Single Channel	Multi-Channel
No Piracy	$\mathrm{D_S^{NP}}$ Demand from physical version	$\mathrm{D_M^{NP}}$ ($\mathrm{D_M^{NP} \geq D_S^{NP}}$) Demand from physical version and digital version
Piracy	$\mathrm{D_S^{P}}$($\mathrm{D_S^{P} \leq D_S^{NP}}$) Demand from physical version	$\mathrm{D_M^{P}}$ ($\mathrm{D_M^{P} \leq D_M^{NP}, D_M^{P} \geq D_S^{P}}$) Demand from physical version and digital version

Subscripts: S – Single Channel, M – Multi-channel, P – Piracy, NP – No Piracy

We assume that $D_S^P \leq D_S^{NP}$ and $D_M^P \leq D_M^{NP}$ because piracy will cannibalize legal sales in both single channel market and multi-channel market. We also assume that $D_M^P \geq D_S^P$, i.e. we assume that demand in multi-channel market would be higher even when piracy exists in the market. The market expansion effect when the market has piracy is given by $(D_M^P - D_S^P)$. This will play an important role in our analysis.

3.1.2 Firm's Decision

In the first stage, we assume that the digital version does not lead to additional piracy. Based on this assumption, the profit function is now as follows,

$$\pi_2 = \underbrace{\int_{t=0}^{t_r} q(t)\left\{D_S^{NP}(1-G(t))p + D_S^{p}G(t)p\right\}dt}_{Profits\ before\ release\ of\ digital\ version} + \underbrace{\int_{t=t_r}^{T} q(t)\left\{D_M^{NP}(1-G(t))p + D_M^{P}G(t)p\right\}dt}_{Profits\ after\ release\ of\ digital\ version} - \underbrace{C(t_r)}_{Adoption\ Cost}$$

(2)

Proposition 2: *If the producer delays the release under conditions in Proposition 1, when piracy appears in the both single channel market and multi-channel market with equal probability, the producer will further delay the adoption of digital platform if market expansion in market under piracy condition is smaller, while accelerate the adoption otherwise.*

Proposition 2 shows that producer will not always delay or advance the adoption when piracy exists in the market. The decision depends on the market expansion effect. Since piracy would function as a competitor in both single channel market and multi-channel market, what really matters is which market is more vulnerable to piracy. When piracy cannibalizes more legal sales in multi-channel market than in single channel market[2], producer will want to delay the release. However, if piracy cannibalizes more legal sales in single channel market, producer would then want to accelerate the adoption of the digital channel.

Incidentally, either situation could occur in the real world. When a large fraction of consumers pirate content because of lower costs, it is more likely to see more cannibalization of legal sales in multi-channel market. However, when a large fraction of consumers pirate content because of unavailability of legal version, cannibalization of legal sales might be will higher in single-channel market.

Thus, we show evidence that it might not always be optimal for producer to accelerate the platform adoption when piracy exists in the market even when the adoption cost is large. More interestingly, as pirated version act as a competitor in the market, the adoption decision depends on how "competitive" the pirated version is in the

[2] $D_S^{NP} - D_S^{P} < D_M^{NP} - D_M^{P} \Leftrightarrow D_M^{P} - D_S^{P} < D_M^{NP} - D_S^{NP}$. Thus, this is equivalent to say that market expansion is smaller in a market with piracy.

market. The producer needs to optimize the adoption decision by looking at how consumers would react to pirated version in both single channel market and multi-channel market.

Similarly, we put forward Corollary 2 regarding this decision when the cost of adoption is negligible.

Corollary 2: *When cost channel adoption is negligible, the producer will always adopt the new platform immediately when the probability of piracy is the same in multi-channel market and single channel market.*

A couple of points are worth highlighting. First, a multi-channel firm has little incentives in delaying the product if releasing the product expands the market. Second, already existing piracy per-se has no impact on release decision. This makes sense. When the technology is costless and there is market expansion, presence of piracy has no effect. We will discuss the case when the technology is not costless.

At this point it is useful to consider the cannibalization effect of digital release on physical sale. We fully expect that physical channel would sell less when the digital version is also available. It is reasonable that firm itself would benefit from multi-channel release simultaneous (unless there are some cost savings in sequential release). Therefore, redistribution of profits across channel is an important issue but those decisions are independent of piracy, which is our focus here. We revisit the issue of cannibalization in Section 5.

Next, we examine the case when product is easier to be pirated in the new channel. In this case, profit function follows:

The producer tries to maximize his profit by adopting the digital platform at time t_r such that the following profit function is maximized,

$$\pi_2 = \underbrace{\int_{t=0}^{t_r} q(t)\left\{D_S^{NP}(1-G(t))p + D_S^{p}G(t)p\right\}dt}_{Profits\ before\ release\ of\ digital\ version} + \underbrace{\int_{t=t_r}^{T} q(t)\left\{D_M^{NP}(1-F(t))p + D_M^{P}F(t)p\right\}dt}_{Profits\ after\ release\ of\ digital\ version} - \underbrace{C(t_r)}_{Adoption\ Cost}$$

(3)

We are interested in learning how this increase in piracy would lead to change in adoption time.

Proposition 3: *If the producer delays platform adoption in the case described in Proposition 2, the producer will further delay the adoption of digital version when the probability that piracy appears in the multi-channel market increases.*

We have already shown in Corollary1-2 that when the cost of adoption is trivial, producer will adopt the digital channel immediately, as long as pirates do not find it easier to pirate in digital channel. Corollary 3 states that under certain conditions, producer might find it beneficial to delay the adoption when it is easier to pirate in the digital channel.

Corollary 3: *In the case of small adoption cost, If there is an increase in piracy due to the digital version and if the following conditions hold true*

(1) $D_S^{NP} > D_M^P$*,*

(2) Probability of piracy is sufficiently low in single channel market at time 0,

(3) increment of piracy level after release of digital version is sufficiently high at t=0 and sufficiently low at t=T, producer will then delay the release time of digital version to some $t_r^* \in (0, T)$*. Furthermore, if F(t) does not grow as fast as G(t),* t_r^* *is unique.*

We need $D_S^{NP} > D_M^P$, so there is significant piracy to reduce demand. (2) Probability of piracy being sufficiently low in single channel market at time 0 ensures that it is feasible to find sufficiently large $F(0) < 1$ to satisfy requirement (3). (3) Sufficiently high $F(t) - G(t)$ at $t = 0$ ensures that expected revenue from not releasing digital version at time 0 outweighs expected revenue from releasing digital version at that point. Producer will then want to delay the release of digital version at time 0. Similarly, sufficiently low $F(t) - G(t)$ at $t = T$ ensures that expected revenue from releasing digital version at time T outweighs that from not releasing digital version at time T. Thus, producer will have the incentive to push forward the release of digital version to some $t < T$.

Corollary 1-3 suggest that if there is no piracy in the market or if releasing digital version does not increase the piracy level, producer will be happy to release digital version along with physical version. Only when digital version generates extra piracy will producers consider delaying the adoption of the digital platform. This finding is contradictory to the common belief that producers should release the digital version as soon as possible to combat potential piracy in the market.

4. Welfare Analysis based on the Dynamic Model

4.1 Consumer Welfare

In this part, we are interested in studying how increasing vulnerability of digital version to piracy impacts consumer welfare. Intuitively, increasing the likelihood of digital version being pirated will have compounding impacts: On the one hand, it might lead producers to delay the release time of digital version; on the other hand, it will increase the likelihood of consumers getting pirated version (for free). We are interested in see how these two factors impact overall consumer welfare. We introduce new notations, which are explained in table 3.

Table 3: Consumer surplus under different market conditions

	Single Channel	Multi-Channel
No Piracy	C_S^{NP} CS from purchase of physical version	C_M^{NP} $(C_M^{NP} > C_S^{NP})$ CS from purchase of physical version and digital version
Piracy	C_S^P $(C_S^P > C_S^{NP})$ CS from purchase of physical version and pirated version	C_M^P $(C_M^P > C_S^P, C_M^P > C_M^{NP})$ CS from purchase of physical version, digital version, and pirated version

Subscripts: S – Single Channel, M – Multi-channel, P – Piracy, NP – No Piracy

We have $C_M^{NP} > C_S^{NP}$, because when digital edition is introduced to the market, consumers will now have digital version in their choice set. Similarly, we have $C_S^P > C_S^{NP}$ because of additional pirated version in the choice set, $C_M^P > C_S^P$ because of additional legal digital version in the choice set, and $C_M^P > C_M^{NP}$ because of additional pirated version in the choice set.

Consumer surplus can be expressed by

$$CS = \int_{t=0}^{t^*} q(t)\{(1 - G(t))CS_S^{NP} + G(t)CS_S^P\}dt + \int_{t=t^*}^{T} q(t)\{\big(1 - F(t)\big)CS_M^{NP} + F(t)CS_M^P\}dt$$

We are interested in how increasing vulnerability of digital version to piracy affect consumer welfare. We exam how $F(t)$ increases from $F(t) = G(t)$ to a sufficiently high piracy level. Without loss of generality, we assume that the adoption cost is negligible.

Suppose we have $G(t)$ and $F(t)$ that ensure all conditions in Proposition 3. Instead of having $F(t) = G(t) + K(t)$, We now assume that $F(t) = G(t) + \beta K(t)$ where β is a parameter the measures the extent of piracy introduced due to the adoption of the digital platform. In this way, as β increases, additional piracy generated by digital version will increase. We are interested in how this change in piracy will affect consumer welfare.

We first present Lemma 1 regarding the optimal release time. Detailed proof of Lemma 1 can be found in appendix.

Lemma 1: *Producer will always adopt the digital platform at $t^* = 0$ when β is small enough. When β is large enough, the adoption time of the digital platform increase monotonically with β.*

Lemma 1 states that for small values of β, piracy induced by digital release is not serious enough to cause delay. Thus firm will continue to release product at time t = 0.

when $\beta \leq \dfrac{\frac{D_S^{NP} - D_M^{NP}}{D_M^P - D_M^{NP}} + \frac{(D_S^p - D_S^{NP}) - (D_M^P - D_M^{NP})}{D_M^P - D_M^{NP}} G(0)}{K(0)}$

$$\frac{dCS}{d\beta} = \int_{t=0}^{T} q(t)K(t)(CS_M^P - CS_M^{NP})dt \quad > 0 \qquad (4)$$

When β is small, increasing piracy does not necessarily cause delay of digital release. It is trivial to see then from Equation (4) that consumers will always be better off in this region. Consumers will have access to pirated version along with the legal version immediately increasing their welfare.

Once β is large and caused delay in digital release, there are two counter-veiling effects. Higher level of piracy is good for users because they have access to the goods at cheaper price. However, higher piracy would cause delay in legal release (as shown in Proposition 1). This delay would lower user welfare. The net effect on consumer welfare depends critically on which effect dominates.

It can be shown that

when $\beta > \frac{\frac{D_S^{NP}-D_M^{NP}}{D_M^{P}-D_M^{NP}} + \frac{(D_S^{P}-D_S^{NP})-(D_M^{P}-D_M^{NP})}{D_M^{P}-D_M^{NP}} G(0)}{K(0)}$

$$\frac{dCS}{d\beta} = \frac{\partial CS}{\partial \beta} + \frac{\partial CS}{\partial t^*}\frac{\partial t^*}{\partial \beta} =$$

$$\underbrace{\int_{t=t^*}^{T} q(t)K(t)(CS_M^P - CS_M^{NP})dt}_{Direct\ Effect} +$$

$$\underbrace{q(t^*)\frac{dt^*}{d\beta}\{(CS_S^{NP} - CS_M^{NP}) + G(t^*)(CS_S^P - CS_S^{NP} - CS_M^P + CS_M^{NP}) - \beta K(t^*)(CS_M^P - CS_M^{NP})\}}_{Indirect\ Effect} \quad (5)$$

The first part of Equation (5) positive, and the second part is negative. This is because $\frac{dt^*}{d\beta} > 0$, and $CS_S^{NP} - CS_M^{NP} < 0$, $CS_S^P - CS_S^{NP} - CS_M^P + CS_M^{NP} < 0$, and $CS_M^P - CS_M^{NP} > 0$.

Unfortunately, it is not easy to show which effect (direct or indirect) dominates. One would need some functional forms to make suitable judgment (we do that in the subsequent sections). However, consumer surplus highlights one issue clearly. In the short run, increase in piracy might be beneficial (when β is small). However, as level of piracy increases, it is not entirely clear if consumers will benefit or not.

What that level of piracy is, is an open empirical question. When is the piracy level high enough that producers start shifting resources in a way that is detrimental to end users? However, our model provides a testable hypothesis that while small level of piracy may be beneficial to end users, the long run effects of piracy can lower welfare.

4.2 Producer Welfare

In this part, we examine how producer surplus will be affected by increasing piracy level from adoption of the digital platform. Producer surplus can be expressed by

$$PS = \int_{t=0}^{t^*} q(t)p\{(1 - G(t))D_S^{NP} + G(t)D_S^P\}dt + \int_{t=t^*}^{T} q(t)p\{(1 - F(t))D_M^{NP} + F(t)D_M^{NP}\}dt$$

Again, we assume that $F(t) = G(t) + \beta K(t)$ and are interested in how changes in β affects producer surplus.

Taking derivative of PS with respect to β, we get

$$\frac{dPS}{d\beta} = \frac{\partial PS}{\partial \beta} + \frac{\partial PS}{\partial t^*}\frac{dt^*}{d\beta} = \int_{t=t^*}^{T} q(t)K(t)(D_M^P - D_M^{NP})dt + q(t^*)\frac{dt^*}{d\beta}\{(D_S^{NP} - D_M^{NP}) + G(t^*)(D_S^P - D_S^{NP} - D_M^P + D_M^{NP}) - \beta K(t^*)(D_M^P - D_M^{NP})\}$$

It can be shown that $\frac{dPS}{d\beta} > 0$. Refer appendix for detailed proof.

Proposition 4: *Increasing piracy caused by the adoption of new channel will always reduce producer surplus.*

Proposition 4 shows that piracy will always hurt producer no matter how they optimize their release time. While Proposition 4 is intuitive, it is worth reiterating the mere change in business strategy does not necessarily solve the problem of piracy. Firms may be able to reduce the impact of piracy by being more proactive but they will always be worse off than when the piracy did not exist.

5. Modeling Customer Heterogeneity

5.1 Consumer Preferences

In previous section, we do not explicitly model the demand of products based on utility. The advantage is that it helps us develop very general results. However, it is hard to obtain an intuitive picture of how release decision, especially consumer surplus, will change dynamically when factors that affect piracy consumption change. In this section, we will explicitly derive demand under different market conditions by modeling consumer utilities. We will then follow up with simulation to show how release time and consumer surplus are affect by different parameters that affect piracy consumption.

In more detail, we focus on a horizontally differentiated market where consumers have varying preferences for the digital and physical versions of the product. Consumers are distributed along a Hotelling line, which is formalized in the assumption below.

Assumptions 3: Consumers' preference for a product depends on the distance of that product from their location $x \in [0,1]$ on the Hotelling line. The distribution of consumers' preference is assumed to be uniform.

Consumers with a lower value of x prefer the physical product whereas consumers with a higher value of x prefer the digital version of the good. In this context, when the producer uses the traditional channel to provide a physical product, it is located at $x = 0$. If in addition, he adopts the digital platform and launces a product, it is located at $x = 1$. The utility of a product for a consumer located at x is given by

$$U = V - m|y - x| - p$$

where V is the maximum valuation for the product, y is the location of the product, and p is the price of the product. To focus on impact of piracy on release choices, we assume that prices for digital version and physical version are exogenous and set equal to p. In addition, we make a simplifying assumption that the quality of digital product, physical product, and pirated version are the same. This is a reasonable assumption, because consumers are usually not able to tell the difference between CD quality and MP3 quality or simply do not care about the difference. Nowadays, consumers can also rip MP3 or lossless files from CDs or retrieve files after they purchase digital downloads, making quality of pirated version similar to that of legal version.

Consumer utility for the physical and digital products can be modeled as following:

Utility from consuming physical version is given by,

$$U_p = v - mx - p,$$

whereas the utility from consuming digital version is given by,

$$U_d = v - m(1 - x) - p.$$

In addition we assume that consumers, although get the same quality from downloading pirated version, needs to incur a piracy cost c, which include learning cost, waiting time, cost of recovering from potential virus and Trojan, moral cost, etc. Also, the consumers are heterogeneous in their piracy costs. To capture the heterogeneity, we assume that there are two types consumers, high-type and low-type. High-type consumers incur high cost of pirating ($c_H > p$), and low type consumers incur low cost of pirating ($c_P < p$). The proportion of high-type consumers is denoted by γ. The utility function from consuming pirated version equals

$$U_c = v - m(1 - x) - c,$$

where $c = c_H$ for high-type consumer, and $c = c_L$ for low-type consumers.

There are 4 market conditions different consumers might face: (1) market with only physical version (2) market with both physical version and digital version (3) market with both physical version and pirated version (4) market with physical version, digital version, and pirated version. Since consumers are distributed at different location on Hotelling line. Consumers will make different purchase decision under different market situation. As shown in the Appendix, we can prove that the Hotelling line under different market situation follows the Figure 1.

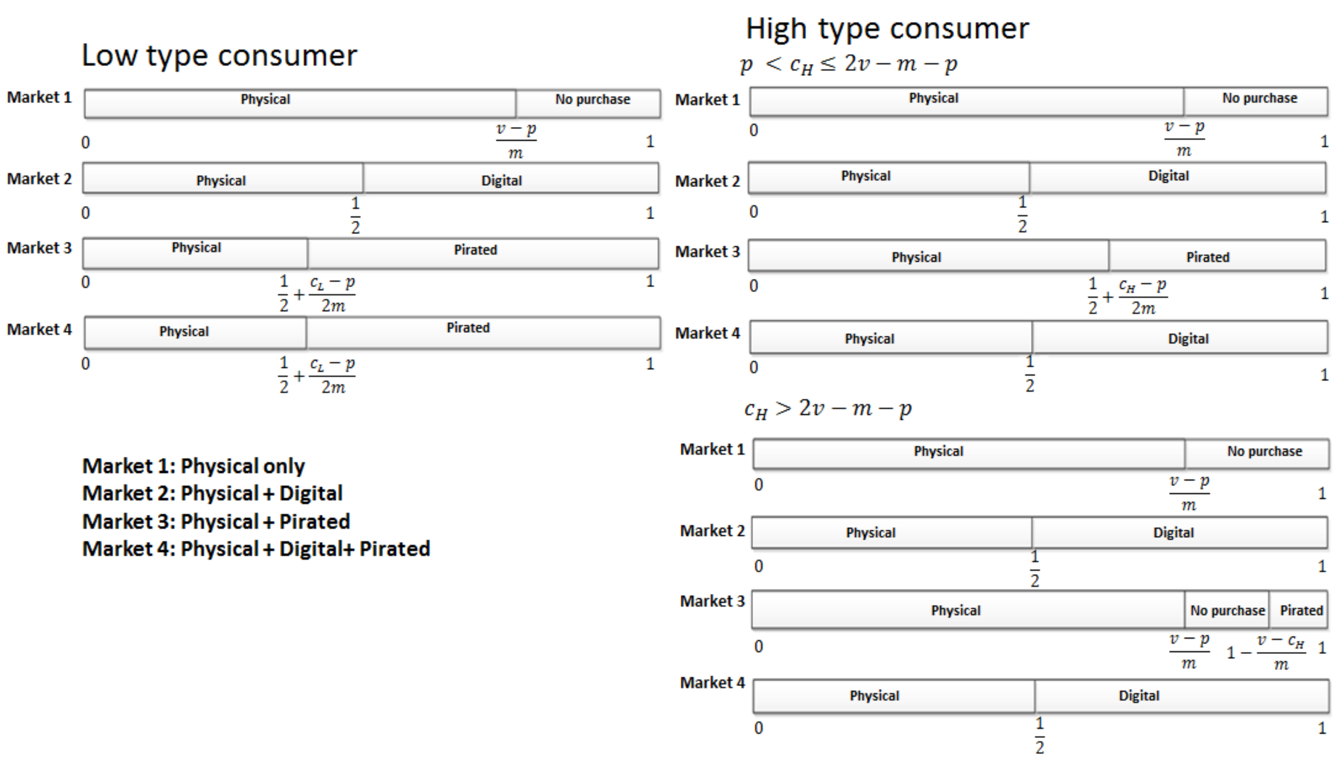

Figure 1 Hotelling Line

From Figure 1, we can easily see that both low-type and high-type consumers will behave the same in a market without piracy. In single-channel market, although both low-type consumers and high-type consumers will consume pirated version, the consumption of pirated version is higher for low-type consumers due to their low cost of pirating. When pirating cost is moderate for high-type consumers, pirated version will still cannibalize some sales of pirated version, while when pirating cost becomes high enough, pirated version will stop cannibalizing legal sales. In multi-channel market under piracy, low-type consumers will always choose between physical version and pirated version, while high-type consumers will always choose between physical version and digital version.

Another way to look at this problem is that, we see two types in the market. Low-type consumer will always choose pirated version when both digital version and pirated version are available, while high-type consumer will always choose digital version when both digital version and pirated version are available. However, they would still consider the other choices if their preferred choice is not available.

From the proof the Hotelling line shown in the appendix, we can easily derive the demand for physical version and digital version for all for 4 market situations. Table 4 shows the market demand when pirating cost for high-type consumer are moderate ($p < c_H < 2v - m - p$), while Table 5 shows the market demand when pirating cost for high-type consumers is high ($c_H > 2v - m - p$).

Table 4 Demand under $p < c_H < 2v - m - p$

	Physical /No Piracy	Physical+Digital / No Piracy	Physical / Piracy	Physical+Digital/ Piracy
Market Condition	(1)	(2)	(3)	(4)
Demand of Physical	$\frac{v-p}{m}$	$\frac{1}{2}$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}+\frac{c_H-p}{2m})$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\frac{1}{2}\gamma$
Demand of Digital	-	$\frac{1}{2}$	–	$\frac{1}{2}\beta$
Demand of Piracy	-	-	$(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}-\frac{c_H-p}{2m})$	$(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)$
Legal Demand	$\frac{v-p}{m}$	1	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}+\frac{c_H-p}{2m})$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma$

From Table 4, we can see that $D_S^{NP} = \frac{v-p}{m}$, $D_M^{NP} = 1$, $D_S^P = (1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}+\frac{c_H-p}{2m})$, $D_M^P = (1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma$. By checking Figure 1, we see that $D_S^{NP} > D_S^P$, $D_S^{NP} < D_M^{NP}$, $D_S^P < D_M^P$, and $D_M^P < D_M^{NP}$, which are the assumptions we had in the general model.

Table 5 Demand under $c_H > 2v - m - p$

	Physical /No Piracy	Physical+Digital / No Piracy	Physical / Piracy	Physical+Digital/ Piracy
Market Condition	(1)	(2)	(3)	(4)
Demand of Physical	$\frac{v-p}{m}$	$\frac{1}{2}$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma\frac{v-p}{m}$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\frac{1}{2}\gamma$
Demand of Digital	-	$\frac{1}{2}$	-	$\frac{1}{2}\gamma$
Demand of Piracy	-	-	$(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)+\gamma\frac{v-c_H}{m}$	$(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)$
Legal Demand	$\frac{v-p}{m}$	1	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma\frac{v-p}{m}$	$(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma$

From Table 5, we can see that $D_S^{NP} = \frac{v-p}{m}$, $D_M^{NP} = 1$, $D_S^P = (1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma\frac{v-p}{m}$, $D_M^P = (1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma$. Again, we see that all 4 assumptions mentioned above hold very well.

5.2 Adoption Time and Welfare Analysis

In this section, we analyze how changing parameters in the market setting will affect the adoption decision and consumer surplus. In particular, we are interested in (1) how changes in proportion of high-type consumer and piracy induced by digital release affect this decision, and (2) how changes in pirating cost faced by both high-type and low-type consumers affect this decision.

For the first question, we first fix p, v, m, c_L, c_H, $G(t)$, and $F(t)$ and then change γ and the gap between $G(t)$ and $F(t)$ to look at how release decision and consumer surplus change accordingly. For the second question, we fix p, v, m, γ, β, $G(t)$, $F(t)$ and look at how release decision and consumer surplus corresponds to changes in c_L and c_H.

In the following simulation, we assume that $p = 3$, $v = 6$, and $m = 4$, which satisfies $\frac{1}{2} \leq \frac{v-p}{m} < 1$. In addition, we assume that $G(t) = 1 - \exp\left(-(t + 0.01)^{0.5}\right)$ and $F(t) = 1 - \exp\left(-\frac{(t+1)^{0.5}}{2.1}\right)$.

Figure 2 shows the relationship between $G(t)$, $F(t)$ and t.

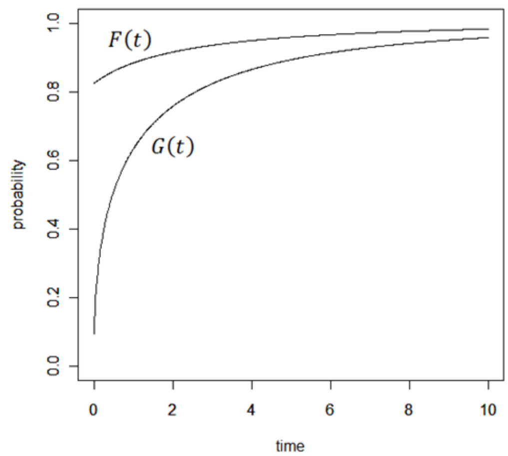

Figure 2 Piracy level in Single channel and Multi-channel market

For the first question, we choose $c_L = 2$, $c_H = 4$. We assume that the gap of piracy level between single channel market and multi-channel market is $\beta K(t)$, where $K(t) = F(t) - G(t)$. We will increase both β and γ from 0 to 1 and see how this change will affect release time and consumer surplus. It is easy to see that both γ and β will affect consumption of pirated version. As β inreases, consumers will get more exposures to pirated version. As γ increase, more consumers will find pirating harder. In this simulation, we first calculate different release time at different γ and β. Release time under different piracy level is shown in Figure 3 (a). After calculating the optimal release time under different consumer composition and piracy level, we then calculate the corresponding consumer surplus. Without losing of generosity, we simply choose T to be the latest release time. Figure 3(b) shows the relationship between γ, β, and consumer surplus.

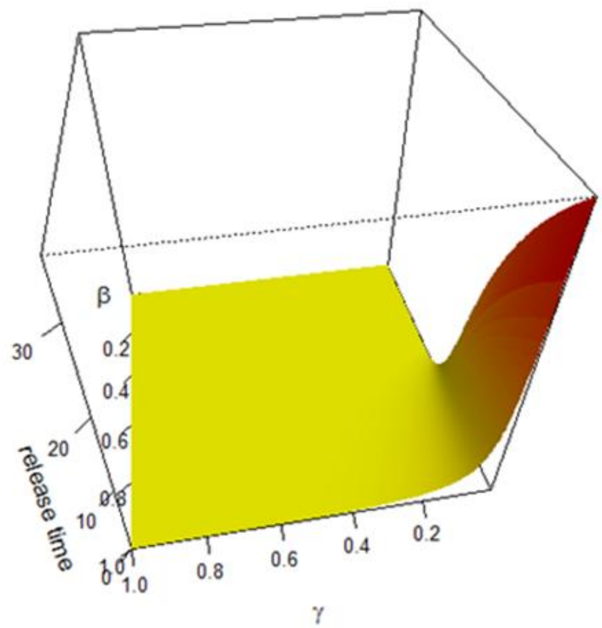

Figure 3 (a) piracy and release time

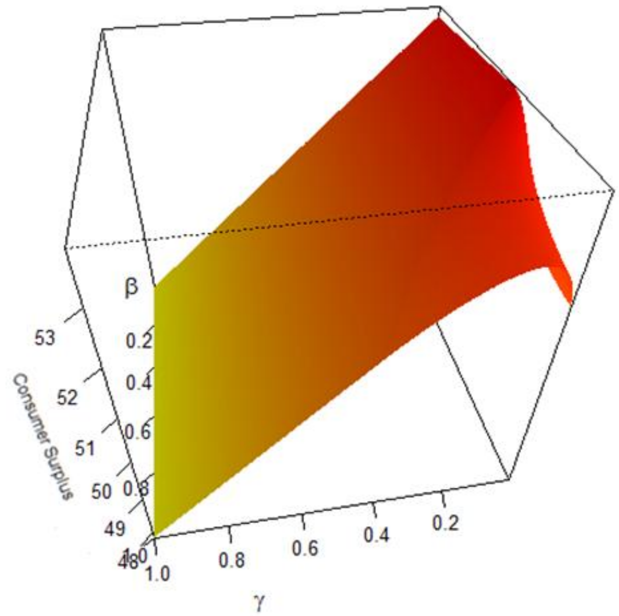

Figure 3 (b) piracy and consumer surplus

From Figure 3 (a), we can see that conditional on the proportion of high-type consumers (γ) staying the same, the producer might begin to delay the release of digital version as additional piracy brought by digital version (β) release increases. Meanwhile, we can see that conditional on piracy level (β) staying the same, the producer will also tend to delay the digital release as number of high-type consumers (γ) decreases. This finding is intuitive, as both of them are factors that lead to piracy consumption, which can be partially avoided by delaying the release.

From Figure 3(b), we can see that consumers do not necessarily benefit from high level of piracy. Holding γ constant, we can see that consumer surplus will be monotonically increasing when piracy generated in digital channel is not high enough to cause delay in the digital release. However, when β is high enough, producer might start to delay the adoption of the digital platform. In our example, the indirect effect from delaying the adoption will dominate the indirect effect from higher availability from pirated version, leading consumer surplus to decrease. We can easily see that when γ is low, consumer surplus under high level of piracy availability will be even smaller than that under no piracy. Similarly, holding β constant, we can see that consumer surplus will first monotonically increase before producers start to delay the adoption due to decreasing proportion of high-type consumers. In our example, when producers begin to push back the adoption date, consumer surplus will first increase because benefit from low pirating cost will dominate loss brought on by the unavailability of a digital version. However, when adoption date is pushed back too much, consumer surplus will begin to decrease. This shows that consumers might benefit from moderate level of piracy availability, while suffer from excessive piracy due to strategic decisions made by the producer.

Another interesting aspect to explore the question is how changes in pirating cost affect release time and consumer surplus, while holding piracy level and consumer constant. In this simulation, we fix β at 1, and $\gamma = 0.5$ while vary c_H from 3 to 6 and c_L from 0 to 3. Figure 4(a) shows how release time will change as pirating cost varies, while the relationship between pirating cost and consumer surplus is plotted in Figure 4(b).

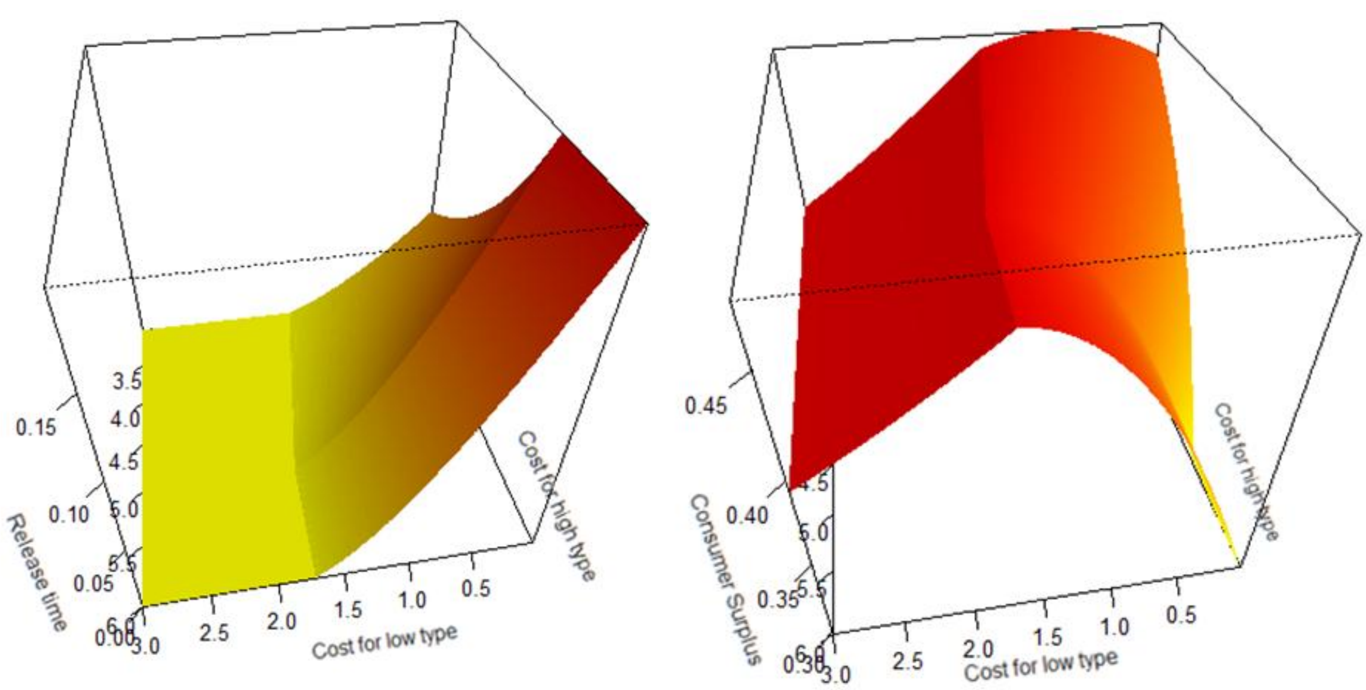

Figure 4(a) Pirating cost and release time

Figure 4(b) Pirating cost and release time

From Figure 4(a), we can see that higher pirating cost for high-type consumers and lower pirating cost for low-type consumer's leads to more delay in adoption of the digital platform. As pirating cost decreases for low-type consumers, more low-type consumers will turn to pirated version in both single channel market and multi-channel market, producer would have the tendency to delay adoption of the digital platform to avoid increasing cannibalization generated from digital version. As pirating cost increases for high-type consumers, behavior for high-type consumers will not change in multi-channel market, while more high-type consumers will buy physical version in single channel market, giving producer more incentive to delay the adoption of the digital platform to generate more revenue from single-channel market. However, when pirating cost is very high for high-type consumers, pirated version will no longer cannibalize physical sales, in that case, increasing cost will not lead to further delay in adoption of the new distribution platform. In sum, we can see that low pirating cost does not necessarily lead to delay in the adoption of the new platform.

From Figure 4(b), we can see that low pirating cost does not necessary leads to higher consumer surplus. In our example, consumer surplus is maximized when pirating cost for high-type consumers are low while for low-type consumers is moderate. We can see that (1) when producer does not delay the release, consumer surplus will increase when pirating cost decreases for low type, while consumer surplus will stay the same when pirating cost decreases for high type. This is because when the digital channel is adopted at immediately, ålow-type will benefit from lower cost when pirating, while high-type consumers will not benefit since they will only consider legal version under multi-channel circumstance. (2) However, when producer begins to delay the adoption due to high cost for high-type and low cost for low type, high-type will immediate suffer as pirating cost increase (loss from both increasing pirating cost and delay effect), while low-type might at first still enjoy some increase in consumer surplus as pirating cost decreases (loss from delay effect is dominated by benefit from decreasing pirating cost) and then will suffer loss in consumer surplus (loss from delay effect will dominate benefit from decreasing pirating cost) (3) When pirating cost for high-type is so high that delay will only be caused by decreasing pirating lost for low type, consumer surplus will still follow (2) expect that the decrease in consumer surplus for high-type will only be due to increasing pirating cost.

6. Discussions and Conclusion

The effect of piracy on the production and consumption entertainment goods has been a topic of ripe debate in academia and popular press for a long time. In this paper, we study the effect of piracy on the adoption of innovation by the producer and extend the important and pertinent literature on piracy. We build a dynamic model of channel adoption in a horizontally differentiated market and analyze how adoption costs and piracy affect the adoption decision of a producer. We find that in general piracy hurts the adoption of new innovative distribution platform contrary to the belief held by several critics of the media industry. Only in certain cases, when the market expansion effects due to the platform adoption is large and a sufficient fraction of consumers are willing to pay for the legal digital version instead of consuming the pirated copy, does piracy act as a competing force and hasten the adoption of the digital platform. Although, piracy always hurts the producer and reduces his profits, its effect on consumer welfare in nuanced. Moderate levels of piracy benefits consumers as some of them are able to consume the product for free. However, when the threat of piracy increases, the producer is reluctant to adopt the digital platform, which hurts the consumers if piracy doesn't occur. Hence, piracy has a non-monotonic impact on consumer welfare, and if the level of piracy is too strong, the consumer welfare might be even lower than a market when there is no piracy.

Our paper makes several managerial and academic contributions. The analysis presented in the paper directly addresses the debate around the effect of piracy and refutes the claim made by several critics of the media industry who argue that piracy is good for consumer welfare and innovation in the entertainment industry. Our results show conclusively that this is not the case. It also addresses the policy question that talks about the regulation or control of piracy. Our analysis shows that it is important to curb policy as it reduces the overall welfare expect in a few specific cases. Furthermore, this paper also provides empirically testable hypothesis that can identify whether piracy has a welfare enhancing or welfare reducing impact in a certain market. Our research also makes an important contribution to the piracy literature. Most papers on piracy consider a static model where the producers make product line or pricing decision based on the level of quality. On the other hand, this paper proposes a dynamic model that explores the long-term strategic decision of adopting a new technological innovation that can provide a comprehensive understanding about the aforementioned issues.

This paper has several limitations. Firstly, we assume that the consumers in our model arrive at the market in a non-strategic exogenous fashion. In reality, consumers might decide when to enter the market based on the release decision of the firm. Secondly, we do not model the competitive landscape, which might play an important role in this setting. Addressing these limitations of our current paper can provide interesting directions for future research. We hope that the dynamic model of channel adoption can contribute the rich and growing literature on the piracy of entertainment goods.

Our paper has several limitations. First, we did not consider bundling issue in this paper, which might be another factor that leads to delay in digital adoption. Since customers could choose to only download their favorite tracks in an album, producer might have willingness of going to digital. It would be an interesting extension of the paper to look at how the decision will be when this unbundling effect is taken into account. Second, we assumed that consumers will only arrive at market once. However, in reality, consumers are strategic in that they might choose return to the market at a later date when preferred version is unavailable or they might choose their best time of entering the market. Thirdly, we do not model the competitive landscape, which might play an important role in this setting. Addressing these limitations of our current paper can provide interesting directions for future research. We hope that the dynamic model of channel adoption can contribute the rich and growing literature on the piracy of entertainment goods.

Appendix. Proofs

Proof of proposition 1

$$\frac{\partial \pi_1}{\partial t_r} = \mathrm{q}(t_r)(D_S^{NP} - D_M^{NP}) - C'(t_r)$$

According to single crossing condition, the following two conditions guarantee that adoption is between 0 and T.

$$\begin{cases} \mathrm{q}(0)(D_S^{NP} - D_M^{NP}) - C'(0) > 0 \\ \mathrm{q}(T)(D_S^{NP} - D_M^{NP}) - C'(T) < 0 \end{cases}$$

These two conditions gives that $\frac{C'(0)}{\mathrm{q}(0)} < D_S^{NP} - D_M^{NP} < \frac{C'(T)}{\mathrm{q}(T)}$

Proof of Corollary 1

When the cost of platform adoption is relatively small, the first order condition in Proposition 1 can be simplified to

$$\frac{\partial \pi_1}{\partial t_r} = \mathrm{q}(t_r)(D_S^{NP} - D_M^{NP})$$

Because $D_S^{NP} < D_M^{NP}$, $\frac{\partial \pi_1}{\partial t_r}$ will always be smaller than 0. Thus, producer will always adopt the new platform immediately.

Proof of Proposition 2

From profit function (1) and (2), we can see that the optional adoption time in two settings follows the following two functions,

$$q(t_r^*)p(D_S^{NP} - D_M^{NP}) = c'(t_r^*) \qquad \text{(P2.1)}$$

$$q(t_r^*)p\left((D_S^{NP} - D_M^{NP}) + \left((D_S^{P} - D_M^{P}) - (D_S^{NP} - D_M^{NP})\right)G(t_r^*)\right) = c'(t_r^*) \qquad \text{(P2.2)}$$

It is easy to show graphically that when $D_S^{NP} - D_M^{NP} > D_S^{P} - D_M^{P}$, the left-hand side of P2.2 will be lower than that of P2.1 at any time, which leads to delay in the adoption of new platform in the presence of piracy. However, when $D_S^{NP} - D_M^{NP} < D_S^{P} - D_M^{P}$, the adoption will be accelerated.

Proof of Corollary 2:

When the cost of platform adoption is relatively small, the first order condition in Proposition 2 can be simplified to

$$\frac{\partial \pi_2}{\partial t_r} = q(t_r)p\left((D_S^{NP} - D_M^{NP})(1 - G(t_r)) + (D_S^P - D_M^P)G(t_r)\right)$$

As long as there is some market expansion effect $D_M^{NP} - D_S^{NP} > 0$ and $D_M^P - D_S^P > 0$; firm should be willing to adopt the digital platform immediately even in the presence of piracy. Since $q(t_r), p$ are all positive, also because $0 \leq G(t_r) \leq 1$, we will get $\frac{\partial \pi_2}{\partial t_r} \leq 0$. Again, just like before, producer will continue to adopt the digital platform at time 0 when probability of piracy is the same in multi-channel market and single channel market.

Proof of Proposition 3:

From profit function (2) and (3), we can see that the optimal adoption time in that setting follows

$$q(t_r^*)p\left(D_S^{NP}(1 - G(t_r^*)) + D_S^P G(t_r^*)\right) + q(t_r^*)p\left(D_M^{NP}(1 - G(t_r^*)) + D_M^P G(t_r^*)\right) = c'(t_r^*) \qquad \text{(P3.1)}$$

$$q(t_r^*)p\left(D_S^{NP}(1 - G(t_r^*)) + D_S^P G(t_r^*)\right) + q(t_r^*)p\left(D_M^{NP}(1 - F(t_r^*)) + D_M^P F(t_r^*)\right) = c'(t_r^*) \qquad \text{(P3.2)}$$

We can see that the left-hand side of P3.2 will be lower than P3.1 at any time (Because $(D_M^P - D_M^{NP})\left(F(t_r^*) - G(t_r^*)\right) < 0$), which means producer will delay the release when pirates can easier pirate in the new channel.

Proof of Corollary 3:

Suppose $\left(D_S^{NP} + (D_S^P - D_S^{NP})G(0)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(0)\right) > 0$ *and* $\left(D_S^{NP} + (D_S^P - D_S^{NP})G(T)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(T)\right) < 0$.

Because $D_S^{NP} + (D_S^P - D_S^{NP})G(t)$ and $D_M^{NP} + (D_M^P - D_M^{NP})F(t)$ are both monotonically decreasing, it is easy to show graphically that there is at least one $t^* \in (0, T)$ that gives global maximum.

To ensure $\left(D_S^{NP} + (D_S^P - D_S^{NP})G(0)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(0)\right) > 0$, we need

$$D_S^{NP} + (D_S^P - D_S^{NP})G(0) > D_M^{NP} + (D_M^P - D_M^{NP})F(0) \quad (1)$$

Plugging $F(t) = K(t) + G(t)$ into (1) and after some arrangement, we get

$$((D_S^P - D_S^{NP}) - (D_M^P - D_M^{NP}))G(0) > D_M^{NP} - D_S^{NP} + (D_M^P - D_M^{NP})K(0)$$

$$=> K(0) > \frac{D_S^{NP} - D_M^{NP}}{D_M^P - D_M^{NP}} + \frac{(D_S^P - D_S^{NP}) - (D_M^P - D_M^{NP})}{D_M^P - D_M^{NP}} G(0)$$

We can easily get $K(0)$ higher than some number, which depends on demand and G(0). Thus, we will need $G(0)$ to be sufficiently smaller than $F(0)$.

To ensure $\left(D_S^{NP} + (D_S^P - D_S^{NP})G(T)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(T)\right) < 0$, we will need

$$D_S^{NP} + (D_S^P - D_S^{NP})G(T) < D_M^{NP} + (D_M^P - D_M^{NP})F(T) \quad (2)$$

Again, we can get

$$K(T) < \frac{D_S^{NP} - D_M^{NP}}{D_M^P - D_M^{NP}} + \left(\frac{D_S^P - D_S^{NP}}{D_M^P - D_M^{NP}} - 1\right) G(T)$$

Following the same argument, we can get that we need G(T) to be sufficiently close to F(T).

(This finishes proof of Condition 2)

Additionally, we need ensure G(t) ≤ F(t) ≤ 1 is always met.

At $t = 0$, we need $G(t)$ to be small enough, so that $F(t) \leq 1$. Plugging $F(t) = 1$ into (1), we have

$$G(0) < \frac{D_S^{NP} - D_M^P}{D_S^{NP} - D_S^P}$$

(This finishes proof of Condition 1)

We then prove the conditions that ensure unique interior solution. It is easy to see that if only one local maximum exists in this problem, we will then have only one global maximum. We can use single crossing conditions to ensure the existence of unique local maximum, which is

$$\begin{cases} \left(D_S^{NP} + (D_S^P - D_S^{NP})G(t)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(t)\right) > 0 & for \quad t < t_r^* \\ \left(D_S^{NP} + (D_S^P - D_S^{NP})G(t)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(t)\right) = 0 & for \quad t = t_r^* \\ \left(D_S^{NP} + (D_S^P - D_S^{NP})G(t)\right) - \left(D_M^{NP} + (D_M^P - D_M^{NP})F(t)\right) < 0 & for \quad t > t_r^* \end{cases}$$

One possible condition that ensures single crossing condition is that $\mathrm{D_S^{NP}} + (\mathrm{D_S^p} - \mathrm{D_S^{NP}})G(\mathrm{t})$ decreases faster than $\mathrm{D_M^{NP}} + \left(\mathrm{D_M^P} - \mathrm{D_M^{NP}}\right)F(\mathrm{t})$ at any t. we will now have for any $\Delta \mathrm{t} > 0$

$$\{D_S^{NP} + (D_S^P - D_S^{NP})G(t)\} - \{D_S^{NP} + (D_S^P - D_S^{NP})G(t + \Delta t)\}$$

$$> \{D_D^{NP} + (D_D^P - D_D^{NP})F(t)\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(t + \Delta t)\}$$

$$\Rightarrow \{D_S^{NP} + (D_S^P - D_S^{NP})G(t)\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(t)\}$$

$$> \{D_S^{NP} + (D_S^P - D_S^{NP})G(t + \Delta t)\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(t + \Delta t)\}$$

Thus, $\left\{D_S^{NP} + \left(D_S^p - D_S^{NP}\right)G(t)\right\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(t)\}$ will be decreasing over time,

Also because $\{D_S^{NP} + (D_S^P - D_S^{NP})G(0)\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(0)\} > 0$ and $\{D_S^{NP} + (D_S^P - D_S^{NP})G(T)\} - \{D_M^{NP} + (D_M^P - D_M^{NP})F(T)\} < 0$, and because $G(\mathrm{t})$ and $F(\mathrm{t})$ are both continuous function, we can easily see that single crossing condition is guaranteed.

To have $D_S^{NP} + (D_S^P - D_S^{NP})G(t)$ decreases faster than $D_M^{NP} + (D_M^P - D_M^{NP})F(t)$ at any t, we will need to have

$$\frac{\partial\left(D_S^{NP} + (D_S^P - D_S^{NP})G(t)\right)}{\partial t} < \frac{\partial\left(D_M^{NP} + (D_M^P - D_M^{NP})F(t)\right)}{\partial t} \Rightarrow (D_S^P - D_S^{NP})G'(t) < (D_M^P - D_M^{NP})F'(t)$$

Since $D_S^P - D_S^{NP} < 0$, and $f(\mathrm{t}) > 0$, thus $\frac{G\prime(t)}{F\prime(t)} > \frac{D_M^P - D_M^{NP}}{D_S^P - D_S^{NP}} > 1$, which mean $G'(t)$ will be sufficiently higher than $F'(t)$ at any time.

(This proves the condition for unique interior solution)

Proof of Lemma 1

From previous proof we know that if $F(t)$ and $G(t)$ satisfy all conditions in Corollary 3, we will have when $\beta K(0) \leq \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(0)$, producer will always be releasing the product at time 0. Thus, when $\beta \leq \frac{\frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}}+\frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(0)}{K(0)}$, $t^* = 0$.

Once $\beta > \frac{\frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}}+\frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(0)}{K(0)}$, publisher will start releasing digital version at $t^* > 0$. Suppose when gap between $\mathrm{G(t)}$ and $\mathrm{F(t)}$ is $\beta_1\mathrm{K(t)}$, which ensures $\exists t^*$, which satisfies

$$\beta_1 K(t)\begin{cases} > \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t < t^* \\ = \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t = t^* \\ < \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{(D_S^P-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t > t^* \end{cases}$$

If $\beta_2 > \beta_1$, we will have $\beta_2 K(t) > \beta_1 K(t)$.

Suppose $\exists t^{**}$ that ensures

$$\beta_2 K(t)\begin{cases} > \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{\left(D_S^p-D_S^{NP}\right)-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t < t^{**} \\ = \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{\left(D_S^p-D_S^{NP}\right)-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t = t^{**} \\ < \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{\left(D_S^p-D_S^{NP}\right)-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t) & if\ t > t^{**} \end{cases}$$

We can see that both $\beta_1 K(t)$ and $\beta_2 K(t)$ will be decreasing functions over time with $\beta_2 K(t)$ higher than $\beta_1 K(t)$ at any t. We also have both $\beta_1 K(t)$ and $\beta_2 K(t)$ higher than $\frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + \frac{(D_S^p-D_S^{NP})-(D_M^P-D_M^{NP})}{D_M^P-D_M^{NP}}G(t)$ at time 0 and lower than that at time T. With those conditions, it is very easy to graphically show $t^{**} > t^*$.

Proof of Hotelling Line under different market situations

Market situation 1 (Physical version only): consumer will either purchase the physical version or exit the market if the utility he receives from physical version is less than 0. Consumer will choose the physical version if

$U_p \geq 0 \Rightarrow x \leq \frac{v-p}{m}$

To simplify the modeling, we put forward assumption 3.

Assumption 4: Demand for physical version in a market where only physical version is available will always be higher than 0 but never be large enough to cover the whole market, i.e. $0 < \frac{\mathrm{v-p}}{\mathrm{m}} < 1$.

Assumption 4 puts some restrictions on $\frac{v-p}{m}$, which describes a market in which producer will at least have some consumers in the market by releasing only physical version. However, the physical version alone is not enough to attract all consumers. This is a reasonable assumption, as demand typically exists in for physical version ($\frac{v-p}{m} > 0$). However, there are some consumers who only have MP3 players, which leads to high transportation cost and in turn no purchase of physical version $\left(\frac{v-p}{m} < 1\right)$. From assumption 3, it is easy to see that consumers located at $x \leq \frac{v-p}{m}$ will purchase physical version, while those located at $x > \frac{v-p}{m}$ will leave the market. Thus, demand for physical version under market situation (1) is $\frac{v-p}{m}$.

Market Situation 2 (Physical version, digital version, no piracy): consumer will choose from physical version, digital version, and no purchase, whichever gives him the highest utility.

Consumers will choose physical version if

$$\begin{cases} U_p \geq 0 \Rightarrow x \leq \frac{v-p}{m} \\ U_p \geq U_d \Rightarrow x \leq \frac{1}{2} \end{cases}$$

Consumer will choose digital version if

$$\begin{cases} U_d \geq 0 \Rightarrow x \geq 1 - \frac{v-p}{m} \\ U_d \geq U_p \Rightarrow x \geq \frac{1}{2} \end{cases}$$

We present assumption 5 that captures cannibalization of physical sales by digital version.

Assumption 5: Demand for physical version will be cannibalized by digital version in a market where only both physical version and digital version are available.

Assumption 5 states that digital version will cannibalize some sales of physical version. One could easily validate this assumption by imagining those consumers who have some both MP3 players and CD players and are slightly in favor of digital version. Although they will purchase physical version when that is the only option, they will be easily attracted to digital market when digital version becomes available in the market. Based on assumption 3 and 4, we can get that under market situation (2), consumers located at $x \leq \frac{1}{2}$ on the Hotelling line will choose to purchase physical version, while consumers located at $x \geq \frac{1}{2}$ on the Hotelling line will choose to purchase digital version. Thus, demands for physical version and digital version under market situation (2) are both $\frac{1}{2}$.

Market situation 3 (physical version, pirated version): consumer will choose from physical version, pirated version, and no purchase.

Consumers will choose physical version if

$$\begin{cases} U_p \geq 0 \Rightarrow x \leq \frac{v-p}{m} \\ U_p \geq U_c \Rightarrow x \leq \frac{1}{2} + \frac{c-p}{2m} \end{cases}$$

Consumers will choose pirated version if

$$\begin{cases} U_c \geq 0 \Rightarrow x \geq 1 - \frac{v-c}{m} \\ U_c \geq U_p \Rightarrow x \geq \frac{1}{2} + \frac{c-p}{2m} \end{cases}$$

Based on assumption 5, it is easy to see that we will have $\frac{v-p}{m} > \frac{1}{2} + \frac{c_L-p}{2m}$ for low-type consumers, which means physical demand and pirated demand for low-type consumers will be $(1-\gamma)(\frac{1}{2} + \frac{c_L-p}{2m})$ and $(1-\gamma)(\frac{1}{2} - \frac{c_L-p}{2m})$ respectively.

For high-type consumers, if $c_H > 2v - m - p$, we will have $\frac{v-p}{m} < \frac{1}{2} + \frac{c_H-p}{2m}$, which means demand for physical version and pirated version will be $\gamma\frac{v-p}{m}$ and $\gamma\frac{v-c_H}{m}$ respectively. However, if $p < c_H \leq 2v - m - p$, demand for physical version and pirated version will be $\gamma(\frac{1}{2} + \frac{c_H-p}{2m})$ and $\gamma(\frac{1}{2} - \frac{c_H-p}{2m})$ respectively.

Thus, if $c_H > 2v - m - p$, total demand for physical version and pirated version will be $(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma\frac{v-p}{m}$ and $(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)+\gamma\frac{v-c_H}{m}$ respectively. However, if $p < c_H \leq 2v - 2m - p$, total demand for physical version and pirated version will be $(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}+\frac{c_H-p}{2m})$ and $(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)+\gamma(\frac{1}{2}-\frac{c_H-p}{2m})$.

Market Situation 4 (Physical version, digital version, pirated version): consumer will choose among digital version, physical version, pirated version, and not buying anything, based on the utilities she receives from each of the choices.

Consumer will choose physical version if

$$\begin{cases} U_p \geq 0 \Rightarrow x \leq \frac{v-p}{m} \\ U_p \geq U_c \Rightarrow x \leq \frac{1}{2}+\frac{c-p}{2m} \\ U_p \geq U_d \Rightarrow x \leq \frac{1}{2} \end{cases}$$

Consumer will choose digital version if

$$\begin{cases} U_d \geq 0 \Rightarrow x \geq 1-\frac{v-p}{m} \\ U_d \geq U_c \Rightarrow p \leq c \\ U_d \geq U_p \Rightarrow x \geq \frac{1}{2} \end{cases}$$

Consumers will choose pirated version if

$$\begin{cases} U_c \geq 0 \Rightarrow x \geq x \geq 1-\frac{v-c}{m} \\ U_c \geq U_d \Rightarrow p \geq c \\ U_c \geq U_p \Rightarrow x \geq \frac{1}{2}+\frac{c-p}{2m} \end{cases}$$

It is easy to see, high-type consumers will not consider pirated version and act just like in market setting (2), while low-type consumer will not consider digital version and just like in marketing setting (3). Thus demand for physical version is $(1-\gamma)\left(\frac{1}{2}+\frac{c_L-p}{2m}\right)+\frac{1}{2}\gamma$, demand for digital version is $\frac{1}{2}\gamma$, while demand for pirated version is $(1-\gamma)\left(\frac{1}{2}-\frac{c_L-p}{2m}\right)$.

Proof of Proposition 4

$$PS = \int_{t=0}^{t^*} q(t)\{(1-G(t))D_S^{NP} + G(t)D_S^P\}dt + \int_{t=t^*}^{T} q(t)\{(1-F(t))D_M^{NP} + F(t)D_M^P\}dt$$

Taking PS with respect to β, we will get

$$\frac{\partial PS}{\partial \beta} = q(t^*)\frac{\partial t^*}{\partial \beta}\{(D_S^{NP} - D_M^{NP}) + G(t^*)(D_S^P - D_S^{NP} - D_M^P + D_M^{NP}) - \beta K(t^*)(D_M^P - D_M^{NP})\} + \int_{t=t^*}^{T} q(t)K(t)(D_M^P - D_M^{NP})dt$$

From condition for optimal release time, we can substitute $\beta K(t^*)$ with $\frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}} + (\frac{D_S^P-D_S^{NP}}{D_M^P-D_M^{NP}} - 1)G(t^*)$ into (23.2) , we can get

Indirect effect = $q(t^*)\frac{\partial t^*}{\partial \beta}\left\{\left(D_S^{NP} - D_M^{NP} - \frac{D_S^{NP}-D_M^{NP}}{D_M^P-D_M^{NP}}(D_M^P - D_M^{NP})\right) + G(t^*)\left(D_S^P - D_S^{NP} - \frac{D_S^P-D_S^{NP}}{D_M^P-D_M^{NP}}(D_M^P - D_M^{NP})\right)\right\} = 0$

Direct effect $=\int_{t=t^*}^{T} q(t)K(t)(D_M^P - D_M^{NP})dt < 0$, due to

$$D_M^P - D_M^{NP} < 0$$

Thus, $\frac{\partial PS}{\partial \beta} < 0$

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