Effects of Consumer Preferences on Endogenous Switching Costs

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Applied Science
in
Management Sciences

Waterloo, Ontario, Canada, 2012

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The paper provides a model that assesses the set of complementary components of varying compatibility and its effect towards consumer adoption decisions. The smartphone market is a system good which utilizes the device and a set of compatible applications (apps). The amount of switching costs may vary depending upon the consumer's decision to switch devices or across platforms. Analyzing the Android ecosystem, the process of custom ROMs (and rooting) and the large set of games, news, etc. apps justify the existence of device-specific and platform-specific apps. The model reinforces the findings of a survey conducted by UBS suggesting the retention rate (i.e. level of switch costs) of Apple users is higher than Android users. The retention among Android devices is much lower in comparison as well. The model observes that the product fragmentation and the interdependence of apps lead to the noticeably lower retention rates across Android devices and platforms.

Acknowledgements

I would like to express my deepest appreciation to Bonwoo Koo for his guidance and support. During this process, he has provided invaluable feedback, guidance and much needed counsel. His knowledge and experience is much greatly appreciated.

I would also like to extend thanks to Benny Matin and Brian Cozzarin for their feedback.

Dedication

This thesis is dedicated to my family: Eva, Simon and Norman for their support through the hardships and the successes in my life. I would also like to extend my deepest thanks to all my friends and the much needed support of Y. G.

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Chapter 1
Introduction

Recent years have observed rapidly growing market share of smartphones in the mobile phone market in the United States, from 13.6% in July 2009 to 40% in July 2011 (comScore Data Mine, 2012). The recent growth has also changed the market structure through various strategies that platform providers have adopted. Currently, the U.S. smartphone market is dominated by three main operating system (OS) platforms: Apple iOS, Google Android and Blackberry OS. As of July 2011, figure 1 illustrates the market shares of Android, Apple and Blackberry are 40%, 28% and 19%, respectively (Nielsen). The market share of Blackberry has decreased from 35% in June 2010 to 19.2% within 6 months and continues to slip (Distimo, 2010).

The increasing role of smartphones and their potential market size in has led to the explosion of the complementary market for mobile applications. The term "applications" (or "apps") is broadly defined as a set of software programs which can carry out particular tasks for the end users (Harris, 2003). Examples of applications include word processor programs, games, virus scanners, etc. In the context of mobile platforms, mobile apps can be defined as the programs designed to be compatible with a specific operating system (OS) with an associated device such as a smartphone, tablet computer and/or portable media player. The strict definition of apps often excludes ebooks and media products (such as movies and music) that are available on the various app stores (PCMag – Digital Content Definition, 2012). As of November 2011, the app market consisted of four major storefronts: Apple App

Store (with 510,412 apps), Android Market[1] (330,845), BlackBerry App World (50,015) and Windows Marketplace (40,000). The two storefronts Apple App Store and Android Market take account of more than 90 percent of all apps, which is consistent with the market share of their compatible smartphones.

The structure of the mobile ecosystem consists of various players who make a decision around a specific platform. The platform – the operating system - is the intermediary market that brings together the various players: consumers, app developers and hardware producers. App developers are usually third-party groups which develop apps targeted for a specific platform. The platform providers benefit from having a large portfolio of app contents and app developers want to have a larger network of users to increase their revenue. This structure of apps and platforms fit into the traditional definition of a two-sided market.

Hardware producers produce smartphones for a specific platform. However, the provision of hardware products varies by the platforms in the United States. Apple hardware products (e.g. iPods, iPhones, iPads) are exclusively produced by Apple itself. On the other hand, hardware products for Android platform are produced by third parties (e.g. Samsung, HTC, Motorola, etc).

Consumers adopt a hardware product of a specific platform, mainly based on the quantity and quality of available apps for the platform. This construct of a two-sided market is slightly different from traditional cases. In the system market of video game consoles or

[1] As of March 6, 2012, the Android Market has consolidated with Google Music and Google eBookstore under the name Google Play. Like the Android Market, Google Play is still the hub in which consumers obtain apps and does not change the observations discussed.

printer/cartridges, consumer receives utility only in the combination of the system goods; for example, a printer or cartridge alone does not provide utility. In the smartphone market, on the other hand, consumers receive utility from each component (hardware device and apps/accessary), though its combination enhances the utility. Consumers initially make a purchasing decision of hardware device and then buy various types of apps afterwards. This implies that the adoption decision of hardware affects the switching costs to an alternative platform in the future and the degree of locked-in to a specific platform. However, since the need of each consumer is different, users in the market possess different levels of switching costs that need not be prohibitive.

The decision of a consumer can be modeled as a two-step process. In the first period, a consumer decides the adoption of a particular hardware (or platform) and the number of complementary products (apps). In the second period, he can switch to another hardware (and apps) or keep the existing hardware and buy more apps. Assuming the consumer chooses a particular hardware, his decision in the first period is how much to invest (or purchase) in the complementary products. If he purchases many apps in the first period, the switching costs to another platform in the second period would increase due to incompatibility of apps between different platforms.

The objective of this thesis is to analyze the amount of investment for two types of components, device-specific components and platform-specific components. That is, there will be components that are only compatible with their current device and components that will be compatible across the platform respectively. For instance, most Android apps are compatible to any Android compliance device; however, the apps will not be compatible on an Apple device creating platform-specific components. Similarly, manufacturers produce apps/accessories that are only compatible with their own brand or devices. More apparent on Android, devices can be personalized with different themes and modified operating systems which require specific instructions in order to unlock such potential. These instructions vary across devices as manufacturers perform different changes upon their base OS leading to device-specific components. Depending on the consumer's subsequent adoption decision, results can differ from the varying levels of compatibility. In a broad sense, the optimal decision is to maximize utility from the entire component set subject to his preferred allocation between the components and the actual utility yields.

This research can to shed some insight on the significant differences in consumer loyalty and retention rates between the Apple and Android platform. Many surveys of smartphone users show that there are more users who suggest they would switch away from Android than Apple. UBS conducted a survey in 2011 suggesting the retention rates of Apple and Android users are 89% and 55% respectively. Furthermore, the retention rates among Android manufacturers are even lower (39% for Samsung and 28% for HTC). There may be other factors which lead to this wide range of retention rates but the paper will explore the area of complementing components and product introductions on the Android platform (Hughes – Apple Insider, 2011).

This thesis is organized as follows. The next section presents in-depth details of the entire smartphone ecosystem and the motivation behind the study. Section 3 presents the related literature and provides an understanding of how this paper differs from the previous research. Section 4 describes the details of the models and the derivation of the equilibrium states for the consumer. Observations will be discussed in a one-period model, a two-period model with perfect information and a two-period model with uncertainty. Section 5 concludes the analysis with application in the current smartphone ecosystem and discusses the future of this research. Details on the model formulation and explanation of the demand interdependence are presented in the Appendix.

Chapter 2
Motivation and Evidence

2.1 Evolution of the Smartphone Ecosystem

The smartphone market is an ecosystem with various components. The general construct of this market possess a device/smartphone, an operating system (OS) and a set of applications (apps) housed within an online storefront. To understand the current state of the mobile platform ecosystem, several areas needs to be explored which help solidify the three components in the market. The emergence of apps for mobile devices comes from the convergence and evolution of several technologies. The most critical developments that paved the way for apps are the original platform of cellphones. The original cellphone was introduced in the early 1980's whose primary function was the added mobility of a conventional telephone such as the Motorola DynaTAX 8000X. As the product began to mature, the device became smaller, stronger and encompassed more functionality such as texting, photo taking, music playing and other personalizations (Webdesigner Depot, 2011).

As the evolution continued, the cellphone platform naturally enveloped the personal digital assistant (PDA) market. A PDA is a handheld device mainly used as a personal information management (PIM) system where users can store contacts, notes and appointments (PCMag – PDA Definition, 2012). These newer cellphones that encompassed the functions of a PDA were coined as smartphones (versus conventional phones defined as feature phones or 'dumb' phones). An agreed upon definition of smartphone (and feature phones) does not yet exist; however, the main characteristics of a smartphone includes functions of a PIM system, mobile connectivity, voice calling and a platform conducive to support third party applications (PCMag – Smartphone Definition, 2012).

Most feature phones contain the same functionality, but the main difference from smartphones is their lack of a platform that runs third party applications. Many of the feature phones contain a proprietary platform with static features/functions. That is, the feature phone had a fixed set of software and it was not conducive to install/upgrade new apps. In the late 90's, RIM produced a line of pagers which allowed for wireless internet, enterprise email and various organizer utilities. The first BlackBerry device provided a product that allowed for mobile productivity by including features such as a physical keyboard, organizers, web access among other things (BerryReview, 2009). The new devices set a catalyst to bring evolution to the cellphone and smartphone market. It is not until the introduction of downloadable/installable applications were these devices considered smartphones.

Concurrent with the evolution of smartphones, there have been many developments in the online shopping landscape. With the introduction of the internet in 1990, various new applications were developed in order to utilize the connectivity. Netscape introduced a browser in 1994 which enabled secure online transactions, and Amazon and eBay were established in 1995 to capitalize the online transactions. In 1999, Napster software allowed users to transfer peer-to-peer files, which helped online industry to secure profits (InstantShift, 2010).

In October 2001, Apple introduced a hard-drive based mobile music player called the iPod, and also launched iTunes which allowed users to purchase music, television shows, movies, books, etc. (Ipod History, 2011). In July 2008, Apple introduced the App Store, a few months prior to the introduction of their new iPhone with the compatible operating system (OS) – iOS. On the first day of the establishment of the Apple app store on July 11, 2008, the store contained 500 apps with approximately 25% portion of free apps (Distimo, 2012). Analysts suggested that the establishment of the app store was a strategic move by Apple to fill a niche in the market and to differentiate itself from their rivals in the market at the time, Palm Treos and BlackBerry products (Blue Ocean Strategy, 2012). These products established at the time, however, were static in their features since there was no market for installable applications.

Lastly, the growing proliferation in social media, connectivity and advancement in information technology is adding to the popularity and demand for apps. Mobile devices have become a platform for dynamic context as opposed to the static, pre-installed content. This development has seen large social media companies such as Facebook, Twitter developing apps on the various platforms (VisionMobile – Clash of Ecosystems, 2011). Recently, large banks have also begun developing apps so their clients are able to keep connected with their finances. The continuing evolution of the mobile device platform fuels the continued interests for developers to create new and novel apps. Compared to the original products, developers are now able to exploit new features such as cameras, lights, touchscreens and GPS features.

With the convergence of these technologies and the solidification of the mobile platform industry, Google also became interested in the market. By expanding into this mobile platform, Google intended to increase their installed base for their ad-based revenue business model. In 2005, Google purchased Android Inc. which developed the Android platform. In order to build an ecosystem that could rival that of the Apple infrastructure (i.e. mature platform, product line and online storefront), Google established the Open Handset Alliance (OHA) which consisted of mobile device manufacturers, software developers and mobile operators. To support this partnership among the various agents, the source code for the Android platform was available to all members. With the source code open to all members and app developers, the Android Market Place contains more variety than Apple (VisionMobile – Open Governance Index, 2011). Android apps do not face an approval process and allows for apps designed to interact directly with the Android OS. The source code of the Apple iOS is closed and they maintain an approval process which limits the variety of apps compatible with their OS (Appcelerator, 2011, 2012).

In order to keep pace with the rising popularity of apps and the smartphone market, BlackBerry and Microsoft both established their app stores in 2009. However, both markets have not seen as high growth as compared to their Apple and Android counterparts.

Comparing the two main platforms, two distinct strategies emerge which have benefitted their market position and growth. The Apple App store was first established in July 2008 starting with only 500 apps. The steady stream of compatible devices complementing the store grew to approximately 303,000 apps in January of 2011. The Android Market was established in October of 2008 positioned as an open-sourced platform for developers to explore. The market features a large proportion of free apps (approximately 67% on Android and 37% on Apple). The number of apps on the app market grew quickly reaching 20,000 apps in about 450 days. In the two months from January 2011 to March 2011, the number of apps on the Android Market grew from approximately 151,000 apps to 204,000 apps. In the same period, apps in the Apple App Store grew from 303,000 to 331,000 apps (Figure 2). The growth can be attributed to various factors such as lower registration costs, no approval process and more content freedom.

2.2 Primary Components and Platform

Analyzing the data of smartphone OS market share and growth of apps, it is evident that the incompatible platforms are converging towards two providers: Apple iOS and Android OS whereas the BlackBerry OS is falling behind (Figure 3). It should be noted that the Android lags behind Apple in the overall mobile OS market share 42.8% to 39.61% in November 2011[2].

Hardware is the physical component in the system. It is a device that allows the users to interact with the platform and apps developed. With the growing phenomenon of mobility and portability, the growth of mobile platforms has increased steadily. Discussed briefly above, hardware for mobile apps/computing can be accomplished on various devices including: smart/cellphones, netbooks, tablets, etc. Much of the research on two-sided markets focus on the idea of openness which is the rationale of the number of sides an organization undertakes. For instance, Apple and RIM both produce their own device that supports their platform. Apple produces a line of smartphones, tablets and portable media players that support iOS and facilitate the use of apps.

[2] Android is the market leader in mobile OS in the smartphone market but the Apple OS continues to lead in the overall mobile OS market since they possess a more diverse product line; Apple continues to have a stronghold in the tablet and portable media player (iPods) market which utilizes their mobile OS.

In contrast, Google does not produce its own devices (or very limited) that support their OS. Devices that support their platform comes from various third party agents; the most notable manufacturers being Samsung, Motorola and HTC (Figure 4). The Android ecosystem is highly fragmented such that the installed base is actually made up of a wide assortment of devices, manufacturers and OS versions. A survey conducted by OpenSignalMaps found that from 61,389 devices, there were 3,997 distinct devices across 599 distinct brands[3]. Similar trend of fragmentation also exists among the versions of Android OS installed (OpenSignalMaps, 2012).

The Android platform uses strict standards for all devices being labelled Android-compatible to minimize the fragmentation; however, being an open-sourced platform, manufacturers are free to modify the provide source code. This reinforces the fragmentation but it also results in a staggered product introduction cycle. New Android devices continuously enter the market from the various manufacturers. Apple devices exhibit a much less continuous stream of introductions since they control their manufacturing. Clearly, more unique Android devices enter the market at a quicker rate compared to the Apple platform.

No definitive set of characteristics exists that defines a smartphone. Broadly, the paper will continue to use the term smartphone to define devices embodying the following properties:

1. Voice-to-voice capabilities and other telephone communication capabilities such as dialing, speakers, text messaging, etc

[3] Some of the distinct devices are due to the installation of custom ROMs (Read Only Memory) which are synonymous to a modified OS for the device.

2. Personal Information Management (PIM) which embodies the features of the previous PDA devices.
3. Connectivity to the internet through data plans and/or Wi-Fi hotspots.
4. Ability to utilize and be receptive to 3rd party applications

The set of properties is not an exhaustive list but provides a base understanding of the capabilities of a smartphone versus a feature phone (PCMag – Smartphone Definition, 2012). Note that the properties avoid physical characteristics of the devices since many of the technical specifications can vary greatly.

2.3 Complementary Components

As of November 2011, there are 4 major app platforms which account for approximately 930,000 apps. The apps stores are: Apple App Store (510,412), Android Market (330,845), BlackBerry App World (50,015) and Windows Marketplace (40,000). The app market is currently in a state of rapid growth; however, much of the growth has been from the Apple and Android platform.

The apps markets are currently competing to establish a larger installed base, and thus the annual revenue may not be a good indicator of market structure. Instead, the number of applications available in each platform, the number of annual or monthly downloaded apps can provide more accurate delineation of the market structure. The number of cumulative downloads as of November 2011 are 15 billion, 4.5 billion and 1 billion for Apple, Android and BlackBerry respectively (Table 1). Note that the figures of apps will include the items such as ebooks and media that are available on the various app storefronts. These items can be downloaded onto the various mobile platforms but require much less development costs and less interaction with the end-user. For instance, BlackBerry App World contains a high number of 'themes' that provide customization but provides little outside of aesthetics; as of Nov 2010, App World had over 15,000 apps but approximately 3,800 consisted of themes (McInnes – BlackBerryCool, 2011).

Looking at the structure of the entire platform, the majority of apps on any platform is developed by third party groups. There are examples of hardware manufacturers developing applications but those applications fill particular niches rather than appeal to the masses. Comparing the two main app storefronts, clear differences emerge in how the platform manages their applications. For instance, the Apple App Store heavily controls the applications developed for their devices. Apple apps must go through approvals which subject the applications to strict guidelines. The Android Market takes a passive approach in their governance allowing for a wider range of subject matter to be published. Under the Android Market, it is possible to develop applications with rather trivial functions or even the presence of adult content. VisionMobile suggests this passive approach aligns with supporting the ad revenue side of Google's operations (VisionMobile – Open Governance Index, 2011).

An interesting issue emerges on the types of application that can be developed on each platform stem from the openness of the source code. The iOS is developed under a closed source code approach while the Android is open. Since the Android source code is open, developers have a larger breadth of functions they can access. For instance, on the list of most popular apps on Android of all time include apps that can change the layout of the OS, 'kill'/manage tasks and processes, interact with key settings of the OS, etc (TechCrunch, 2010). Examples of these apps are Root Explorer (Filer Manager), Advanced Task Manager, Beautiful Widgets, SetCPU for Root Users, etc. These types of apps are far less apparent on their Apple counterparts. Evidently, applications are not compatible across the platforms which force developers to develop applications on multiple platforms should they want to appeal to both markets.

Asides from applications being incompatible across platforms, applications and components can also be incompatible across devices/brands. Even though most applications are developed by 3rd part groups, some applications are being developed by the respective hardware manufacturers. Concentrating on the Android Market, Samsung, which manufactures a range of device utilizing the Android OS, also develop applications specific to their product lines. Leveraging off their network of products, Samsung has begun to develop applications that are compatible only with their own devices allowing users to enhance the connectivity of their products (e.g. controlling their DVD players, televisions, etc. via their smartphone).

In early 2012, to coincide with their launch of the Samsung Galaxy Note, Samsung partnered with the developers of Angry Birds, Rovio, to supply the game on their Galaxy Note for free (which also included a special stage exclusively on Samsung devices). Following the same strategy, an app formerly only available on the iOS platform, FlipBoard, has worked with Samsung to provide the application on Android. The partnership provided users of the new Samsung Galaxy S3 to have exclusive rights to the application for the first month of introduction (Sadewo – Android Authority, 2012). Ultimately, users who choose to utilize Android through Samsung products would benefit from these extra perks but at the same time, incur higher costs to switch out of their brand.

However, much of the device-specific switching costs can be seen through the fragmentation of the Android ecosystem. As stated, the figures from OpenSignalMaps illustrated the volume of unique manufacturers, devices and OS versions within the platform (OpenSignalMaps, 2012). This level of fragmentation coupled with manufacturers' effort to differentiation the stock Android OS[4] has led to the varying compatibility towards certain apps. For instance, the popular ability of installing custom ROMs which are modified Android OS requires the user to 'root' their phone[5]. Rooting is the process of granting administrative privileges to the user (Rose – PC World, 2011). The complexity of rooting a phone can vary since it is dependent upon the technical specifications of the device, the degree of differentiation applied by the manufacturer, the stock version of the OS, etc. Certain devices can be rooted using a single app and other requires a lengthier process. As well, since the custom ROMs are outside the realm of the Android Market, their compatibility across devices also varies (PC World – Rooting, CyanogenMod – Devices, 2012). The varying ability to root and customize specific phones supports the existence of device-specific apps.

A simpler example can be attributed to physical accessories of smartphones such as battery packs and carrying cases where they are designed to fit perfectly with specific models. The smartphone system contains a plethora of other accessories such as carrying

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[4] Stock Android OS refers to the operating system installed on the given device by the manufacturer.

[5] The most popular custom ROM to date, CyanogenMod, has accumulated approximately 3 million users as of August 2012 (CyanogenMod – Stats, 2012).

cases, screen protectors, batteries, etc. which can be unique to each individual device. In particular to carrying cases, most devices (even within the same brand) very in design causing tight fit cases to be incompatible outside that device. VisionMobile states that the phone accessories market to have been $32 billion in 2011. By 2018, the market is estimated to be worth $84.6 billion globally (GIA via Kim – Gigaom, 2011). To simplify the effects of these components on switching costs, the brand-specific switching costs will be categorized with the device-specific switching costs.

2.4 Consumers

Evidently, the market is comprised of consumers with various preferences which affect their adoption decision. Price is a major factor which affects a consumer's decision to adopt a platform and to invest in the complementary components. Naturally, consumers download more free apps than paid apps. A report from Distimo on December 2010 shows that on Apple, daily downloads of the top 300 free apps total to over 3 million whereas the top 300 paid apps only generated approximately 350,000 downloads. This trend of consumer behaviour being highly skewed to free apps is consistent across all platforms; however, the trend is most noticeable on the Android platform (Malik – Gigaom, 2009).

The trend towards free apps supports the description of apps to embody the properties of simplicity, cheapness and instant gratification (Economist, October 2011). PinchMedia finds that app usage diminishes at an exponential rate where app usage can decrease 80% to 90% after 5 days. This result can be seen across all price points. Even though games are the most popular category, only news (mainly sports) and social media apps attract users on a daily basis (148apps.biz, AppBrain, 2012; PinchMedia, 2009).

This level of instant gratification of apps can be seen through the results of a conducted survey. A Nielsen survey found that 59% of app users reorganized apps for easy access and 56% of users delete unhelpful apps. As well, 62% of the users deleted unhelpful apps within the first 2 weeks. It can be suggested that there is a certain level of experimenting of apps by users; however, most users stated that many obtained exposure on new apps through browsing the app store (49%) and by family/friends (34%). Lastly, a major factor that influences a user from downloading/purchasing an app is the ratings and reviews it receives (PEW/Nielsen, September 2010).

It is clear consumers benefit from a strong network when utilizing apps due to the externalities. Analyzing the Apple and Android platform, both have lively ratings/reviews of apps to assist this process. However, the Android platform exhibits a much more skewed distribution of rating activity. The top 30 apps have approximately 11,000 to 20,000 ratings on the Android market versus around 6,000 ratings for apps on the Apple App Store. However, the subsequent 210 apps, those apps have significantly smaller number of ratings on Android (few hundred per app) whereas the same grouping of apps for Apple remains relatively consistent with 2,000 to 6,000 ratings according to Mobilewalla (Gigaom, 2011). This leads to a narrow exposure of popular apps for Android users. Nielsen Smartphone Analytics has reported that the top 50 apps represent 60% of the app usage. More specifically, the top 10 apps represent 43% of the app usage (Kim – Gigaom, 2011).

It is not difficult to conceive that the smaller set of popular apps can hinder the demand and exposure of others apps and accessories. VisionMobile suggests there is interdependence among components in the ecosystem that help strengthen overall demand.

Their report states that strong sales in smartphones and apps can help drive the sales of accessories (VisionMobile – Mega Trends 2012).

Finally, Hunch.com conducted a survey among 15,818 Hunch users to gather important insight on the demographic differences between the various mobile OS users. The survey was conducted for the period of Q2 2011. Most striking, the survey suggests Android users were 31% more likely to be later adopters, 57% more likely to favour full features over design and 100% more likely to be PC users. In contrast, Apple users were 50% more likely to be early adopters, 122% more likely to favour design over full features and 100% more likely to be Mac users (Hunch, 2011). Some clear differences between the two groups of users emerge based upon their preferences.

Chapter 3
Review of Literature

3.1 Switching Costs

The main area of research embodied in the mobile platform system relates to switching costs. The research in the field of switching costs has extended in the past 3 decades to coincide with the changing environment it is present. The environment of research have started from single products (exogenous switching costs) industries to currently, system products where goods are interconnected and utility is dependent upon each other (endogenous switching costs).

3.1.1 Exogenous Switching Costs

In 1987, Klemperer produced a series of papers relating to the effects of switching costs on the competitiveness in markets. A large body of subsequent research in the area of switching costs leverages the body of work done by Klemperer. The model used by Klemperer and various others in this area of research is a Hotelling Line which represents a distribution of consumers in the markets and their relative preferences towards two competing firms. In the general structure, consumers are situated along the Hotelling line where the two competing firms are situated on opposite ends of the line segment. If we assume that both firms are producing comparable products, all things being equal, consumers along the line segment will tend to purchase from the firm closest to them. Conceptually, as consumers are further away from a firm (or the representation of the product), the product is less appealing and so, there is a larger transport costs to move the consumer to that product; ultimately, that transportation cost would yield a larger negative effect on utility. The point in which a typical consumer is indifferent between both firms can be seen as an indifference point in the market (ceteris paribus, the indifference point would be the midpoint between the two firms). Such indifference point would provide insight on the market share of the product. Consumers to the left of the indifference point would choose one firm and the consumers to the right would choose the other firm. The use of this model to analyze the competition in a market can be attributed to von Weizsäcker (1984). The first in the series of Klemperer's papers is a review of the findings of von Weizsäcker work, *The Cost of Substitution* (1984).

In this landmark paper by von Weizsäcker, he suggests that the existence of switching costs associated with the products, the market is more competitive in the future. Consider that each time a consumer decides to switch suppliers, he will incur switching costs. It seems illogical for a consumer to switch products continuously over time since each switch will incur additional costs. So, von Weizsäcker argues for the long-run that the consumer must make a decision based upon their expected future preferences and tastes. This emphasis on their future preferences is a trade-off on their present period preferences. Since consumer decisions are forward looking, suppliers are bounded by this constraint to treat their consumers well by providing competitive prices (markets). If a firm indicates an attitude of exploitation of locked-in consumers, consumers will factor that into their decision and purchase from the other supplier. He suggests that a firm's reputation is the mechanism that will enforce the fair treatment of their consumers. That is to say that if a firm exploits profit from locked-in customers in a particular period, new consumers (and consumers who may be still willing to switch) will not willingly incur high switching costs from that supplier knowing that they will be exploited. Consumers willingly incur high switching costs if they know future markets will be competitive (or are subject to relative constant prices).

Klemperer's (1987a) first paper in his series builds upon von Weizsäcker work and suggests a result contrary to von Weizsäcker. Klemperer shows that the presence of switching costs makes markets more competitive in the first period and less competitive in the second period. That is, he suggests that suppliers will exploit locked-in consumers since they would be able to exert monopoly power over those consumers. His results differ from von Weizsäcker's findings because Klemperer does not assume the presence of a reputational constraint which forces suppliers to hold prices constant. So, a supplier's success in the second period is the ability to exploit profit from their locked-in consumers. This implies that the key success factor for a supplier is obtaining large market share in the first period. This leads to intense competition in the first period and less competition in the second which is a contrast to the results of von Weizsäcker. Klemperer (1987b) extends his findings further suggesting that the monopoly in the second period does not necessarily benefit suppliers. As stated, the ability to exploit profit from locked-in consumers requires intense competition in the first period. It is ambiguous how the profit from period two compares with the costs of competition in period one. It is plausible that such intense competition erodes the profits in period two, effectively creating a zero profit scenario across the time horizon.

Klemperer (1987b) and Farrell and Shapiro (1988) build upon this area by analyzing the relationship between the two suppliers within this switching cost construct. The presence of switching costs associated with the goods make firms' price similar to a collusive behaviour in the market (Klemperer 1987b). Switching costs makes the demand of goods more inelastic; if a consumer is locked into a supplier, a small price cut from a competing supplier provides little incentive to switch since they are committed. With this established, both suppliers in the market would decide to hold prices instead of cutting to induce switching. Without switching costs, suppliers may have an incentive to cut prices to build up their market share and increase profits. But with switching costs, the market is segregated into sub-markets where each supplier exert their market power within their own market, similar to an equilibrium established with collusive behaviour (Klemperer 1987b).

These results were subjected to a constraint where the population of consumers is fixed and suppliers are competing for the same consumers in each period. Farrell and Shapiro (1988) consider the effect of infusion of another set of unattached consumers (consumers who have not previously committed to a supplier). They coined the term 'overlapping generation' to refer to the inter-temporal differences among the consumers point of decision. The model considers a supplier who is the incumbent where they are present in the first period and accumulated market share in the period. In the second period, a new set of consumers enter the market with the possibility of an entry of another supplier ("new entrant"). The results mirror the results of Klemperer which suggests that under switching costs, a market can be segregated into sub-markets. If switching costs are significant and the incumbent possesses a sizable market share from period 1, the incumbent would not price goods to prevent the existence of the new entrant. It can be more profitable for the incumbent to focus on exploiting the existing consumers than competing for the entire market. This reinforces the idea that suppliers are less competitive in the second period with switching costs. The large market-share coupled with switching costs allows suppliers to be less diligent in pursuing the new consumers (Farrell and Shapiro 1988). This fat cat effect of suppliers can be seen in research from Tirole and Fudenberg (1984) on the under/over investment in expansion or Christensen's view towards innovation. This identification of attached/unattached and sub-market competition set the base for research relating to consumer price discrimination.

Several economists have explored mechanisms where suppliers can use to profitably induce switching or the ability to price discriminate against attached and unattached consumers. Chen (1997) investigates suppliers who use discount coupons for price discrimination compared to outcomes without price discrimination. He finds that firms that engage in price discrimination are worse off and deadweight loss exists with switching costs. This reinforces earlier research done by Caminal and Matutes (1990). They suggest that the use of coupons lessens the competitiveness in the market and using price commitment strengthens it. This view is consistent with von Weizsäcker's model where suppliers must commit to prices forced upon by the reputational effect which leads to more competitive pricing in future periods. The importance of considering coupons and price commitment is the interpretation of whether switching costs is exogenous or endogenous. In the model by Klemperer, the consumer incur the switching costs once they decide upon the supplier and in the perspective of the supplier, switching costs are exogenous. However, under the models of Chen, Caminal and Matutes, suppliers can, to some extent, control the amount of switching costs that they or the consumer will burden (Chen 1997, Caminal and Matutes 1990).

3.1.2 Application of Switching Costs in Antitrust Cases

Before engaging in reviewing the more recent literature exploring endogenous switching costs, it is important to understand the context which legitimizes the ongoing exploration of this area of research. The importance of analyzing switching costs and the structure of the market in recent years stem from several highly publicized antitrust cases before the courts. The most notable involved Eastman Kodak Co. and Image Technical Services (ITS). Kodak Co. were manufacturers of photocopier equipment and providers of services. ITS was also a provider of support services upon the Kodak photocopier equipment. The equipment market is considered the primary market where the services were coined the aftermarket. This structure of the market is a practical representation of the models explored by Klemperer and others. ITS argued that Kodak was conducting anticompetitive behaviour by restricting the availability of parts required to compete in the aftermarket. As expected and echoed by the research, it is not unexpected a supplier will choose to exert a degree of market power in their sub-market with the presence of switching costs. However, the ongoing debate and the bane of some economists is to assess the degree of market power a supplier has in the aftermarket. A review by Shapiro and Teece on the case outlines the issues that need to be investigated (1994).

The review suggests the importance of being able to assess market power and the effect it may have in the competitiveness of the market. As stated above, the question lies in whether the market power in the aftermarket is justified for the intense competition in the primary market. Lastly, as viewed from a different perspective, the authors state that the lack of market power in the primary market does not imply a lack of market power in the aftermarket. Kodak attempted to justify their competitive strategy by stating that the primary market was indeed competitive. The significance of this fact is similar to the line of argument by von Weizsäcker where they suggest that should the supplier attempt to exert market power in the aftermarket, consumers would explore the alternative and the reputational effect will ultimately hurt a supplier's ability to exploit for profit. This reputational effect would force Kodak to remain 'competitive' in the aftermarket. Eventually, the courts concluded that Kodak was imploring anticompetitive behaviour since the reputational effect would only hold should consumer exhibit forward looking tendencies with perfect (or significant amount) of information. In the end, this case does stress the importance of analyzing switching costs and its effect in the competitiveness of the market.

3.1.3 Endogenous Switching Costs and Price Discrimination

Borenstein, MacKie-Mason and Netz (2000) used a model similar to Klemperer with overlapping generations. The findings from the model were consistent with Klemperer. They found that regardless of the market structure in the primary market, suppliers will choose to exert their market power in the aftermarket. The stylized model of switching cost casts a shadow over the questions raised by Shapiro and Teece on the matter of antitrust and competition in a primary-aftermarket structure and the need for better assessment of market power in the aftermarket. The emergences of these results stem from a fundamental assumption Borenstein et al has made in their model. von Weizsäcker has argued that reputational effects will keep future prices constant since exploiting consumers in the current period will deter potential (unattached) consumers to adopting. However, Borenstein et al echo the sentiments of the courts in the Kodak case where while they agree with the idea of the reputational effect, the magnitude of such effect is largely unknown. They argue that such effect may not provide sufficient incentives for suppliers to maintain competitive prices which allows for the results in their model.

Thus far, the literature explored focused upon exogenous switching costs and endogenous switching costs burdened by the supplier. Marinoso (2001) considers switching costs in the construct of the primary and aftermarket. The primary market consists of sales of printers and the aftermarket involves the sales of compatible ink cartridges. Evidently, both these types of goods are complements (or system goods where both goods need to be used together) and with incompatibility serving as a mechanism to induce switching costs, suppliers can implore pricing strategies to discriminate between attached and unattached consumers. In the context of printers, the model looks at a consumer who requires one cartridge per printer. In the second period when the cartridge becomes obsolete, the consumer is face with the decision to purchase another cartridge from the same supplier or upgrade the entire system. Thus, the switching costs are decided by the incompatibility of cartridges such that should the consumer choose to change suppliers, the consumer would need to purchase a printer as well as a replacement cartridge. The sequential purchasing of the component of the system allows the suppliers to discriminate in the second period against existing and new consumers. Previous research has shown that it may be difficult to price discriminate when new consumers enter the market (or are face with an adoption decision) but under the model of Marinoso, the supplier can use bundling techniques to discriminate. New consumers require both components (i.e. a printer and a cartridge) whereby existing consumers only require a replacement cartridge. Thus, a supplier pricing strategy would depend on the price of their bundle versus the price of their competitor's complement. This enables the exploitation of locked-in consumers as well as attracting new consumers in the market. It should be noted that Marinoso explores the facet of compatibility and suggests firms' preference towards compatible components. This is contrast to the typical thought of exploiting locked-in consumers through incompatibility as seen in the Kodak case; Marinoso supports the claim that the competition in the primary market drains the ability to leverage market power in the aftermarket (Haucap 2003).

A fundamental assumption made by most of these models is the homogeneity of the consumers. The literature discussed above factor in the diversity of the consumer population through the *distance costs* a given consumer would incur depending on the firm he chooses. However, this neglects the different behaviours that may occur from the diversity of consumers. The different distance costs can change the outcome of the decision but it does not change how the consumer behaves. Extension from these models from subsequent researchers attempt to account for the differences in preferences and behaviour. The results from models hinging upon long term commitment and reputational effects focus upon foresighted consumers. That is, a consumer makes an adoption decision and rationally incurs switching costs considering the expected value/costs of the decision. As Klemperer, Shapiro and Farrell infer that these foresighted consumers make the current demand inelastic since the effect of current period price cuts are diluted in a longer time frame; ultimately, firms earn zero profit over the period. Miao introduces the concept of myopic consumers who make decisions based upon single period benefits. He justifies the existence of myopic consumers through empirical findings and suggests that a myopic heuristic may be used by some consumers to simplify complex decision making. More importantly, he finds that with the present of myopic consumers in the population, the traditional thought of zero profit might not come to fruition. Other models assume that myopic consumers are protected by foresighted consumers; however, Miao shows that since consumers behave differently, suppliers can identify and exploit them which produce profits. Furthermore, even if suppliers possess different production efficiencies, the presence of myopic consumers provide an incentive for less efficient suppliers to remain in the market. The result is consistent with the court's position in the Kodak cases stressing the imperfect information of consumers allows for the monopoly position in their respective aftermarkets. However, it is important to note that policy implications are once again ambiguous. Like other before who suggests welfare effects are sensitive to certain parameters, Miao cautions that policy to standardize technology (weakening switching costs in the aftermarket) may not necessarily protect myopic consumers (Miao 2010). Xue et al. (2006) present a model analyzing switching costs and customer retention with myopic consumers in the market. They also stress the fact that myopic consumers in the market can produce less than optimal social outcomes in terms of firm's investment in technology. However, they do not take a policy approach to remedy the issue. they suggests that firms can bridge the gap between myopic and foresighted consumers which would lead to investment in technology and ultimately, consumers would be more willing to accept higher switching costs associated with the benefits (Xue, et al. 2006).

Doganoglu (2010) considered the assumption where consumers do indeed switch suppliers over periods. Previous models have shown that consumers do not switch at equilibrium which is argued by a certain degree of foresighted consumers and switching cost barriers. However, Doganoglu questioned the assumptions of high switching costs and homogeneous products such that consumer preferences may change over time or their true preferences would be revealed in subsequent periods. By considering this, he shows that contrast to traditional views, a low level of switching costs can in fact produce lower prices than compared with markets without switching costs. Ultimately, the magnitude of the switching costs (where high switching costs are prohibitive to switch and low switching costs are not) forces the suppliers to consider whether it can exploit their consumers or more profitable to retain their consumer base to future periods. These results prove important to policy makers as it questions the traditional views of switching costs softening competition and echoes the warnings of Miao suggesting that this generalized oversight of switching costs may produce policies and strategies that end up hurting the consumers or subsets of them.

3.2 Consumer Technological Adoption

There are various factors which affect a consumer's choice towards adopting a particular technology or good. Evidently, switching costs plays a large factor in a consumer's choice; however, the benefits from improved products and network externalities are also a major factor.

3.2.1 Replacement Framework

Joseph Guiltinan (2010) has compiled a review of recent literature relating to the consumer adoption and investment decisions. Summarizing the consumer decision process from Ellison and Fudenberg (2000), they note that a consumer's replacement decision is a process which involves various factors that balance the utility of the current good versus the replacement good subject to the costs between the two choices. Using this framework, a consumer chooses the option which yields the greatest utility less the associated costs across the time horizon. Ellison and Fudenberg (2000) used this framework to model the decision process of consumers in the software industry. Consumer software usually does not involve heavy investment towards maintenance/repair and/or even resale. Dynamic models after the Ellison and Fudenberg framework considered aspects of repair and maintenance to determine optimal replacement (Hartman 2001, Wang 2002). By considering these properties, the net price of replacement (i.e. price of new good less trade-in value) becomes an endogenous function. The model in this paper will closer resemble the framework of Ellison and Fudenberg since it will assume the salvage value of smartphones to be exogenous.

It should be noted that others have investigated replacement decisions through more psychological factors. Many of these empirical studies have found some consumers consider technological obsolescence as well as functional obsolescence. That is, a consumer may replace a good to remain in sync with current technology and not necessarily due to failed performance (Cooper 2004, Bayfus 1991). van Nes and Cramer (2008) considers different properties of a product which can trigger a consumer's "need arousal" when it comes to new products (Guiltinan 2010).

The model in the paper does not consider those psychological factors which 'arouse' a consumer to replace a product. Others have considered the psychological factor of loss aversion. Okada (2006) considers loss aversion to be the disutility which results from removing oneself from an attached good and/or the indirect costs of replacing the good. This concept is loosely applied to the model where a consumer can lose an opportunity given a wrong decision in an uncertainty market (Guiltinan 2010). However, this loss/risk aversion in the model considers much less of the psychological factors as described.

3.2.2 Incompatibility and Standard Wars

Another aspect of consumer adoption revolves around standards and compatibility. Much of the research in this area revolves around the concept of switching and policy implications around competition. From the section above, without an agreed upon standard, the incompatibility creates switching costs for the user. A large body of work has been done around the concept of 'Standard Wars' (Stango 2004) or the idea of competing standards. As stated, since incompatibility creates barriers in switching, consumers are usually hesitant to adopt in a market with competing standards. The uncertainty in which standard would be dominant usually has a negative impact on welfare since consumers are slow to adopt the underlining technology which curb innovation and productivity gains. The policy implications in this area focus on a balance of trying to allow standards to compete but also to remove the uncertainty by moving towards a dominant technology.

This leads into the research of Klemperer where firms compete heavily in the first period to obtain the installed base to reap the benefits of the locked-in effect in the future period. However, another effect that must be considered is this hesitancy of consumers. Consider the example of the QWERTY keyboard layout. Before the QWERTY layout was deemed the dominant layout in the 1970s, consumers were hesitant to invest in the typewriting technology fearing adoption of an inferior standard (Farrell and Saloner 1986). Adoption of the technology required investment in physical typewriters as well as education of users which would constitute as the switching costs. It was only after the QWERTY layout was considered the dominant layout did firms adopt the technology for mass usage (David 1985, Foray 1997).

The model in this paper does not directly address the hesitancy of consumers adopting a particular standard (i.e. Apple versus Android). On a market view, it is assumed that both platforms can coincide in the same environment similar to the market structure of video game consoles. However, it is possible to address this effect in the section considering uncertainty in the market.

3.2.3 Network Effects and Externalities

The smartphone market clearly fits into the construct of a two-sided market encompassing network effects and externalities. Considering the OS as the platform, it brings together primary devices and complementing components. The network externality can be seen from either side of the platform such that greater usage of devices and/or components benefits the users in the platform (Economides 1996). Likewise, across both sides of the platform, greater consumption of one side benefits the other as well which is a key to a two-sided market construct. As the install base of smartphone users increase, it strengthens the demand of components and vice versa. Rysman (2009) provides a good overview of the two-sided market construct.

Through the context of the QWERTY example, one can understand the benefits of broad adoption of a technology or standard. Namely, as the number of users of the technology increases, there will be a greater network effect and positive externalities. When the QWERTY keyboard became the dominant standard, typewriters manufacturers only needed to produce one type of keyboard opposed to carrying multiple types. Users only needed to specialize in this particular layout allowing them to become more proficient towards the one layout but also, provide a larger pool of candidates for firms who required typewriting skills. This larger population of QWERTY-skilled workers and the certainty of the standard, firms invested into the typewriting technology which helped improved productivity (David 1985, Foray 1997). Evidently, there are many benefits in this scenario and other similar two-sided market constructs.

However, it should be noted that these benefits also lead to increased switching costs. Regardless of the existence of a 'better' keyboard layout, its productivity gains may not justify the costs of changing layouts. Even though the Dvorak keyboard layout was considered the superior layout, after the adoption of QWERTY, the cost would prove too much to switch. As described, a change in layout would require changes from firms who employ users and users must retrain (Foray 1997). This locked-in effect largely drives the results of past research suggesting firms compete heavier in current periods for future profits.

Many of the research models with the assumption that the market will be willing to make a decision between two firms with uncertainty opposed to waiting until a dominant standard emerges. This assumption can be justified where two (or more) standards can coexist in the market such that consumers do not run the risk of being 'stranded' onto an inferior technology. Farrell and Saloner (1986) consider the scenario where competition of two standards is not so seamless. They suggest that adoption is a gradual process such that consumers experience different levels of welfare at different time points of adoption. In particular, since much of the benefits of the network effects occur after mass adoption, many of the early adopters do not experience those benefits in the early stages. With this transition period, Farrell and Saloner examined the effects of competing firms trying to curb adoption through preannouncements and pricing strategies and its effect towards innovation.

In tune with the two-sided market construct, Church and Gandal (1993) consider the complement side of the network effect in analyzing the software in the computer market. Since the complement market is such an integral aspect of the system good, they suggest the characteristic of those complementary products can lead to over-adoption towards the underlying technology.

The model in the paper mirrors the Church and Gandal construct such that a heavier emphasis is placed on the interaction of components in the adoption of smartphones. However, the robustness of interpretation on the parameters of consumer preferences allows for interpretation of early adopters and late adopters in the market.

Chapter 4
The Model

The structure of the smartphone platform industry conforms to the configuration of "system goods." System goods involve a primary good and a set of complementary goods which are purchased sequentially after the adoption of a primary good. The complementary goods are purchased to obtain additional utility from the primary good and the set of complementary goods is considered horizontally differentiated products (Marinoso 2001). In the context of the smartphone platform, the apps are horizontally differentiated such that the quality of a particular app on a given platform is similar.

4.1 Assumptions

Consider a Bertrand duopoly market structure in which two smartphone platforms are available: Apple iOS (by Apple) and Android (by Google). Due to natural deterioration and planned obsolescence, the primary hardware device lasts only for two periods. Being a single device provider, Apple is assumed to introduce new hardware devices every other period. On the other hand, hardware devices utilizing the Android platform are assumed to be introduced every period. The size of the quality improvement of new devices at the end of the second period is assumed to be the same, but the Android devices introduced at the end of the first period have more features than the older model[6] (including Apple device introduced at the start of the first period). In addition, the older Android device will be subject to deterioration through use and through the obsolescence due to introduction of a new device. The shorter

[6] The subjectivity of metrics barred a direct comparison of Apple to Android devices; however, the comparison of individual features/metrics does not show a large variation which would support a unanimous superior technology.

product introduction cycle of the Android platform quickens the rate of perceived planned obsolescence which in turns devalues the existing products in the series (Figure 5). Utaka (2006) suggests that products in a market with shorter product introductions (or more frequent introductions) deliver a higher rate of perceived planned obsolescence to consumers. The price of the devices on both platforms is identical in period 1 and the price of the newly introduced Android device in period 2 will be lower by the salvage value of the existing device. We naturally assume that there is a market available that allows a consumer to sell its existing Android device. However, to simplify the case, the second hand market will not exist prior to the first period so that the set of consumer choices will remain between a newly introduced Apple or Android device.

Each of the OS platforms is designed using a different computing language such that the apps are not directly compatible across platforms. While the same app title may exist on both (or multiple) platforms in practice, they are developed separately as independent apps. We assume the prices of paid apps are the same for each type of platform. Secondly, the set of components will exhibit marginal diminishing returns on utility. However, for simplicity, the model does not introduce deterioration of the set of components. The lack of deterioration of components will not change the main observations from the model unless deterioration is rather large. So, it will be assumed that complement components have a longer life than the hardware such that consumers face the incursion of switching costs.

In addition, there will be two types of components in the market: device-specific apps and platform-specific apps. Device-specific apps would be complementary goods only compatible with a particular device, whereas the platform-specific goods will be compatible across all devices under the particular platform. The device-specific goods would be analogous to hardware-related components such as the customization of the OS through ROMs and the physical accessories such as carrying cases and battery packs. The platform-specific components would be the software/content consumers use that are only compatible with the given platform. Typically, these components would be apps for gaming, social networking, news updates, etc.

Given a fixed price of hardware, consumers choose only one type of platform (or hardware device) between Apple and Android. The primary component is ex ante homogenous but ex post heterogeneous, and thus consumers will be faced with incompatible platforms, different learning curves and redundant features if they adopt both technologies. Consumers are uncommitted and are not affected by other externalities of the platforms. Thus, a consumer's adoption decision will be made independently from external factors[7]. This assumption can be justified by focusing on the set of consumers who are making their first purchase decision in the mobile platform environment. If this assumption is not made, the structure of system goods can present other effects which influence a consumer's adoption decision. For instance, since the model is presented such that complement components (i.e. apps) are incompatible, they serve as a means to lock-in consumers and deter them from switching to another platform. It is possible that a consumer has already indirectly adopted a platform through a vertically differentiated primary component (e.g.

[7] A particular externality that will be excluded from the model is the effect of network externalities of other consumers on the choice maker. There are various papers which state the presence of an effect from these direct network externalities towards undecided consumers. The proximity of the effect to the decision maker (e.g. users who are kinship versus strangers) also affects the equilibrium choice. The assumption of small consumers will encompass a relatively uniform distributed market share.

mobile media players, mobile tablets, personal computers) which presents a higher switching cost than compared to an uncommitted consumer. That is, a consumer who has purchased a MacBook laptop (Apple) is more likely to adopt an Apple smartphone opposed to an Android (Hunch, 2011). So, the refinement of the consumer set reduces these locked-in effects in the consumer adoption decision. So, the model will consider the purchasing behaviour of a consumer who has already adopted the Android device in period 1.

4.2 Consumer Adoption Model

Consumers receive utility both from the primary component, the device, and from the set of complementary goods, apps. Even though the discussion of complementary goods could also include accessories, the term apps will be used as a generalized term. There are two types of apps i = {m, n} and the allocation between the set of components is analogous to a Hotelling model. The consumer's position along the line will indicate the allocation between the two app types. We will assume that the m-type components are incompatible with other primary devices within the same platform and n-type components are compatible across the same platform creating device-specific and platform-specific apps respectively. The consumer will begin with an Android device and his decision would be to decide the amount of investment and allocation of apps.

The allocation of m and n type components would be affected by the consumer's preferences towards hardware (θ) and software dimensions (γ). Once the Android device in purchased, a consumer determines the level of investment (or spending) on m and n subject to their preferences. A representative consumer's utility in period 1 can be expressed as:

$$U(m,n) = \theta f(m) + \gamma g(n) - p_m m - p_n n - 2c\sqrt{(\gamma m - \theta n)^2} \qquad (1)$$

where f(m) and g(n) represent the utility functions of m and n-type components respectively and p_i is the price of each type of components. The preference parameters are bounded $0 \leq \theta \leq 1$ and $0 \leq \gamma \leq 1$ where values approaching 1 would indicate high preferences/affinity and values approaching 0 would indicate low preferences/affinity. The fifth term in equation (1), a penalty factor $2c\sqrt{(\gamma m - \theta n)^2}$, serves to enforce the consumer's purchase decisions by penalizing consumers who deviate from their preferred allocation. Consumers who exhibit s small distance between θ and γ would require a more balanced allocation than a consumer with a larger deviating hardware-software preference. Lastly, c is a parameter that represents the strength of the interdependence between the two types of apps.

The penalty factor is analogous to the comparison of the actual component ratio to the ideal component ratio as defined by the purchase of {m, n} and the consumer preferences {θ, γ} respectively. In particular, the penalty factor mirrors the comparison of the deviation between $\frac{m}{n}$ and $\frac{\theta}{\gamma}$. Broadly, the penalty a consumer faces will be determined by absolute distance between the two ratios. In actuality, the penalty factor encompasses three elements: (i) deviation from actual to ideal ratio; (ii) magnitude of consumer preferences and; (iii) magnitude of consumer behaviour. See Appendix A.1 for the derivation of the penalty factor. It should be noted that it is assumed $\theta + \gamma \neq 0$ and $m + n \neq 0$.

4.3 One Period Model

As a base case scenario, consider a myopic consumer's decision in a single period model. Assuming Cobb-Douglas utility functions for the components m and n where $\theta f(m) = \theta W_m m^{\alpha}$ and $\gamma g(n) = \gamma W_n n^{\beta}$, the consumer's utility function is

$$U(m,n) = \theta W_m m^\alpha + \gamma W_n n^\beta - p_m m - p_n n - 2c\sqrt{(\gamma m - \theta n)^2} \quad \text{(2a)}$$

where α and β are both less than 1 due to diminishing returns. The base quality of the apps is denoted by W_i and a constant c is added to determine the magnitude of the penalty factor towards the consumer.

Non-Binding Penalty Behaviour This behaviour occurs when the consumer incurs a penalty for his allocation; that is, his actual allocation will deviate from his preferred. The utility maximization conditions are

$$\alpha\theta W_m m^{\alpha-1} - p_m - \frac{2\gamma c(\gamma m - \theta n)}{\sqrt{(\gamma m - \theta n)^2}} = 0 \quad \text{(3a)}$$

$$\beta\gamma W_n n^{\beta-1} - p_n - \frac{2\theta c(\theta n - \gamma m)}{\sqrt{(\gamma m - \theta n)^2}} = 0 \quad \text{(4a)}$$

The optimality conditions are defined only if $\gamma m - \theta n \neq 0$. If $\gamma m - \theta n = 0$, the function becomes indeterminate. When $\gamma m - \theta n \neq 0$, it follows that $\sqrt{(\gamma m - \theta n)^2} = \pm(\gamma m - \theta n)$. From (3a) and (4a), the consumer will maximize his utility in the current period with the allocation:

$$(m^*, n^*) = \begin{cases} \left(\left[\frac{\alpha\theta W_m}{p_m - 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{\beta\gamma W_n}{p_n + 2\theta c}\right]^{\frac{1}{1-\beta}} \right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = -(\gamma m - \theta n) \quad \text{(5a)} \\ \left(\left[\frac{\alpha\theta W_m}{p_m + 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{\beta\gamma W_n}{p_n - 2\theta c}\right]^{\frac{1}{1-\beta}} \right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = (\gamma m - \theta n) \quad \text{(6a)} \end{cases}$$

Binding Penalty Behaviour When $\gamma m - \theta n = 0$, the consumer incurs no penalty and invests in apps as dictated by his preferences. Once the condition is satisfied, the relation $m = \frac{\theta}{\gamma} n$ holds. This produces the utility function:

$$U\left(\frac{\theta}{\gamma}n, n\right) = \theta W_m \left[\frac{\theta}{\gamma}n\right]^\alpha + \gamma W_n n^\beta - p_m \left[\frac{\theta}{\gamma}n\right] - p_n n \quad \text{(2b)}$$

From the updated utility function (2b) and analogous to previous analysis, the consumer will optimize their component allocation by satisfying:

$$\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m n^{\alpha-1} + \gamma\beta W_n n^{\beta-1} - p_m\frac{\theta}{\gamma} - p_n = 0 \qquad (3b)$$

For simplicity, if it is assumed that α = β, (3b) can be reduced to $n^* = \left[\frac{\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n\beta}{p_m\frac{\theta}{\gamma}+p_n}\right]^{\frac{1}{1-\alpha}}$ and it follows $m^* = \frac{\theta}{\gamma}n^*$ ➔ $m^* = \frac{\theta}{\gamma}\left[\frac{\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n\beta}{p_m\frac{\theta}{\gamma}+p_n}\right]^{\frac{1}{1-\alpha}}$

The parameters α and β dictates the degree of diminishing utility of the app types. From market observations, it would suggest that n-type apps (e.g. games) would exhibit higher diminishing returns. As the difference between α and β increase, the penalty-binding case would become dominant over a larger range favouring the m-type apps. However, even though this is the case, the general observations with the condition α = β would still be valid.

Summary of Consumer Behaviour To summarize the effects of the penalty factor on the utility function, the consumer has the following demand for components:

$$(m^*, n^*) = \begin{cases} \left(\left[\frac{\alpha\theta W_m}{p_m - 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{\beta\gamma W_n}{p_n + 2\theta c}\right]^{\frac{1}{1-\beta}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = -(\gamma m - \theta n) \\ \left(\frac{\theta}{\gamma}\left[\frac{\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n\beta}{p_m\frac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}}, \left[\frac{\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n\beta}{p_m\frac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = 0 \\ \left(\left[\frac{\alpha\theta W_m}{p_m + 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{\beta\gamma W_n}{p_n - 2\theta c}\right]^{\frac{1}{1-\beta}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = (\gamma m - \theta n) \end{cases}$$

The three cases formulated denote the scenarios when the consumer invests in greater, less or exact number of a particular app-type as defined by his preferences. Figure 6 illustrates the cases with respect to $\omega = \frac{W_n}{W_m}$ where ω represents the relative quality between n and m type apps. With equal values of preferences, as the quality of m and n-type apps divert, the consumer would deviate from his preferred allocation and purchase more of the higher quality app all else being equal.

More specifically, the range in which a case is dominant varies with the values of the parameters. The magnitude of these cases determines the sensitivity of the parameters with respect to consumer behaviour. For instance, consumers with strong preferences toward both types of apps would exhibit a larger penalty-binding range than consumers with weak preferences. This smaller range for consumer with weak preferences implies they are more sensitive to the quality and price of the apps.

These results are justified in that it captures the inertia of the consumer. The consumers with high preference values possess greater inertia in embracing the technology such that they would be less sensitive to minor utility changes. In contrast, consumers exhibiting less inertia would be less enthusiastic about adopting and thus, would be more critical of the values of utility and price. Figure 8 depicts the cases with consumer preferences $\theta = \gamma = 0.1$. Under these low preferences, the penalty-binding case is superior only when $0.93 \leq \omega \leq 1.07$. In figure 7, this band for which the penalty-binding case is superior is significantly larger when consumer preferences $\theta = \gamma = 0.9$ ($0.52 \leq \omega \leq 1.92$).

Implications and Observations It is important to understand the magnitude of each case with the consumer (and market) since the consumer's purchasing behaviour varies within them. For instance, consumers in the penalty-binding case exhibit positively correlated demand functions for apps. Formally, the demand of n in the penalty-binding case is an increasing function with respect to W_m (and W_n). As the quality of apps increase, the demand of n increases as well. Since $m = \frac{\theta}{\gamma} n$ holds in this case, the demand of m-type apps increase with n. However, this positive correlation between m* and n* is not consistently carried over into the non-binding cases. Through the formulation of these cases, the demand of m and n are independent of W_n and W_m respectively. This independence implies that increasing W_m or W_n would not affect the consumer's purchase pattern of the other component. Likewise, the changes in prices have similar effects. These results are consistent with the conventional thought that $\frac{dm}{dW_m} > 0$ and $\frac{dm}{dp_m} < 0$ (and consistent with n-type).

However, it is interesting to note how large the effects are in relation to each other. Depending on the values of W_m and p_m, it may be more efficient for a firm to increase utility or decrease prices. That is, the magnitude of W_m and p_m would determine whether $\left|\frac{dm}{dW_m}\right|$ is greater than $\left|\frac{dm}{dp_m}\right|$. Figure 9 shows the demand of m in the non-binding case as a function of W_m and p_m. As seen in the figure, as p_m increases, the demand of m becomes less sensitive with changes in W_m. Likewise, with large values of W_m, the demand of m becomes less sensitive with change in p_m with all other factors being equal. The relation is consistent in the penalty-binding case as well. Figure 10 show the demand of m under the penalty-binding case which encompasses the same relations.

Lastly, analyzing preferences under the same framework provides like results. From the non-binding penalty case where the consumer invests in more m-type apps than he prefers, the following relations exist:

$$\frac{\partial m^*}{\partial \theta} > 0 \qquad \text{and} \qquad \frac{\partial n^*}{\partial \theta} > 0$$

$$\frac{\partial m^*}{\partial \gamma} < 0 \qquad \text{and} \qquad \frac{\partial n^*}{\partial \gamma} > 0$$

These relations suggest that as a consumer is favouring the investment towards m-type apps, if θ increases, this reinforces the consumer's behaviour and he would continue his investment towards m-type apps. The strengthened demand of m also drives up the demand of n. However, when γ increases, the demand of the two app types are no longer positive correlated. The utility of increasing the demand of n does not compensate for the magnitude of the penalty in that the demand of m would ultimately decrease.

Note that the observations of the varying correlation of the demands of the app types are simplified for discussion. The change in qualities, prices and preferences have been assumed to be minor in that consumers did not transition to another case. For instance, from the above scenario, increasing γ would drive the demand of m-type apps down. However, there may be a point where the consumers transitions into the penalty-binding case where the demands are positively correlated.

Firms must be aware of the different cases and the magnitude of the effects. Clearly, as individual components in the system, strengthening the position of a specific piece (i.e.

improving quality, cutting price, increasing preference) will produce beneficial results. However, with respect towards the system, blindly supporting a specific component can be harmful towards a complementing piece and/or towards the system as a whole. As stated, the correlation between the two demand functions can vary and so, strengthening one can lead to adverse results to the other. Depending on the strategy a manufacturer wishes to undertake, they need to be aware of the correlation and how sensitive the parameters are such that a consumer may transition into another case.

As well, asides from the magnitude and correlation within the cases, the rate of change differs also varies. For instance, from the scenario above, increasing θ can raise the demand for both types of apps but the increase towards m would be greater than towards n. Likewise, the increase of γ would increase n greater than the reduction in m. Ultimately, depending on the strategy of the firms, they must carefully balance these countervailing effects.

4.4 Two-Period Model with Switching Costs

Now, consider a two-period model with a rational consumer who considers the switching costs across the useful life of the device. In the second period, a new device will be introduced by a competing manufacturing where n-type apps are compatible but the consumer must replace his set of m. At the end of period 1, the consumer has an option of keeping his existing device or upgrading to a newly introduced device. If the consumer chooses to stay with his current device, his utility function is:

$$U_{Stay} = \delta\theta V_S + \theta W_m m^{\alpha} + \gamma W_n n^{\beta} - 2c\sqrt{(\gamma m - \theta n)^2}$$

where V_s is the utility from the device from the previous period and the values of m and n would be identical to the set from period 1 since he does not need to replace them.

If the consumer chooses to upgrade to the new device, he would gain the utility from the new device subject to the costs and from his set of components. Notice that the consumer has additional costs from upgrading the device and replacing his set of m which is incompatible. The utility function under this scenario is:

$$U_{Upgrade} = \theta V_U + \theta W_m {m_2}^{\alpha} + \gamma W_n n^{\beta} - 2c\sqrt{(\gamma m - \theta n)^2} - p_m m_2 - p_u$$

where V_u and p_u is the utility of the new device from period 2 and the associated costs respectively. The consumer would retain the same set of n-type apps in period 2 but would be required to purchase a new set of m-type apps denoted as m_2.

It will be assumed that the prices remain static across the periods and the base utility remains the same. Generally, the consumer would upgrade his device in the second period if his set of apps do not form a prohibitive level of switching cost and the device introduced is superior to the old device. Namely, the utility of the new device less price and switching costs is superior to the old device. A formal argument will be made by considering the decisions a consumer will make.

4.4.1.1 Non-Upgrading Consumers

Consider that a consumer makes the decision at the start of period 1 that he will not upgrade to the new device since the improvements are not significant and/or the level of improvements do not justify its costs. So, considering that the set of apps do not face any depreciation, the consumer would invests in m and n such that he will derive utility from the components across two periods while incurring the cost once. Evidently, given no depreciation, the consumer will purchase all the components in period 1 to derive utility across the maximum length of the two periods.

Similar to the myopic case, the consumer would invest in apps which maximize his utility. However, the foresighted consumer would plan across the two periods which derives a function which is an aggregated form of a single-period function with the corresponding function in section 4.4. The foresighted consumer would maximize the following utility function:

$$U_N(m,n) = 2\theta W_m m^\alpha + 2\gamma W_n n^\beta - p_m m - p_n n - 4c\sqrt{(\gamma m - \theta n)^2}$$

Similar to the utility function for myopic consumers, the function for foresighted consumers also exhibit different cases. Note that the function is based on static yields of the apps. If the parameters relating to the utility of apps change, the utility function needs to be modified. For instance, consider if the utility of m apps increase in the second period associated with the new device, the term $2\theta W_m m^\alpha$ can be modified to $(2+\Delta)\theta W_m m^\alpha$ where Δ reflects the level of improvement. For simplicity, consider the static formulation without loss of generality. The demand of apps for non-upgrading consumers is:

$$(m^*,n^*) = \begin{cases} \left(\left[\dfrac{2\alpha\theta W_m}{p_m - 4\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\dfrac{2\beta\gamma W_n}{p_n + 4\theta c}\right]^{\frac{1}{1-\beta}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = -(\gamma m - \theta n) \\ \left(\dfrac{\theta}{\gamma}\left[\dfrac{2\left(\dfrac{\theta^{1+\alpha}}{\gamma^\alpha}\alpha W_m + \gamma W_n \beta\right)}{p_m \dfrac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}}, \left[\dfrac{2\left(\dfrac{\theta^{1+\alpha}}{\gamma^\alpha}\alpha W_m + \gamma W_n \beta\right)}{p_m \dfrac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = 0 \\ \left(\left[\dfrac{2\alpha\theta W_m}{p_m + 4\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\dfrac{2\beta\gamma W_n}{p_n - 4\theta c}\right]^{\frac{1}{1-\beta}}\right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = (\gamma m - \theta n) \end{cases}$$

Again, it should be noted that the assumption α = β is made without loss of generality.

4.4.1.2 Upgrading Consumers

Consider a consumer who has made the decision to upgrade to the new device in the second period. Since the set of m are incompatible across devices, the consumer would only derive utility from them when the specific device is employed. After the upgrade, the consumer must invest in m for the new device. Considering the ideal position of the consumer in period 2, the utility function coinciding with that position is

$$U_U(m,n) = 2\theta W_m m^{\alpha} + 2\gamma W_n n^{\beta} - 2p_m m - p_n n - 4c\sqrt{(\gamma m - \theta n)^2}$$

The utility function above implies that for the two periods, in order to maintain the optimal set of components, the consumer must invest in the set of m twice in the two periods. Similarly, it is assumed the utility of the apps do not change for simplicity without loss of generality. So, the demand of apps for the upgrading consumer is:

$$(m^*, n^*) = \begin{cases} \left(\left[\frac{2\alpha\theta W_m}{p_m - 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{2\beta\gamma W_n}{p_n + 4\theta c}\right]^{\frac{1}{1-\beta}} \right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = -(\gamma m - \theta n) \\ \left(\frac{\theta}{\gamma}\left[\frac{2\left(\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n \beta\right)}{2p_m \frac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}}, \left[\frac{2\left(\frac{\theta^{1+\alpha}}{\gamma^{\alpha}}\alpha W_m + \gamma W_n \beta\right)}{2p_m \frac{\theta}{\gamma} + p_n}\right]^{\frac{1}{1-\alpha}} \right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = 0 \\ \left(\left[\frac{2\alpha\theta W_m}{p_m + 2\gamma c}\right]^{\frac{1}{1-\alpha}}, \left[\frac{2\beta\gamma W_n}{p_n - 4\theta c}\right]^{\frac{1}{1-\beta}} \right) & \text{if } \sqrt{(\gamma m - \theta n)^2} = (\gamma m - \theta n) \end{cases}$$

4.4.1.3 Comparison of Non-Upgrading and Upgrading Consumers

Intuitively, it is not difficult to follow that the foresighted consumer invests in a larger set of apps since the costs of those components will be amortized across a longer timeframe than their myopic counterparts. That is, since the consumer considers the longer timeframe, each component provides a larger marginal utility than the myopic case. However, since the myopic consumer optimizes his allocation per each period, it follows that the foresighted consumer over-invests in components in the first period. Ultimately, the foresighted consumer would make up the difference in the second period where he experiences the utility of the components without incurring additional costs. This brief assessment reveals the source of the switching costs a consumer will face. The foresighted consumer optimizes his utility by over-investing in period 1 to reap the benefits in period 2. Thus, this over-investment creates a commitment whereby a consumer is locked into their original decision or realizes the loss.

Comparison of the two foresighted consumer cases yields similar results. If the consumer decides to upgrade his device in the second period, the utility derived from m-type apps would only be present if the consumer re-invests. Thus, the utility from m components are considered as single period investments which would provide lower marginal utility. This leads the consumer to purchase a smaller set of m which can also suppress the demand of n depending on the magnitude of the penalty factor. For instance, a strong penalty factor would suppress the demand of n should the demand of m decrease. Ultimately for the incompatibility, the result $m_N^* > m_U^*$ and $n_N^* \geq n_U^*$ emerges implying the non-upgrading consumer invests in the most apps.

Since it is established that the source of switching costs stem from the incompatibility of the apps and the potential loss of utility, a consumer would only choose to upgrade should the new device compensates for the loss of utility. More formally, a foresighted consumer would be indifferent between upgrading and not upgrading when

$$U_N(m_N^*, n_N^*) + \theta V_N(1-\delta) = U_U(m_U^*, n_U^*) + \theta V_U - p_U$$

where N and U indicate non-upgrading and upgrading consumers respectively, V_i is the utility of the primary device and p_u is the price of upgrading. For simplicity, the price of upgrading includes the price of the device less the salvage value of the previous device and m components. As well, $0 \leq \delta \leq 1$ represents a discount on the value of the older device which suggests a declining utility of the device through usage and/or natural rate of obsolescence. From this formulation, this would imply that when $V_U > \frac{U_N - U_U + \theta V_N(1-\delta) + p_u}{\theta}$, the foresighted consumer would be better off aligning his investment patterns towards the goal of upgrading devices in period 2.

So, this value of V_u reinforces the results above that the cost of switching is determined by the net improvement with respect to the older device and the loss of utility from the allocation of m and n. Notice that the costs of replacing the set of m which are incompatible are embedded in the term, $U_N - U_U$, accounting for the lost utility. With the assumption that the consumer has perfect information on deciding on whether to upgrade or not at the beginning of the first period, the outcome from the foresighted consumer would always be superior to that of the myopic consumer.

Implications and Observations Naturally, the implications from the one-period model is also applicable in this case. Specifically, the correlation of the demand still varies between the cases and the sensitivity of the consumer is dependent upon their preferences. However, the two-period model allows firms to possibly segment the market based on preferences. Consumers committed to a decision would align their purchasing behaviour to support that scenario. Namely, consumers in the market would possess different levels of switching which can lead to some being locked in towards a device and/or platform. New entrants in the market can better cater products to a segment in which they can compete.

The value of V_u allows manufacturers introducing new products to gauge the level of improvement necessary which can induce upgrade or even platform switching. The presence of the preference parameters in the model suggests new entrants can capitalize on consumers with low inertia such that the positioning of their product and/or apps, market segments may be available for profit.

4.5 Extensions to the Model

The two extensions that would be discussed are the effects of information uncertainty towards the consumer decision and the option of platform switching.

4.5.1 Two-Period Model with Uncertainty

Consider the case where consumers are uncertain about the parameters V_u and p_u which suggests that the uncertainty stems from the new device introduction. It would be assumed that the app quality and price will remain constant across the two periods. The latter assumption is justified since due to the large number of apps and the fragmentation of devices, variation in those parameters are far less apparent in the short term.

Utility Across Periods It is evident to see that committing to a non-upgrading decision exposes the consumer to the greatest risk since it requires the greatest level of commitment.

In order to achieve optimal utility across two periods, the consumer over-invests in m and n apps in period 1 to reap the benefits from period 2. A consumer who is foresighted would be inclined to purchase more components in general than their myopic counterparts. Non-upgrading consumer would invest the most in components, followed by the upgrading and myopic consumer. Note that the comparison is based upon total component (m and n).

Depending on the given set of parameters, the consumer may face negative utility in period 1 in order to achieve the gains from period 2. It can be shown mathematically that the non-upgrading consumer experiences the lowest satisfaction through the first period utility function. However, since it is established through the myopic consumer case that he is at the optimal one-period maximum, it follows that increasing investment in components will lead to a sub-optimal result. This sub-optimal first period is the effect that leads to consumers locked into their decision. In the previous section, consumers are willing to take these first-period sub-optimal positions since they are certain of the benefits in period 2; however, if the parameters in period 2 are uncertain, a consumer must balance the decision of switching with their risk exposure.

Ultimately, the myopic consumer experiences the most balanced utility production across the two periods, followed by the foresighted, upgrading consumer and the foresighted, non-upgrading consumer absent of whether they have made the correct investment decision. Depending upon the amount of information and certainty, a consumer may consider not exposing themselves to such risk.

Cost of an Erroneous Decision In a two-period model, a consumer would be presented with an opportunity to change their original decision. That is, a consumer may wish to change their decision should the newly introduced device no meet their original expectations. Formally, if $V_U > \frac{U_N - U_U + \theta V_N(1-\delta) + p_u}{\theta}$ the consumer is better off upgrading and act accordingly. However, given uncertainty, should the value of V_u not satisfy this condition, the consumer may choose to revise his decision. Since the utility of the new device will be revealed in period 2, the consumer can revise his decision now under perfect information.

Consider first the case of the foresighted consumer who decides to upgrade in the first period and revises his decision to remain with the current device in period 2. Since the consumer was foresighted, he would have invested in a level of m and n which exceeds his one-period optimal amount. With no deterioration in the set of m and n, this consumer would optimize his allocation subject to his new decision by making no further investment in m and n. The consumer who switches from an upgrading decision to a non-upgrading decision would simply retain the same device and apps for the next period.

Now, consider the case where the consumer is switching his decision from a non-upgrading decision to an upgrading decision. This case is less straight forward since the consumer would be required to purchase a new set of m should he now choose to upgrade. However, the amount of m the consumer purchases does not necessarily imply that he would purchase the same amount from the previous period. The problem becomes solving the second-period utility function with n given. The amount of n from period 1 would coincide with the optimal n from the foresighted, non-upgrading consumer problem which could be situated in of the cases. In period 2, the case the consumer resides in may differ from period 1. If in the second period, the consumer is in the Non-binding penalty cases, the optimal amount of m would be the same as the myopic consumer such that

$$m^* = \left[\frac{\alpha\theta W_m}{p_m \pm 2\gamma c}\right]^{\frac{1}{1-\alpha}}$$

If the consumer is in the penalty-binding case, the amount of m would be $m^* = \frac{\theta}{\gamma} n$ since the value of n is given.

From the above formulation, the effect on utility of changing decisions can be derived. Utility from the original decision can be compared to the utility from the updated decision. This provides a threshold in the deviation between the actual and expected device improvement in which the consumer would revise his decision. That is, the device improvement must be significantly larger in order to warrant changing his decision from non-upgrading to upgrading. Thus, in a market with uncertainty, switching costs will present itself in the allocation of m and n, as well as in the correction of decision.

More formally, consider the difference in utility between the decision to staying and changing decisions (i.e. Utility of the non-upgrader versus the utility of the non-upgrader to upgrader decision; and vice versa):

(5a) Utility $_{\text{Non-Upgrading}}$ – Utility $_{\text{Non-Upgrading to Upgrading}}$ and likewise,

(5b) Utility $_{\text{Upgrading}}$ – Utility $_{\text{Upgrading to Non-Upgrading}}$

Since it was shown that with perfect information, the utility of the foresighted consumer derives the highest utility if the decision is correct. Thus, switching decisions provides less utility and the above differences are positive which constitute as the additional cost of switching. Depending on the parameters and the consumer preferences, the difference between (5a) and (5b) can be positive or negative. It may be that a consumer who starts with the non-upgrading decision faces larger switching costs than the consumer who anticipates upgrading or vice versa.

The result may be ambiguous but consumers who begin in an upgrading position tend to incur a lower switching cost from correcting their decision. When the quality of both types of apps is similar, the range in which the upgrading position incurs larger switching costs is smaller than the non-upgrading position. As well, the magnitude of the costs tends to be lower for the upgrading position.

Figure 13 represent the difference between a non-upgrading position costs versus an upgrading position; that is, (5a) – (5b). When the value is positive, the cost of switching for the non-upgrading consumer is greater and vice versa. Figure 13a illustrates the scenario where $W_m = W_n = 3$ and figure 13b on the right illustrates $W_m = W_n = 10$. The figures are consistent with the suggestion that the upgrading position possess the smaller range and lower magnitude.

When the quality of the apps begin to diverge, the about results become more dominating. Figure 14a represent the difference between (4a) and (4b) where $W_m = 5$ and $W_n = 3$ and figure 14b possess values of $W_m = 3$ and $W_n = 10$. Notice that the area in which the function is negative has reduced and the magnitude has dampened.

With the uncertainty in the net quality of the new device, most consumers would take on less risk from beginning with the upgrading decision. This observation can help understand the lower retention rate in this market construct. The uncertainty reduces the appeal of heavy investment in apps which ultimately, reduces switching costs with respect to devices and platforms.

Implications The model is formulated such that the utility of apps is largely independent from the utility of the platform. The consumer assesses the net utility of the device only to determine whether or not to upgrade in the next period. However, after that assessment is made, the consumer's allocation of m and n is determined by the utility of the apps. That is, if the consumer deems the next period product to embody a large improvement which warrants upgrading devices in the next period, he will act accordingly (i.e. m* and n* as per the foresighted, upgrading consumer if $V_U > \frac{U_N - U_U + \theta V_N(1-\delta) + p_u}{\theta}$). The values of m* and n* in this scenario will not change even if V_u continues to increase. Ultimately, the uncertainty in the next period device, V_u, only affects the condition $V_U > \frac{U_N - U_U + \theta V_N(1-\delta) + p_u}{\theta}$.

So with this independence between the components and device, a consumer decision on the investment of m and n would be bounded by myopic case and the foresighted, non-upgrading case. Once again, it suggests that the myopic consumer invests in the smallest set of components but faces the most balance utility across the two periods with the least risk exposure. The foresighted consumer, who chooses to forego upgrading, invests the heaviest in components with the largest deviation in utility and greatest exposure to lost utility. Thus, depending on the risk characteristics of the consumer and the certainty over the assessment of the new device, a consumer may choose any of the 3 possible outcomes.

It should be noted that a rational consumer may indeed choose invests in m and n based upon a myopic mentality. With uncertainty, the myopic choice provides the greatest flexibility, albeit at the expense of maximizing utility. As well, it is consistent with the other economists who suggests that consumers who face complex decisions may opt to choose the myopic decision (i.e. maximize over 1 period at a time) in order to simplify the decision.

4.5.2 Platform Adoption and Switching

Consider the presence of a competing platform where all apps are incompatible across platforms.

Platform Adoption In general, given that products are comparable and all things being equal, consumers will gravitate to the platform that better align to their preferences. Namely, consumers with high values of θ would adopt platforms where the quality of m-type apps are greater all things being equal. This suggests that the market can exhibit a degree of segmentation across consumer preferences since manufacturers can identify different sub-markets by behaviour. With varying quality of devices and apps across platforms, the results may be ambiguous.

Platform Switching Consumers who adopt the myopic heuristic in spending towards apps would be more susceptible towards platform switching. The reduced investment towards apps creates a lower barrier in switching platforms. Specifically, since apps are incompatible across platforms, both m and n-type apps form the basis of switching costs. Trivially in a base case if both platforms contain the same quality of components, the platform switching consumer would require a significantly better device from the competing platform to warrant switching. This trivial observation is interesting to note since it is consistent with theoretical frameworks and market observations. Consumers are usually worse off switching between competing platforms due to the transition costs. Consumers would need to replace incompatible components as well as re-educate themselves. This higher switching costs associated with a platform supports the view slower adoption of a standard in a market where dominancy is unclear as outlined in section 3.2.2.

However, comparing the device introduction cycles sheds insight on how switching costs can vary between platforms in the same market. Consider a platform where a new device is introduced every other period. In the framework of the two period model, the consumer would face the decision to either switch platforms altogether in the second period or remain with the device through two periods. There is no option to upgrade devices in the second period. Notice that under this construct, the consumer would not face the risk that a new device in the second period would devalue his existing device. Without the intermediate device introduction and the associated devaluation, consumers would be more willing to behave like the foresighted, non-upgrading consumer (as per section 4.4.1.1) which results in greater barriers to switch platforms and devices.

This provides a possible factor explaining the UBS findings on the retention rates between Apple and Android platforms. The model suggests that the more controlled device introduction from the Apple platform leads consumers to incur a higher level of switching costs. The fragmented system of Android creates larger uncertainty which dampens the demand of apps which lowers switching costs towards the platform and specific devices.

A more dynamic analysis of platform switching is not examined in this paper; however, the analysis would follow the same constructs. That is, the consumer possesses the decision options as stated above as well as the option of available on the competing platform. The functional forms of the demand of components on the competing firms would be similar to those derived in chapter 4.

Chapter 5
Discussion and Conclusion

Throughout the paper, the model discussed two types of apps: device-specific and platform-specific. It was assumed that platform-specific apps are compatible across devices and device-specific apps were incompatible across devices. Both types are incompatible across platforms. This is analogous to game apps and hardware/device customization apps. This distinction is important since the level of switching costs can vary when transitioning to different devices. For instance, the switching costs of changing devices would be more heavily affected by the set of device-specific apps whereas both types of apps will affect the decision to switch platforms.

However, the paper takes a simplified look on the varying types of components in the mobile ecosystem. It is possible to consider components that are incompatible across platforms, devices and/or manufacturers. For instance, generic games apps provide only switching costs toward platform switching whereas custom phone cases provide switching costs for devices and platform. One can also consider components made from specific manufacturers that only work within the manufacturer. For instance, there are various applications that are only compatible across manufacturers. Under the Apple platform, it is evident to see the interconnected network through their use of iTunes and other similar means to connect all their devices. Samsung, a manufacturer in the Android market, is employing a similar strategy where applications are available allowing their smartphones to interact with their brand of DVD players, printers and other hardware. In general, it is not difficult to consider the varying effects of these components on switching and loyalty towards platforms, devices and manufacturers.

On average, surveys have shown that consumers under Apple exhibit a high level of loyalty towards the brand such that for their next replacement, they do not intend to switch platforms. A survey conducted by UBS suggests that approximately 89% of the respondents for Apple users were expected to stay within their platform provider. In contrast, Android users exhibited must less loyalty towards their brand. The survey suggests that only 55% of the respondents for Android indicated that they intended to remain with the Android platform (Hughes – Apple Insider, 2011).

More in-depth analysis shows that the brand loyalty is even less pronounced towards the hardware manufacturers. Since Android devices are created by various 3rd party manufacturers, a consumer committed towards the Android platform has many different options available to choose from. The major manufacturers providing devices for Android include: Samsung, HTC, Motorola, LG, etc. In the survey conducted by UBS, only Samsung and HTC exhibited positive consumer retention; the manufacturer's brand retention was 39% and 28% for HTC and Samsung respectively. Finally, it should be noted that the survey suggests that 31% of current Android users intend to switch to Apple in their next replacement period. UBS Research suggests the strong brand loyalty towards Apple stems from a robust ecosystem that serves as a means to burden users with a higher level of switching costs (Hughes – Apple Insider, 2011). The Apple ecosystem presents various primary component goods such as smartphones, tablets, mobile media players, etc. which are all centralized through their specific user account.

Considering the Android ecosystem specifically, it is evident that the level of loyalty among their users is much lower compared to the Apple platform and compared to the actual devices. These observations are consistent with scenarios from the model. The Android ecosystem is analogous to the model above such that homogeneous products (asides from an increase in performance which implies a higher utility) are introduced every period by different manufacturers. It is assumed the products are relatively homogeneous suggesting that the manufacturers continue to compete for the same group of consumers and not establishing a new market segment. From the model, several observations can be made that is applicable to the Android ecosystem as defined.

Firstly, the presence of an upgrading decision in the next period leads consumers to consider the utility of the alternatives in the next period. With perfect information, it is assumed that a consumer can gauge the threshold in which he would be better off upgrading devices in the next period. It can be observed that when a consumer decides to upgrade devices in the next period, he will invest less towards components. More specifically, the consumer would invest in less compatible and incompatible components across the period if he decides to change devices in the next period. Intuitively, it is quite trivial to observe that a consumer would invest in a smaller set of incompatible components should he decide to switch devices in the next period. Since the components are incompatible, the components become obsolete with the new device and a new set must be purchased. The lower marginal utility derived from these components lead to the reduced demand. However, the model also presents an interesting dynamic with the compatible components. The interdependence of the demand of both types of components can lead to a situation whereby reduced demand of one type of component also reduces the demand of the other. As formulated above and most evident in the penalty-binding cases, when investment decision is highly influenced by preferences, reduced demand of one type of component can dampen the demand of the other. Ultimately, in the perspective of the firms (i.e. Android Platform/Google) where increasing switching costs may be beneficial, doing so may not be as simple as to increase demand of a single line of components (i.e. apps). This strengthens the thought that the mobile device market has truly evolved to a system good whereby utility must be balanced across multiple components.

A report compiled by Vision Mobile describes support this view of system goods in the mobile market. The success of the platform embodies a 'core business' and a 'complement'. A business case of Research in Motion and the BlackBerry can be examined through the framework of the model to justify their inability to retain consumers and their continuing distress. Asides from the growing set of primary devices (e.g. cellphones, tablets, personal computers, televisions, etc.), Vision Mobile considers accessories to be a major factor of differentiation for manufacturers and platforms in this market space. The importance of accessories comes from the addition of revenue streams and explored in the model, the incursion of switching costs to the consumer. The Apple ecosystem is filled with various accessory lines connected through a unique connector. This allows them to strengthen their hold on their consumers and build upon their network. In comparison, the Android platform lacks such a developed market of accessories that benefit their hold on their users.

Vision Mobile assessed the accessories market for mobile devices in 2011 to be US$32 billion. This figure is estimated to grow towards US$84.6 billion globally by 2018 (GIA via Kim – Gigaom, 2011). Currently on the market, there is an assortment of components which enhances the features, performance and the appearance of devices. With respect to applications, there is a growing market for gamepads, styluses and other peripheral components. Global Industry Analyst (GIA) Inc. suggests the strong sales of smartphones in recent period have helped strengthen the sales of mobile phone accessories. Furthermore, the breadth of features and capabilities of smartphones help drive the strong sales even more. Their research suggests that smartphone users spend on average US$60 on accessories versus US$30 for their feature phone counterparts (GIA via Kim – Gigaom, 2011). It is evident that the growing size of this market and its interdependence with the platform leads itself to further research to understand the dynamics and how consumers behave.

Secondly, it is important to observe that with uncertainty in the market, a consumer generally faces greater risk investing in more components which coincides with the non-upgrading decision. There may be cases where there is greater risk expecting to upgrading devices but the magnitude is generally not as wide compared to the first case. Typically, uncertainty would result in consumers purchasing less total components in order to allow for flexibility in the next period. This is a trivial observation which is consistent with much of the research in switching costs and standard setting. With greater uncertainty in the future periods, consumers are less willing to adopt and/or incur larger levels of switching costs.

The multiple manufacturers in the Android platform are conducive to have continuous, staggered product introduction which can create uncertainty for consumers.

Even though Google provides a common OS for all the manufacturers, the open-sourced property allow manufacturers to customize the platform to better interact with their hardware before introducing it to the market. As well, the manufacturers may also introduce varying hardware which would be dominant in the future development. For instance, with the success of the Android platform, many manufacturers in this market have been trying to differentiate themselves and provide stability (i.e. reduce uncertainty) with their subsequent devices. However, various manufacturers have begun to introduce generational products that follow a more stable introduction cycle. For instance, Samsung has introduced several generations of their Galaxy branded phones which follows a reasonable introduction schedule. As well, their devices possess unique applications that only work with their devices. Their devices contain Samsung Kies (and similarly, Kies Air) which attempts to maintain consistent interfaces/interaction with the device/platform.

Comparing the Android and Apple platform, the former does provide greater uncertainty. Due to the various manufacturers, many new innovations to hardware and/or software can introduce randomly and across various manufacturers. Since Apple is the sole producer of their devices, large innovations usually coincide with a major product launch. Ultimately, consumers who have purchased an Apple device are only faced with a decision about switching or staying with the platform (opposed to the Android consumer who must also consider upgrading devices). This can suggests that the lower uncertainty in Apple which would imply that a consumer who plans to stay with the Apple platform would invest into a larger set of components. The uncertainty in in devices does not exist for the second period and cannot lead to the effect of the dampening demand of components through the interdependence. This can partly explain the higher loyalty exhibited by Apple consumers.

Another result from the model that is consistent with observations in the market is that consumers with low preferences are more sensitive towards the parameters of the components. From the model, it is shown that small changes in the parameters of the components can lead to consumers with low preferences changing their investment behaviour. Conversely, consumers with high preferences are less sensitive towards similar changes. Intuitively, this is justified since consumers with low preferences derive less utility and thus, would be more critical to the utility yields. As described in section 4.3, consumers with high preferences are situated in a larger band in which the penalty-binding case is superior. These consumers are characterized by investing in components that fully match the ratio of their preferences. The high preferences and the interdependence of the demand support the larger range of the penalty-binding case. That is, the preference towards both hardware and software related components forces the consumer to invest in both types regardless of the utility yield within the relevant range. This is important since the demand of one component can reinforce (or dampen) the demand of another type of component. These type of consumers demand more components than consumers with lower preferences.

There can be a strong implication for manufacturers of hardware and/or software components. Clearly, if a manufacturer can gauge the magnitude of the interdependence a consumer exhibits, it is possible for a firm to drive up the demand (and thus, switching costs) through means of the complement component. As well, manufacturers of devices and their associated accessories may position themselves to discriminate across consumer preferences.

Assessing the behaviour of the preferences, an observation can be made that low preference consumers invests less in components and possess lower switching costs. These consumers may be preferable to build up a consumer base but possess unappealing purchasing behaviour for long term success of a platform and/or manufacturer. Using this model, it is possible to consider this component effect on the switching costs and loyalty between Android and Apple platform users. From the lack of standardization of accessories in the Android platform and the lack of breadth, results of the model would suggests that Android users would purchase less software related components from the weak assortment of the hardware related components.

Many of the surveys and data collected have shown that Android consumers are much less willing to spend towards investing in software components. This may partly be explained through the lack of hardware related components in the market which also in turn, support the lower switching and brand loyalty towards the Android platform and to the individual Android devices. The Apple platform possesses both software components and a variety of hardware components which can mutually support the demand of these high preference consumers. This can lead to ideal level of investment in both hardware and software components which help the Apple platform retain users. Also, as suggested, the lower uncertainty under the Apple platform likewise supports this higher level of loyalty.

Lastly, the parameter c in the penalty factor needs to be examined. The parameter c can be considered as the coefficient of interdependence of the components. Evident from the formulation, significantly large values of this parameter would lead consumers to always purchase based upon their preferences regardless of the utility yield of the components. In the extreme case of $c = 0$, the consumer would purchase each type of components independently. Note that changing the value of c only changes the amount of components purchased in the non-binding cases. That is, given a consumer is purchasing against his preferences which indicate that he experiences a better yield towards a particular component type, changing the value of c would move his allocation closer or farther away from the preferred allocation. However, a consumer who is in the penalty-binding case, minor changes of c (i.e. the consumer is still within the penalty-binding case) would not change his actual allocation.

This is important aspect to note since only when a consumer is in the penalty-dominant case can manufacturers leverage the interdependence to support the demand of another component. For instance, in the non-binding penalty cases, the utility yield of the other components does not affect the demand of the other. Consider that a manufacturer produces both types of components. Increasing the utility of m components would not change the demand of n components for non-binding consumers. However, the demand for n components will increase for consumers in the penalty-binding case. It should be noted that the converse is true such that deteriorating utility of a particular component type will also negatively impact the demand of the other component.

Extensions and Future Research The model provides a simple framework to analyze what effect various components has towards an individual's decision set and their willingness to incur switching costs. Much of the research in this area focuses upon the manufacturers/firms and their pricing decisions/strategies. This is the natural extension of the model. The model has used stylized assumptions to simplify the interpretation and results.

Namely, the model focused primarily on one platform with two staggered manufacturers and the component parameters were largely exogenous. In the context of the environment, the Android platform was the main point of focus. However, it can extend where consumers can also consider the change of a platform. In the formulation, if another platform was present with similar features (e.g. Apple), the consumer would need to consider that component types m and n would be both incompatible (and needs replacement). When considering only a device change, consumers consider only the incompatibility of m. However, this is a trivial extension where similar results would arise. That is, the presence of an additional platform creates larger uncertainties for the consumer and if the consumer values flexibility, it would dampen the demand of components which form the basis of switching costs.

More interestingly, the perspectives of the manufacturers need to be considered in this model. Firstly, considering profit, it is possible to begin to assess whether the market can be segmented/discriminated through consumer preferences. As well, this opens the discussion to whether platforms and manufacturers are truly in a competitive market segment. The model considers the dynamic aspect of switching costs such that consumers at different preferences behave differently. These behaviours produce different levels of switching costs that are not necessarily prohibitive should a competing device emerge. A holistic view of the consumers may shed insight on the market segmentation.

This further leads to the examining of which segments may be most competitive (and profitable to obtain) and how individual manufacturers compete under competitive or oligopoly environment. Similarly and briefly discussed above, it is worthy to consider the competition of components and how individual providers compete. As discussed, demand effects on other components vary depending on the case a consumer resides in. In particular to the Android ecosystem where a greater number of unique producers exist, the model can help identify how component producers interact.

The model forms a base to analyze the mobile market where switching costs is much more dynamic across the preferences of consumers. Switching costs incurred may not be prohibitive reducing the locked-in effect. As well, the interdependence towards components and the varying compatibility across devices, manufacturers and platforms add to the dynamics of switching costs.

Appendix A

A.1. Penalty Factor Formulation

The model utilizes two parameters in order to emulate heterogeneous consumers in the market. As seen in the general utility function (i), the penalty factor is $2c\sqrt{(\gamma m - \theta n)^2}$. Ultimately, the penalty factor is the mechanism which controls the consumer's allocation between m and n. Namely, the utility of m and n are not necessarily independent of each other. The consumer's preference will determine the ideal allocation of components assuming components are equivalent (the preferences suggests the balance of m and n regardless of price and utility yield). Obviously, the set of m* and n* is the consumer's actual behaviour. Since the consumer can possibly invest more or less than his preference suggest, $\sqrt{(\gamma m - \theta n)^2}$ is analogous to $|\gamma m - \theta n|$which obtains the absolute magnitude the consumer deviates from his preferences. The penalty factor compares the actual behaviour with the ideal preferences and its magnitude is determined by 3 properties: (i) Proportional Difference; (ii) Magnitude of Preferences; and (iii) Magnitude of Actual Behaviour.

Proportional Difference This property measures the difference between the ideal allocation and the actual allocation purchased by the consumer. The penalty factor in the utility function is formulated by analyzing the proportion of m the consumer purchased compared to their relative preference towards hardware; however, it should be noted that the same analysis could be done with respect to n (and software preference). So consider a consumer's investment in m* and n* which would translate to the proportion $\frac{m^*}{m^*+n^*}$ of hardware-modifying components and $\frac{n^*}{m^*+n^*}$ of software-modifying components. Similarly with preferences, $\frac{\theta}{\theta+\gamma}$ and $\frac{\gamma}{\theta+\gamma}$ indicate the ideal allocation of hardware and software-modifying components a consumer should purchase. Logically, $\sqrt{\left(\frac{\theta}{\theta+\gamma}-\frac{m^*}{m^*+n^*}\right)^2}$ measures the absolute difference between the two proportions and the penalty increases are the deviation grows.

Magnitude of Preference (MP) This property accounts for the strength of the preferences. The proportion of hardware and software measures only relative differences; however, the magnitude of the penalty factor if the consumer possesses stronger preferences. For instance, consider two cases (a) θ and γ both equal 0.1 and (b) θ and γ both equal 0.9. Both cases yield a proportion of 0.5; however, it should be expected that the consumer with greater preferences will be more resistant to deviate from their ideal allocation. In the context of the model, the greater resistance to deviate would imply the consumer incurs a larger penalty for deviating. The proportions can be expressed in the context of a Hotel Line such that the extreme points correspond to a component portfolio of 0 m (all n) to all m (0 n). Since different values of preferences can produce the same proportions, the length of the Hotel Line needs to vary with respect to the absolute values of the preferences.

Consider the preference space of θ and γ where both parameters are bounded by 0 and 1. Given a pair θ-γ in the preference space, the Hotel Line used to express the ideal proportion is analogous to a line of negative 1 slope passing through θ-γ. The line has a slope of negative 1 since the components are assumed to be equivalent. The line segment is bounded between the θ axis and the γ axis. Since every Hotel Line representation has a slope of negative 1 and passes through the point θ-γ, then as the values of preferences increase, the Hotel Line moves further away from the origin and its length increases. Ultimately, stronger preferences increase the length of the Hotel Line which accounts for magnitude of the penalty from preferences.

So, the length of the line segment can be derived using the Pythagorean Theorem since the line segment intersects θ axis and γ axis. Since the line segment has a negative 1 slope, it intersects the θ and γ axis at θ + γ.

Using the Pythagorean Theorem, the length of the Hotel Line, based on the given θ-γ is: $\mathrm{MP}^2 = (\theta + \gamma)^2 + (\theta + \gamma)^2 = 2(\theta + \gamma)^2$. Thus, $\mathrm{MP} = \sqrt{2(\theta + \gamma)^2} = \sqrt{2}(\theta + \gamma)$.

Magnitude of Behaviour (MB) This property accounts for the size of the component portfolio. It should be expected that if a consumer is incurring a penalty for his currently allocation, a larger portfolio of the same allocation should result in a greater penalty. The formulation of this effect is similar to the magnitude of preferences. Once again, consider a line passing through (m, n) with a slope of negative 1, the absolute magnitude of the size of the component portfolio can be expressed as: $\mathrm{MB}^2 = (m + n)^2 + (m + n)^2 = 2(m + n)^2$. Thus, $\mathrm{MB} = \sqrt{2(m + n)^2} = \sqrt{2}(m + n)$.

Formulation Given the form of the 3 effects, the total penalty function can be expressed as $\sqrt{\left[\frac{\theta}{\theta+\gamma} - \frac{m}{m+n}\right]^2}\sqrt{2}(\theta + \gamma)\sqrt{2}(m + n)$. Consider two additional assumptions: (i)$\theta + \gamma \neq 0$ and (ii) $m + n \neq 0$. Case (i) is justified since if $\theta + \gamma = 0$, it implies the consumer has no desire for hardware or software components and ultimately, these consumers would not enter the market. As well, the purchase of any primary device (i.e. smartphone) would include a set of hardware and software components which would imply m + n ≠ 0.

With the two additional assumptions, $\sqrt{\left[\frac{\theta}{\theta+\gamma}-\frac{m}{m+n}\right]^2}\sqrt{2}(\theta+\gamma)\sqrt{2}(m+n)$ can be expressed as:

$$\sqrt{\left[\frac{\theta}{\theta+\gamma}-\frac{m}{m+n}\right]^2 4(\theta+\gamma)^2(m+n)^2} = 2\sqrt{\left[\frac{\theta}{\theta+\gamma}-\frac{m}{m+n}\right]^2 (\theta+\gamma)^2(m+n)^2} \qquad \text{(i)}$$

Simplifying (i):

$$= 2\sqrt{\left[\frac{\theta}{\theta+\gamma}-\frac{m}{m+n}\right]^2 (\theta+\gamma)^2(m+n)^2}$$

$$= 2\sqrt{\left[\frac{\theta^2}{(\theta+\gamma)^2}-2\frac{\theta}{\theta+\gamma}\cdot\frac{m}{m+n}+\frac{m^2}{(m+n)^2}\right](\theta+\gamma)^2(m+n)^2}$$

$$= 2\sqrt{\theta^2(m+n)^2-2\theta m(\theta+\gamma)(m+n)+m^2(\theta+\gamma)^2}$$

$$= 2\sqrt{\theta^2(m^2+2mn+n^2)-2\theta m(\theta m+\theta n+\gamma m+\gamma n)+m^2(\theta^2+2\theta\gamma+\gamma^2)}$$

$$= 2\sqrt{\theta^2m^2+2\theta^2mn+\theta^2n^2-2\theta^2m^2-2\theta^2mn-2\theta\gamma m^2-2\theta\gamma mn+\theta^2m^2+2\theta\gamma m^2+\gamma^2m^2}$$

$$= 2\sqrt{\theta^2n^2-2\theta\gamma mn+\gamma^2m^2}$$

$$= 2\sqrt{(\gamma m-\theta n)^2}$$

So, $\sqrt{\left[\frac{\theta}{\theta+\gamma}-\frac{m}{m+n}\right]^2}\sqrt{2}(\theta+\gamma)\sqrt{2}(m+n) = 2\sqrt{(\gamma m-\theta n)^2}$ ■

Therefore, the utility is: $U(m,n)=\theta f(m)+\gamma g(n)-p_m m-p_n n-2c\sqrt{(\gamma m-\theta n)^2}$ ■

A.2. Numerical Illustration

Consider the illustration with a given set of parameters as expressed in the table below. Notice that $V_U = \frac{U_N - U_U + \theta V_N(1-\delta) + p_u}{\theta}$ so that it should be expected that the consumer is indifferent between upgrading and not upgrading. Given these set of parameters, the utility for a myopic consumer is as follows:

Parameters					
Theta	0.9			Vn	10
Gamma	0.9	c-dist	0.35	Vu	23.28
Alpha	0.7			Pu	5
Beta	0.7				
Wm	3	Pm	2	d	0.2
Wn	3	Pn	2		

Table 2: Parameters

Naïve Consumer - 1 Period	m	n	Utility	U2 Stay	U2 Up
Penalty-Suppressed (LS)	2.922834	0.33242	-1.17312	5.337391	-0.50828
Penalty Dominant	**0.8281**	**0.8281**	**1.4197**	**4.7323**	**3.076**
Penalty-Suppressed (RS)	0.33242	2.922834	-1.17312	5.337391	4.672552

Table 3: Myopic Consumer Utility per optimal Allocation

Consider the 3 possible cases of the utility function, the myopic consumer maximizes his utility in the penalty-binding case. He maximizes his utility investing in 0.828 in m and n components yielding utility of 1.4197 in period 1. Should he decide to stay with his device in period 2, he would yield 4.7323 in period 2 or 3.076 should he choose to upgrade.

Non-Upgrading Consumer	m	n	Utility	Utility 1	Utility 2
Penalty-Suppressed (LS)	229.5445	1.637749	-499.238	-480.802	-18.437
Penalty Dominant	**8.3472**	**8.3472**	**14.309**	**-9.54**	**23.849**
Penalty-Suppressed (RS)	1.637749	229.5445	-499.238	-480.802	-18.437

Table 4: Non-Upgrading Consumer Utility per optimal Allocation

In the case of the foresighted, non-upgrading consumer, he also falls in the penalty-binding case where he invests in 8.3472 units of m and n deriving a utility of 14.309 across two periods (-9.54 and 23.849 in periods 1 and 2 respectively).

Upgrading Consumer

	m	n	Utility	Utility 1	Utility 2
Penalty-Suppressed (LS)	2.922834	1.637749	2.481997	-0.39675	2.878748
Penalty Dominant	**2.1606**	**2.1606**	**5.5558**	**0.6173**	**4.9384**
Penalty-Suppressed (RS)	0.33242	229.5445	-504.067	-481.578	-22.4888

Table 5: Upgrading Consumers Utility per Optimal Allocation

The foresighted, upgrading consumer invests in 2.1606 units of m and n deriving a total utility of 5.5558 across two periods (0.6173 and 4.9384 in periods 1 and 2 respectively). Under both cases of the foresighted consumer, the illustration reinforces the observation that the higher utility across the two periods comes from over-investment (which hurts current period utility) in period 1 for greater utility in period 2.

Switching Costs – New Device Improvments

Non-Upgrading Consumer	8.347	8.347	14.309
Upgrading Consumer	2.161	2.161	5.556
Difference	6.186601	6.186601	**8.7537**
Net Improvement of Device			13.28187
Utility of New Device subject to Theta			11.95368
Utility of Non-Upgrading Consumer (2 Periods)			21.50944
Utility of Upgrading Consumer (2 Periods)			21.50944
Difference			**0**
Decision Under Perfect Information			Ind

Table 6: Summary of Switching Costs – Utility of New Product for Indifferent Consumers

Naturally, since both types of apps provide the same utility yield, it should be expected that the consumer would purchase the same proportion of m and n which aligns with their preferences. From the summary, as expected, the consumer is indifferent between his decision to upgrade and his set of apps is significantly smaller if he chooses to upgrade. This reinforces the fact that even though n-type apps are compatible across devices, the switching costs stemming from the incompatible set of m suppressing the demand of n. Currently, the value of c, representing the strength of the penalty factor, is given as 0.35. Reducing this value enough can dampen the suppression of the demand of n. For instance, if c = 0 (i.e. there is no penalty from allocation choice), the foresighted, upgrading consumer would invest in 8.3472 units of n which is identical to the demand of the non-upgrading consumer.

Comparing the myopic and the foresighted consumers, the foresighted consumer derives a higher utility than the myopic consumer. The foresighted consumer both derive a utility of 21.50914 whereas the myopic consumer derives a utility of 13.352 and 20.449 if he chooses to not upgrade or upgrade respectively.

Lastly, it should be stressed that the foresighted consumers can attain a higher utility as long as they hold perfect information. With no risk of uncertain information regarding the new device in the second (or future) periods, the consumer can act in full confidence that under this set of parameters, he will be indifferent to the product introduction in period 2. However, even though the illustration suggests the foresighted consumer can achieve higher utility than the myopic consumers, the exposure to risk is higher if they were present. For instance, the myopic consumer has a more balance utility schedule than the foresighted consumers. If the consumers choose to stay with their current device, the utility in each period are 1.4197 and 4.7323 for the myopic consumer and -9.54 and 23.849 for the foresighted consumer. Relatively speaking, during period 1, the foresighted consumer experiences a large disutility from his choice. Thus, with uncertainty present in the environment, it is not difficult to assume consumers may vary their level of exposure (in terms of disutility) depending on the quality of the information they can gather about the new device. The next section will discuss the consumer decisions under uncertainty.

Observations from the Numerical Illustration From the given set of parameters, some general observances can be made of the consumer behaviours:

- With the relative utility (i.e. $W_m = W_n = 3$), the consumers with low values of θ would be most adverse to upgrading. The consumers who possess low values of θ require the highest net utility of the new product to be indifferent.
- Larger values of W_m and W_n would lead to a market where consumers with high preferences face more barriers to upgrade. Since the low values of preferences make those consumers less sensitive towards app quality, the consumers who require a higher net utility are now individuals with higher values of preferences.
- In general, the utility of m components have a greater effect on V_u than the yield from n components. Figure 12b on the right possesses values of $W_m = 6$ and $W_n = 3$. Intuitively, this is justified since the decision to upgrade hinges upon the comparison between using m components for one or two periods. The effect of the n components is less prominent since it is dampened by the coefficient c of the penalty factor. Figure 12a on the left possesses values of $W_m = 3$ and $W_n = 6$. As the utility of hardware components increases, the consumer requires a higher net utility of the new device to remain indifferent.

Figures and Tables

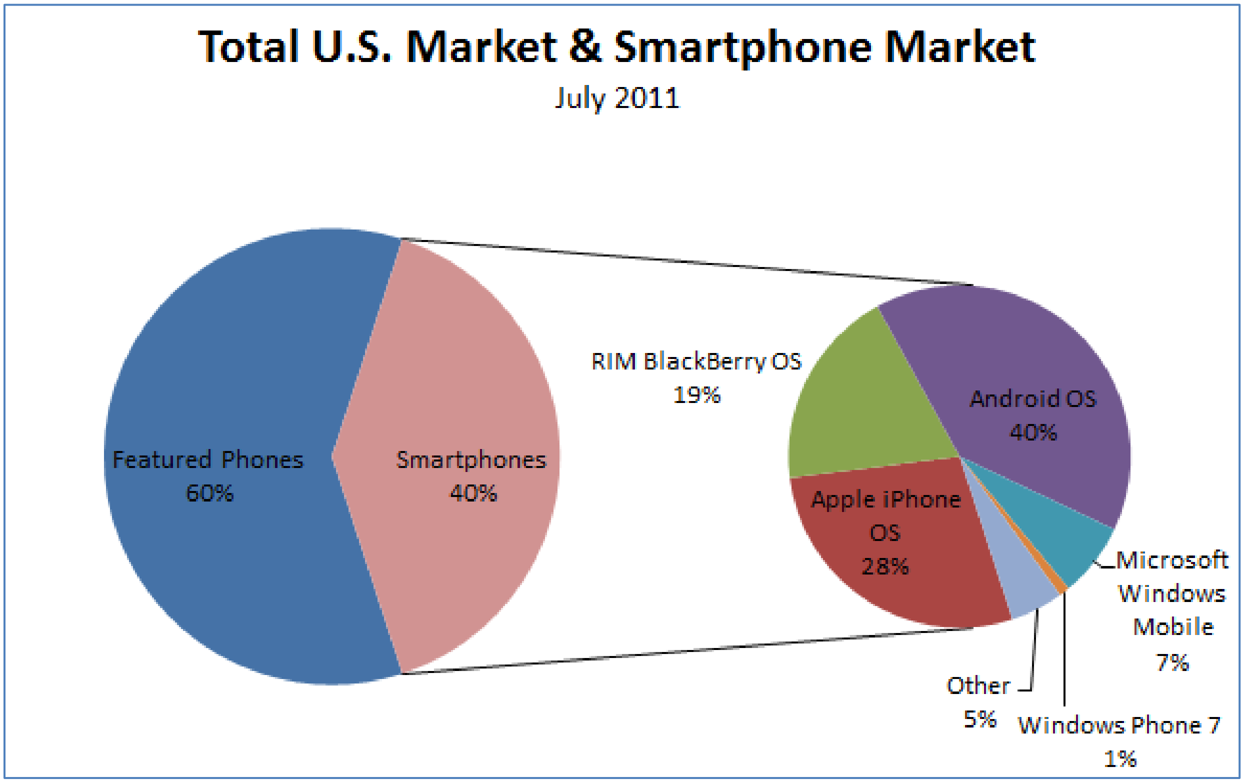


Figure 1: Total Smartphone Market Share as of July 2011 for U.S. (Nielsen)

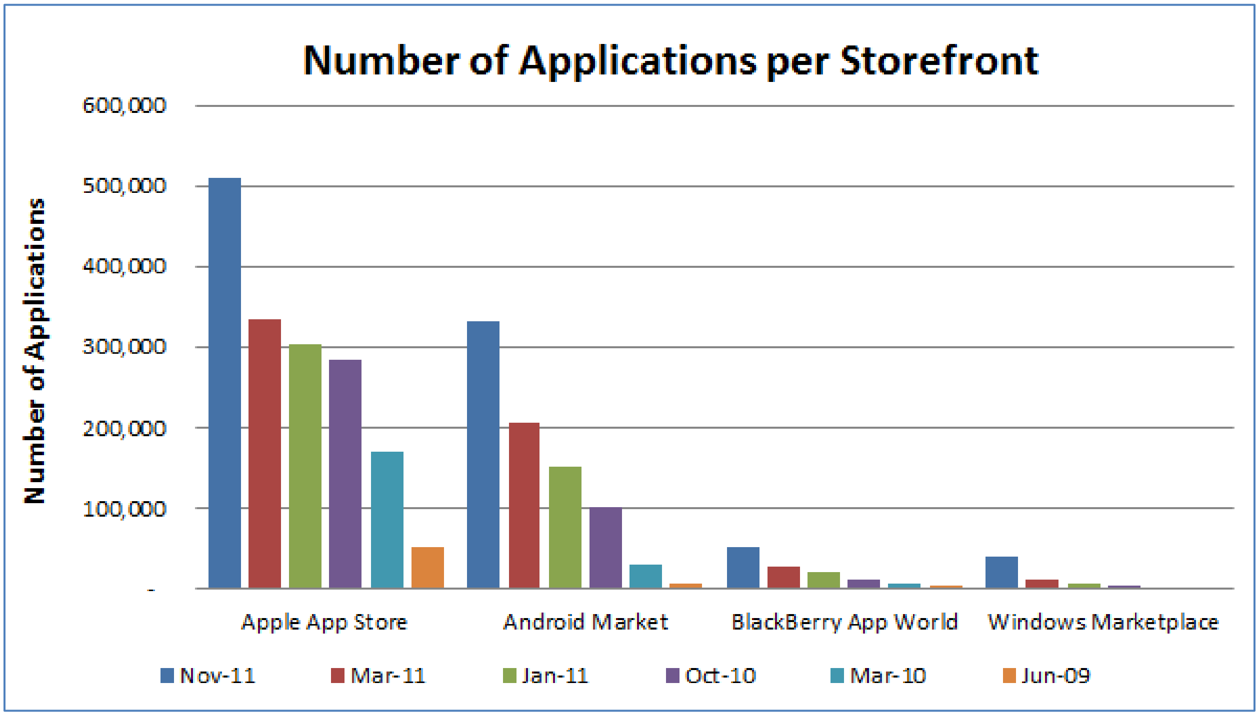


Figure 2: Number of Applications from June 2009 to November 2011 for each Storefront (148Apps.biz, AppBrain.com, Androlib.com, *Distimo Monthly reports*)

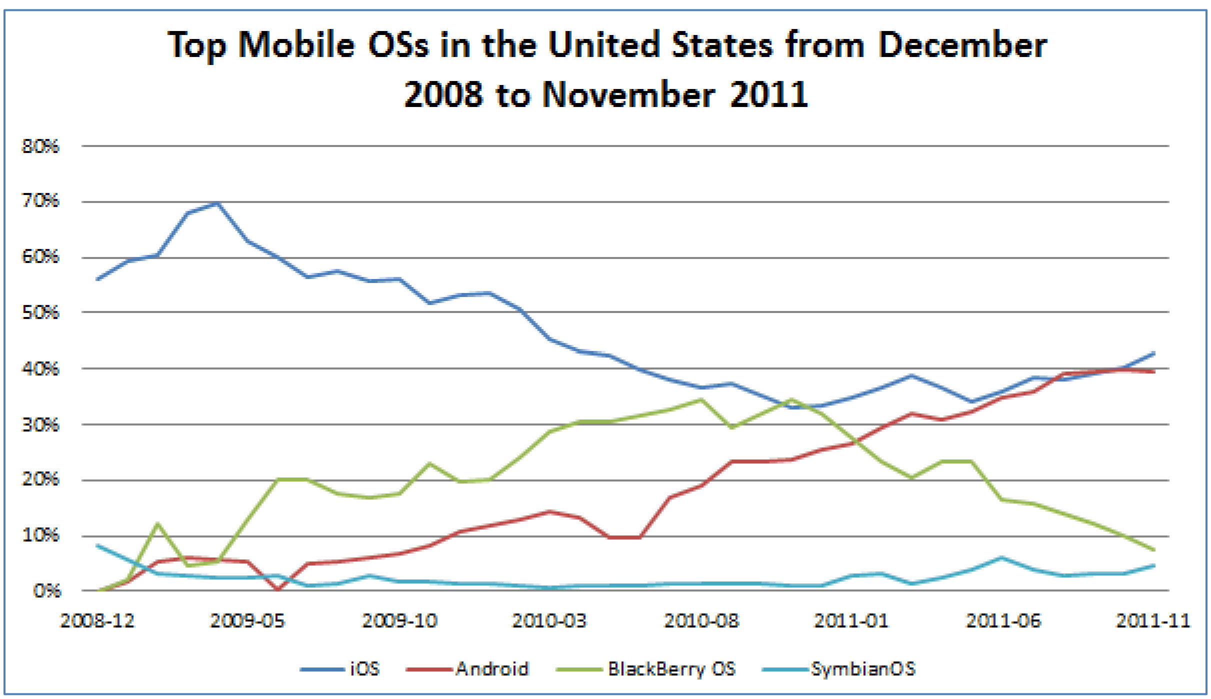


Figure 3: Total Mobile OS Market in U.S. for December 2008 to November 2011 (StatCounter Global Stats)

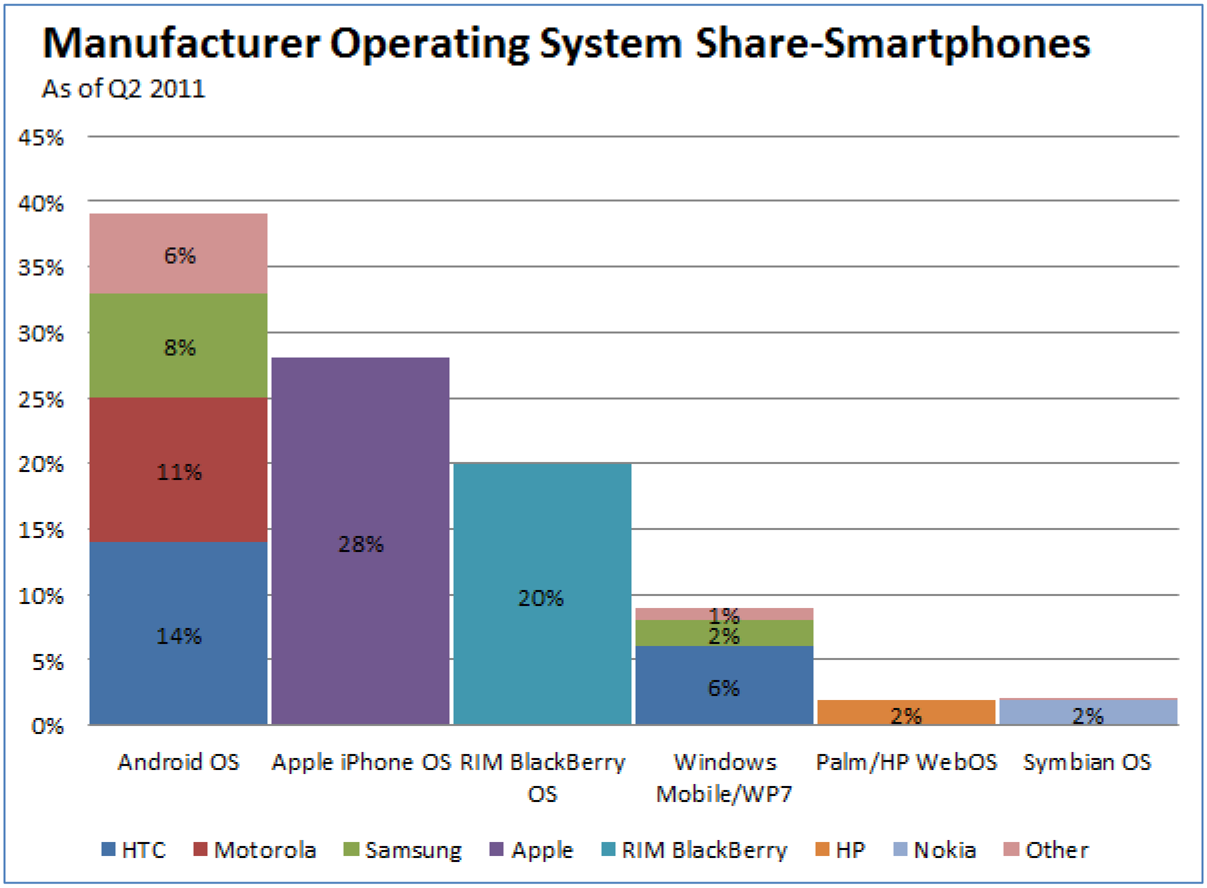
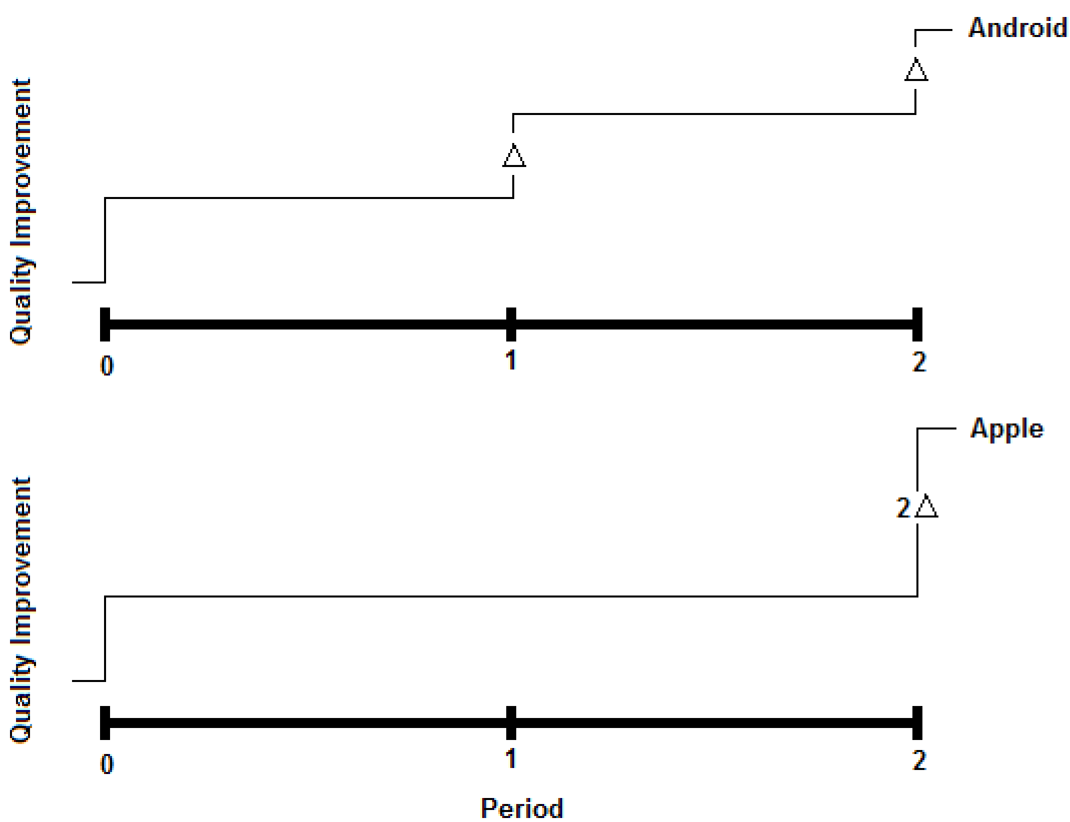


Figure 4: Device Manufacturers for each Mobile OS (Nielsen)

The Model – Device Introduction Assumptions



Note that at 0, Android and Apple introduce a device with the same level of quality whereby consumers are indifferent between the two. At 1, Android introduces a new device with improvement Δ while Apple maintains the same device. At 2, both firms will produce a new device but Apple will present a larger improvement making the quality of the competing devices equivalent. In general, it is assumed that Android has a shorter product introduction cycle than Apple but both firms will produce comparable devices.

Figure 5: Model – Device Introduction Assumptions: Product Introduction Cycle and Quality Improvements

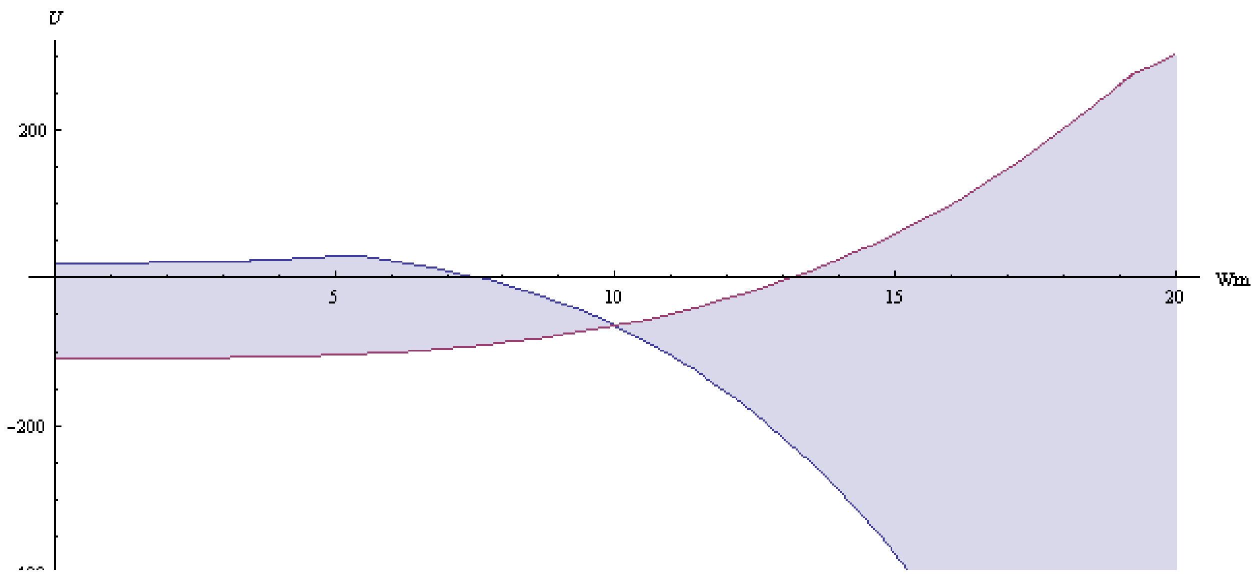


Figure 6: Penalty-binding Cases with Respect to W_m

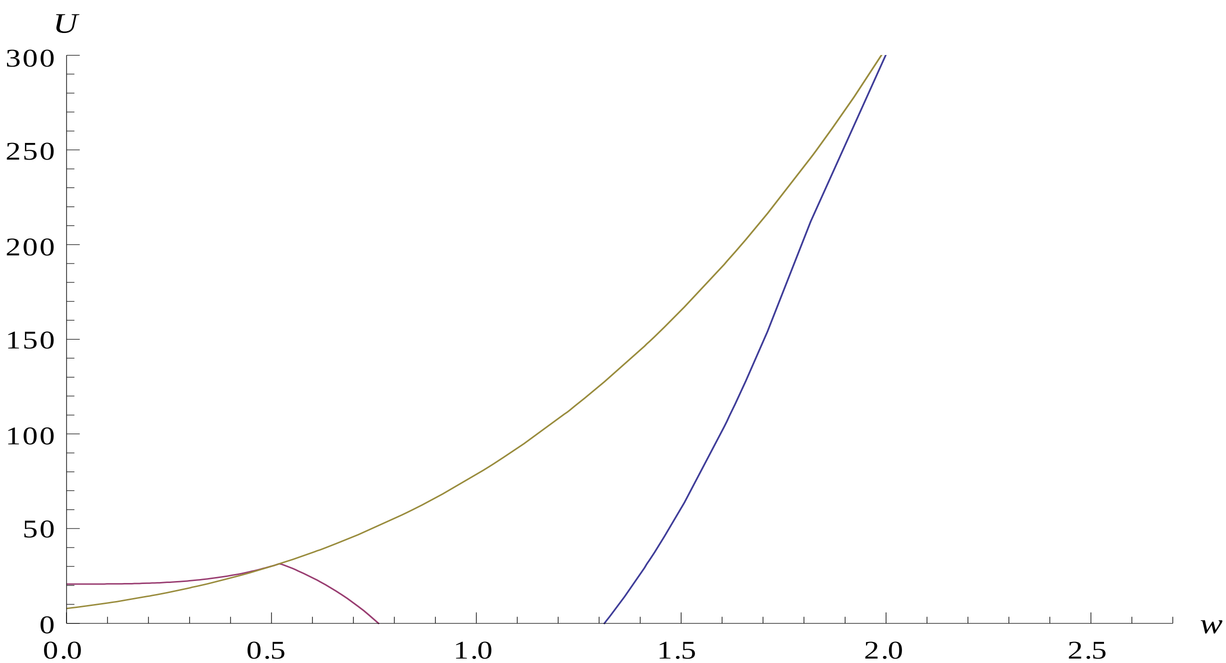


Figure 7: Non-Binding and Penalty-Binding Cases with Respect to W_m (Where θ = γ = 0.9)

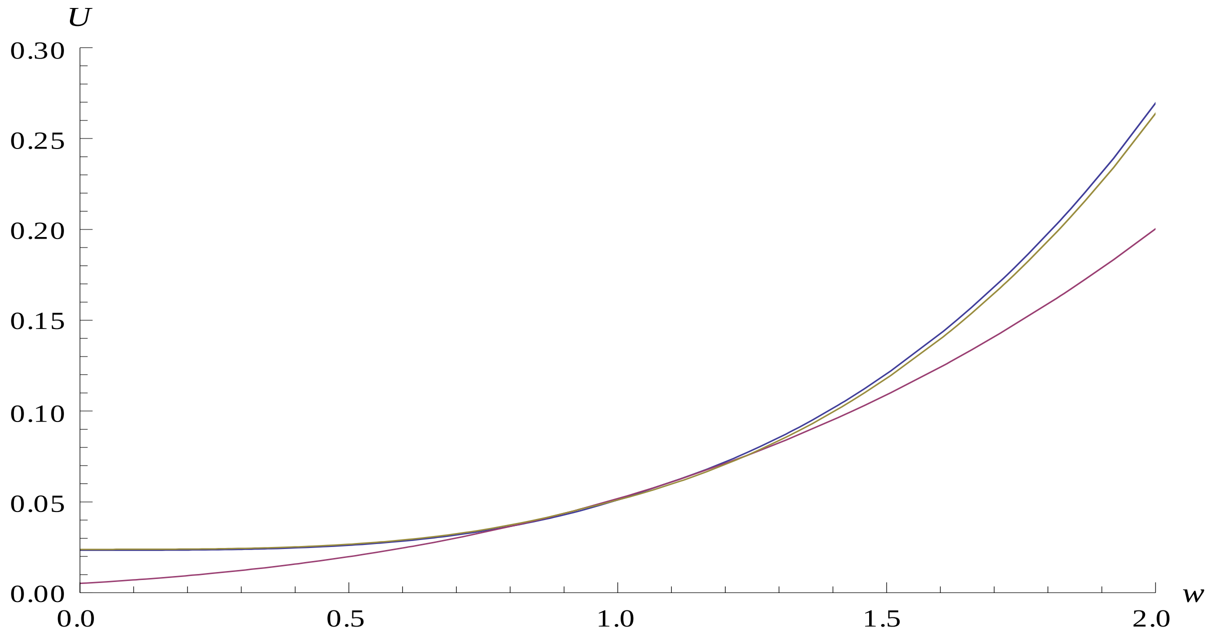


Figure 8: Non-Binding and Penalty-Binding Cases with Respect to W_m (Where θ = γ = 0.1)

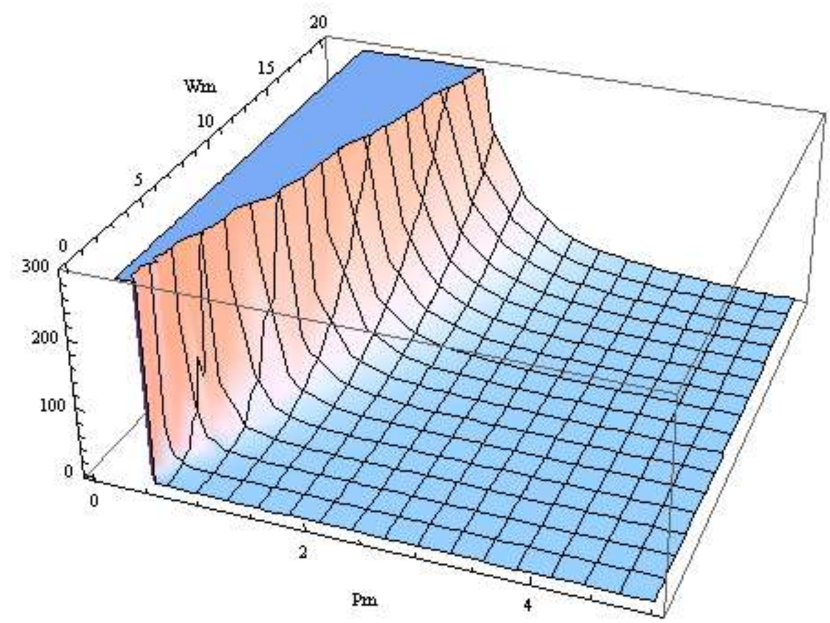


Figure 9: Demand of m under the Non-Binding Penalty Behaviour with respect to Utility

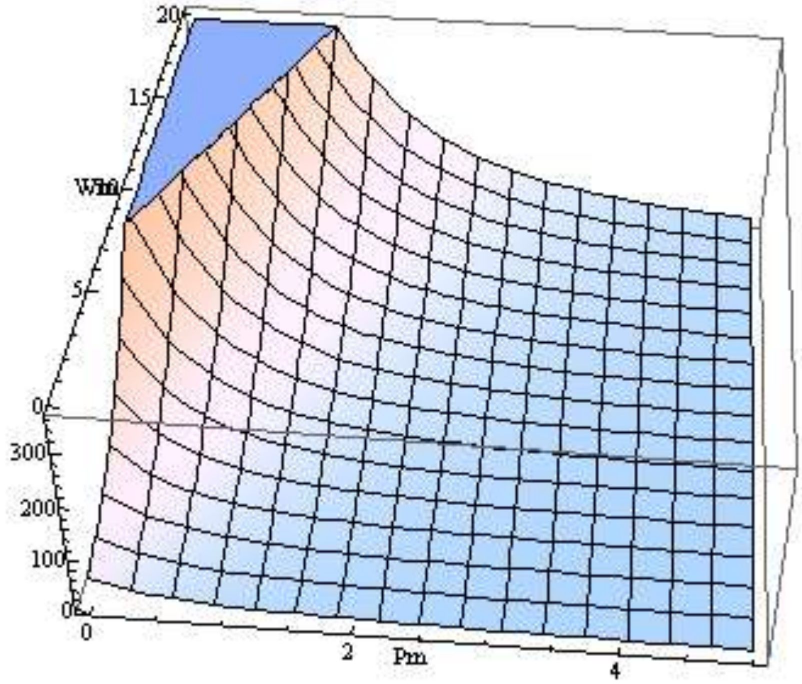


Figure 10: Demand of m under the Penalty-Binding Behaviour with respect to Utility

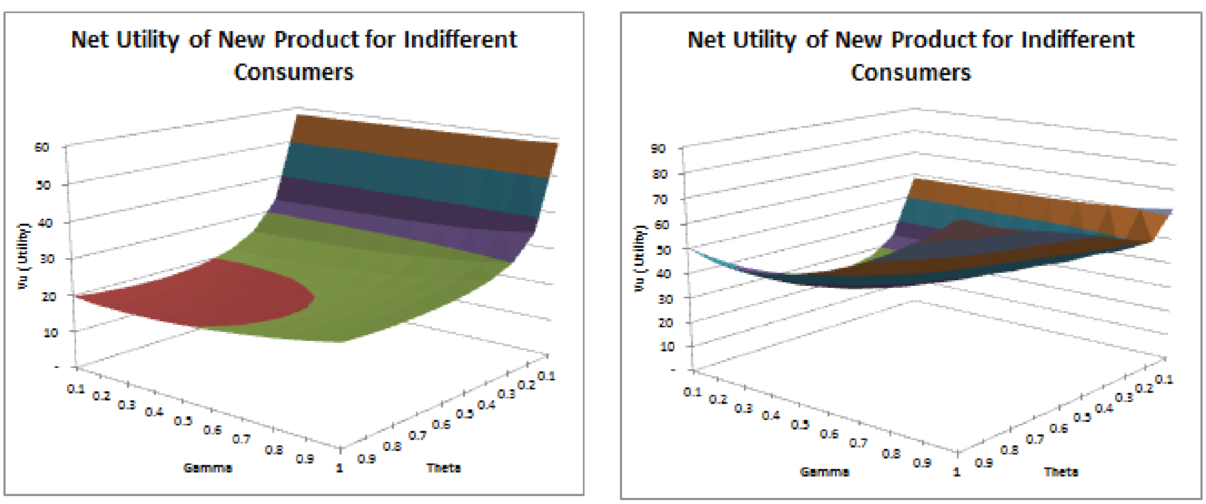


Figure 11: Net Utility of New Product where Consumers are Indifferent; (a) Left – $W_m = W_n = 3$ (b) Right – $W_m = W_n = 5$

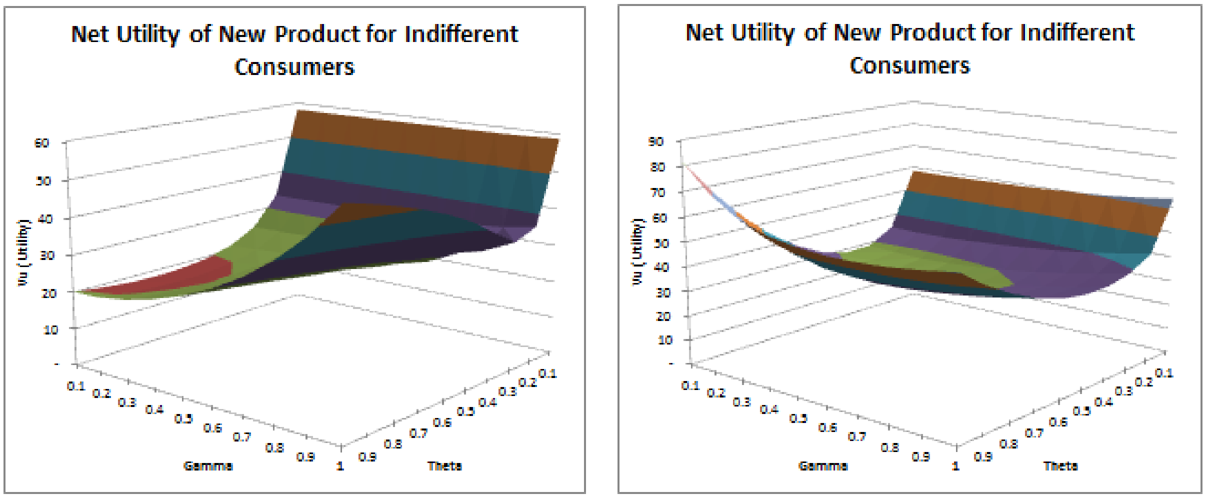


Figure 12: Net Utility of New Product where Consumers are Indifferent; (a) Left – $W_m = 3$, $W_n = 6$ (b) Right – $W_m = 6$, $W_n = 3$

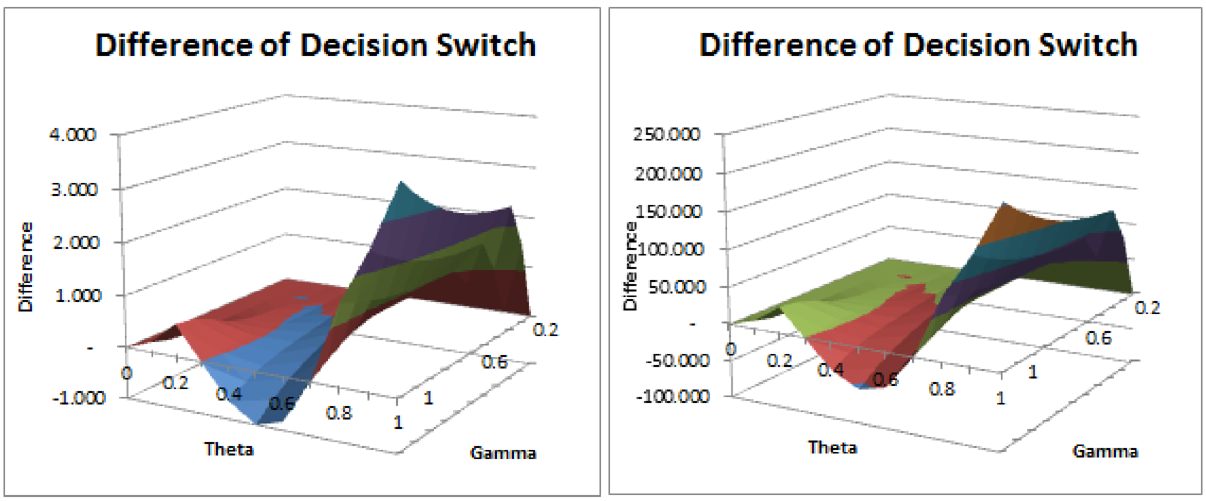


Figure13: Difference of Decision Switch – Correction Cost; (a) Left – $W_m = W_n = 3$ (b) Right – $W_m = W_n = 10$

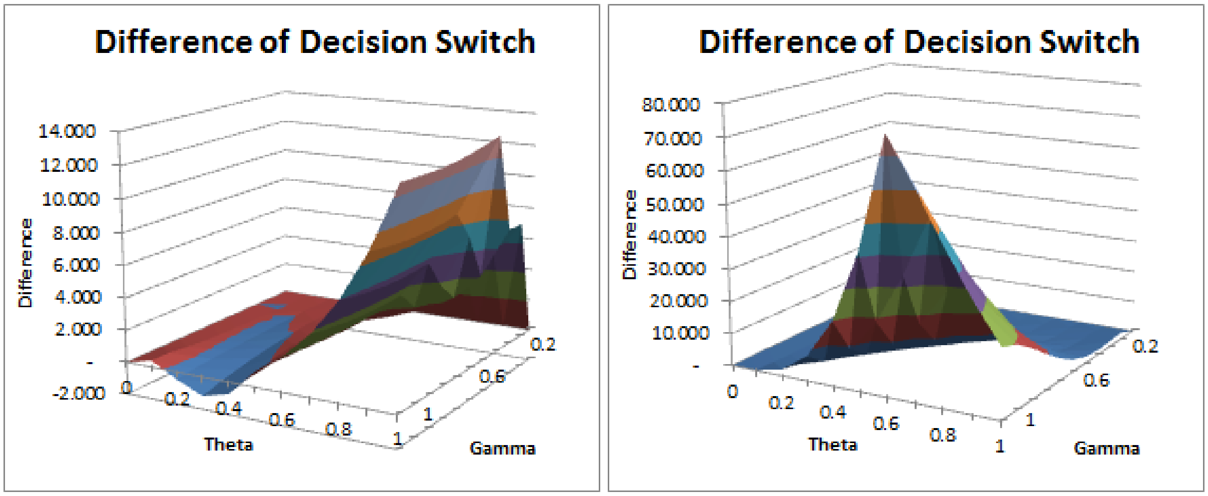


Figure14: Difference of Decision Switch – Correction Cost; (a) Left – $W_m = 5$, $W_n = 3$ (b) Right – $W_m = 3$, $W_n = 10$

	Approx. Number of Apps	Approx. Number of Downloads
Apple App Store	510,412	15 billion
Android Market Place	330,845	4.5 billion
BlackBerry App World	50,015	1 billion
Windows Marketplace	40,000	N/A

Table 1: Cumulative Download across Application Storefronts as of November 2011

- Apple figures are from http://148apps.biz/app-store-metrics/?mpage
- Android figures are from http://www.appbrain.com/stats/number-of-android-apps
- BlackBerry App World are from the RIM website
- Windows Marketplace figures are from http://www.mobilemag.com/2011/05/31/windows-marketplace-for-mobile-hits-20000-apps/

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