The Smartphone as a Multilayer Two-sided Platform

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Abstract

End users want mobile apps, but acquiring them requires selecting a smartphone and a wireless carrier. These requirements lead to a complex market that has elements of bundling, supply chains, smartphone-as-a-platform and carrier-as-a-platform. Bundling applies because a smartphone requires a carrier to function, but users may find that certain smartphone-carrier combinations are unavailable. Supply chains apply because smartphone OS vendors and cellular carriers engage in double marginalization rather than act as an integrated entity. Smartphone-as-a-platform applies because OS vendors charge app developers for access to users. Carrier-as-a-platform applies because wireless carriers charge users for access to apps. We propose a unified analytical framework of a multilayer platform that captures the essential features of this market in a parsimonious way and yet is flexible enough to allow analysis of different market structures. We show that exclusive contracting changes the basis of competition in multilayer mobile platforms. Wireless carrier firms prefer (have higher expected payoffs) if OS firms enter into exclusive contracts with them, but our model shows that for many parameter values the OS firms are indifferent to exclusive or non-exclusive entry. On the other hand, OS firms prefer for wireless carriers to make risky quality investments even if the carriers themselves do not find the investment attractive. Limited cooperation arises endogenously in our model wherein OS firms agree to enter exclusively on a carrier and subsidize its investments. Some profitable quality investments will not occur if exclusive contracts are disallowed by a regulator.

Keywords: Multilayer two-sided platform, mobile platform, cross-side network effects, exclusive contract
1. Introduction

Apple Inc. introduced the iPhone smartphone in 2007 and its App Store in 2008, leading to an unprecedented boom in mobile connectivity and computing. Cisco’s Visual Networking Index predicts that there will be more than 10 billion mobile-connected devices in 2017—approximately 40% more than the projected world population at that time [Cisco, 2013]. This mobile connectivity explosion was accompanied by the creation of a new market for software applications (apps) which run on mobile operating systems. The apps market has seen unprecedented growth in last four years that is likely to continue in the future. A recent Gartner report forecasts over 185 billion mobile app downloads by 2014, generating $58 billion in revenue—a staggering 1000 percent growth over 2011 estimated revenue from all apps of $5.1 billion [Gartner, 2011].

Although iPhone was neither the first smartphone nor was the first one to be launched exclusively on one wireless carrier [Hahn & Singer, 2010; MacCrory & Shivendu, 2013], Apple was the first one to launch an online marketplace for software applications called the “iPhone App Store” [West & Mace, 2010]. It appears that Apple has significantly benefited by the availability of third-party apps [Lin & Ye, 2009; Laugesen & Yuan, 2010]. A well-known technology columnist at the Wall Street Journal, Walt Mossberg claimed “the App store is what makes your device worth its price. It’s the software, not the hardware that makes these gadgets compelling” [Mossberg, 2009]. While it is widely accepted that Apple’s entry in the wireless phone market with iPhone revolutionized the mobile computing market, the impact of Apple’s decision to bundle it with AT&T wireless service on quality of services, profitability, and competition is less clear.

In the standard model of a two-sided market, a network owner acts as a broker between customers on the two sides of the market. A smartphone platform is a two-sided market: app developers are attracted to a platform with more end-users, and a platform with more app developers attracts more end-users. However, while the operating system owner has direct contractual relationships with app developers, it can only connect end-users to its app developers through wireless carriers who are imperfect substitutes for one another. In that sense, a smartphone platform is a multilayer platform consisting of two layers. One layer is the operating system firm and the other layer is the wireless carrier. Instead of one platform owner between the two sides (users and app developers), we have two strategic firms.2

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1 Even before the advent of wireless phones, exclusive arrangements between telephone companies and telephone instrument manufacturers were pervasive. Prior to AT&T’s breakup in 1982, all telephone instruments in the United States were supplied by AT&T [McMurrer, 2011].

2 Perfectly competitive mobile carriers would be strategically neutralized, leaving the operating system vendor as the sole “owner” of the platform. It is interesting to note that mobile carriers exercised near-total authority over their
Therefore, in the case of smartphones, the supply chain joining the app developers on the one side to the users on the other side requires the cooperation of two strategic firms. The ownership structure can have a dramatic impact on the size and profitability of a platform [Yoo et al., 2007]. In the case of the iPhone’s multilayer network, many end-users in the US were anxious for access to the iPhone but were dissatisfied with AT&T’s service as a carrier [Olmstead, 2012]. As the number of applications available on the iPhone increased, network effects increased the value of the iPhone such that more and more of these end-users (grudgingly) signed up with AT&T service to get iPhones [Johnson, 2009]. Absent the exclusive contract, these end-users believe they would have been better off with the OS they wanted on the carrier of their choice.

While wireless carriers argue that contract exclusivity gives them stronger incentives to innovate [Hahn & Singer, 2010], consumer groups and some public policy analysts argue that exclusive arrangements lead to higher prices, lower choices for the consumers and therefore, a loss in social welfare [Consumer Reports, 2009]. Existing models of two-sided markets that abstract the platform as a homogenous strategic entity are inadequate to study the effects of an exclusive contract (between the OS and the carrier) in this context. Interesting questions arise when mediation between two distinct set of consumers requires the coordination of two or more strategic actors, e.g. Apple and AT&T in a smartphone platform.

In this paper, we first develop a framework to study multilayer platforms like smartphones. Second, we use this framework to study the impact of exclusivity on market outcomes. Since exclusivity limits one of the strategic firms to part of the market, does this end up hurting the firm? Or in other words, when is exclusivity optimal for the OS? How does exclusivity arrangement between OS and carrier impact quality investment by carriers? For example, did exclusive contracts affect how long it took to roll out 3G networks?

When multiple two-sided networks compete, one option for the platform provider is to employ exclusive contracts [Choi, 2010; Armstrong & Wright, 2007]. We observe heterogeneity across industries along two dimensions: (i) whether the contract is exclusive between the provider and the platform; and (ii) who has the control rights over strategic variables like advertising and pricing [Hagiu & Lee, 2011]. This two-sided platform literature (see [Rochet & Tirole, 2006] for detailed literature review) uses the term “exclusive contract” meaning that customers (on at least one side of the market) are required to contract with a single platform provider. In the smartphone industry structure, each side of the market is served by a different firm (e.g., developers by OS vendors, and end users by mobile service carriers) and each platform consists of two strategic firms: one providing the OS and the other providing wireless platforms prior to the advent of smartphones [Sharma et al., 2007], indicating that feature phone operating systems were in effect perfectly competitive.
connectivity. In our context “exclusive contract” refers to an exclusive contract between the layers of the platform, that is, a situation where an OS is available only on one carrier. For example, Apple’s smartphone with Apple’s iOS was available through AT&T and no other mobile service carrier.

Prior literature has studied the impact of exclusive contracts either in a framework of two-sided markets [Hagiu, 2006; Armstrong & Wright, 2007; Hagiu & Lee, 2011] or in the framework of tying and bundling [Whinston, 1990; Bakos & Brynjolfsson, 1999; Carlton & Waldman, 2002; Gans, 2011; Cai et al., 2012]. These studies have not taken into account the setting where the platform itself consists of multiple strategic firms which must cooperate in order for two sides to connect to each other [Heitkoetter et al., 2012]. Similarly, prior literature has examined the implications of exclusive contracts for prices, profits, and social welfare [Katz & Shapiro, 1986; Rasmusen et al., 1991; Balto, 1999; Shapiro, 1999], but it is not clear if their findings will hold when the “two inside layers” of the platform enter into an exclusive contract.

In this research we study a multilayer mobile platform with smartphone users on one side and app developers on the other side. The two layers of the platform are OSes which are connected to the developers and carriers which are connected to users. The two sides of platform connect to each other only through both layers of the platform. Users are heterogeneous in their horizontal preferences for OSes and their vertical willingness to pay for quality of carriers. Developers are heterogeneous in their horizontal preference for OSes and indifferent to the quality of carriers. The OS firms (like Apple) can have either an exclusive arrangement with a carrier or non-exclusive arrangements with all carriers. An important feature of our model is that carriers can make an uncertain investment in quality improvement, and the incentives to invest in quality may depend on whether an OS firm has an exclusive carrier.

In this setting we find that prior to the introduction of platform-style smartphones, carriers make quality improvement investment only when the probability of success of investment is neither too low nor too high. The range of probability of success that induces investment is centered on one-half and this range increases as (i) same-side network effects increase or (ii) the magnitude of quality improvement increases or (iii) the relative difference between the lowest and the highest willingness to pay for quality increases. Moreover, the introduction of smartphones or OSes with cross-side network effects weakly increases market coverage and carrier profits. OS firms’ decisions to enter exclusively or non-exclusively depend on (i) cross-side network effects and (ii) the relative difference between the highest and lowest willingness to pay for quality. An decrease in either of these values increases the range of other parameter values for which OS firms prefer exclusive entry. The introduction of mobile OSes increases carrier profits only if each OS enters the market exclusively. In the event that OS firms prefer to enter

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3 The inclusion of OS-enabled devices that bypass Carriers (e.g., iPod Touch and Wi-Fi tablets) do not materially affect our results. See page 22.
exclusively, they would be willing to make a side payment to an exclusive carrier to offset the cost of the uncertain quality investment. The OSes would not be willing to pay to non-exclusive carriers.

When two or more strategic firms constitute a multilayer platform, a number of distortions manifest compared to the case when a single entity controls the platform. The first major distortion is double marginalization. The set of “optimal” prices that would maximize total profits is never achieved because each OS firm and each carrier firm sets prices to maximize its own profit. Since it would be more profitable for a single entity to control the operating systems and the carrier, incentives may lead to anticompetitive behavior in the market. Therefore, identifying contractual arrangements that improve joint profitability (such as risk-sharing for investments to improve quality) without impeding a fair and competitive marketplace is important.

The second major distortion in a multilayer network is weakening the incentives to invest in quality. Suppose that it would be in Apple’s interest to subsidize an upgrade to wireless broadband capacity so that end-users would find its OS more valuable, which would in turn attract more application developers. Unfortunately for Apple, an investment in improving a carrier’s capacity will improve the performance of any OS on that carrier’s network, thereby weakening Apple’s incentive to subsidize the investment. Similarly, if it was in Verizon’s interest to subsidize an investment in the software development kit for Android OS, the spillover to other Android-using carriers would discourage the investment. The only ways to ensure that these investments are made would be to extract payments from competitors (which are not feasible) or restrict the recipient of the investment from contracting with the investing firm’s competitors at all (which requires exclusive contracts).

In order to mitigate the second distortion, a multilayer network may lead to the third major distortion in the form of exclusive contracting. Was the exclusive contract between Apple and AT&T one that improved profitability, encouraged investments, or reduced competition? A handful of studies (some inspired by the Apple/AT&T contract) have looked at exclusive contracts from a variety of perspectives. [Katz, 2010] and [Sharma et al., 2011] have analyzed the decision to enter the market as a new OS vendor; [Hagui & Lee, 2011] and [Cai et al., 2012] have examined pricing mechanisms in detail; and [Armstrong & Wright, 2007] look at entire platforms as if the OS and carrier are owned by the same firm. However, none of these studies has considered the special nature of the multilayer two-sided networks involved.

This research contributes to the two-sided platform literature in three broad areas: quality investment, pricing, and exclusive arrangements by generalizing the ownership structure of the platform. Only under some narrow set of parameter values would the carriers make the quality investments on their own. In a somewhat wider range, OSes find it profitable to subsidize the carriers to make quality improvement investments but only if the OS has an exclusive contract with a carrier.
Our work is also closely related to the stream of literature relating to tying in two-sided markets. While the extant literature has studied the impact of tying or exclusivity between one side and the platform [Doganoglu & Wright, 2006; Amelio & Jullien, 2007; Choi, 2010], we study the exclusive contracts between two strategic firms who form the platform or in other words, between the layers of the platform. While the extant literature finds that tying may be social welfare enhancing when users can multi-home in a two-sided platform [Choi, 2010], we show that exclusive contract between the two layers of the platform is never user welfare enhancing.

The rest of our paper is organized as follows. In §2, we describe the analytical model and key assumptions. In §3 we analyze the competition within a layer of the platform taking the actions of the other layer as exogenous. In §4, we analyze strategic interaction between OSes and carriers and study the impact of exclusivity on market outcomes. We conclude by discussing our results, implications of relaxing some of our assumptions and by identifying suitable managerial recommendations in §5.

2. Model

We consider a multilayer two-sided platform setting in which each mobile platform is controlled by two distinct strategic firms; a wireless network provider (carrier) like AT&T and a mobile operating system (OS) vendor like Google.4 While many other firms are involved in bringing a smartphone to market, the OS vendor and carrier have significantly more bargaining power because they have monopoly access to a segment of an essential market (developers in the case of an OS and users in the case of a carrier). To keep the analysis tractable, we consider a market that consists of two carriers $C_0$ and $C_1$, and two mobile operating systems (OSes) $M_0$ and $M_1$. Applications (apps) which run on an OS are valuable to users, but they can access apps only by connecting to the OS through the carrier’s wireless network. Therefore, the two strategic players of the mobile platform, OSes and carriers, form a vertical supplier-retailer relationship to connect developers to users and in that sense, the mobile platform is multilayer and two-sided [MacCrory & Shivendu, 2013].

We consider that the competitors at each layer of the platform – $C_0$ and $C_1$ at the carrier layer and $M_0$ and $M_1$ at the OS layer – are differentiated from one another along a dimension other than price. At the OS layer, the differences are primarily horizontal in that different people come to different conclusions on their “best-fit” OS even if there is no material difference in price or availability.5 At the carrier layer, the differences are primarily vertical in that people agree about which carrier’s quality

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4 Google developed its Linux-based mobile operating system, Android, in conjunction with Open Handset Alliance which is a consortium of 86 hardware, software and telecommunication companies [Helft & Markoff, 2007].
5 Smartphone handsets vary along several important dimensions including screen size, battery life, ruggedness, weight, storage capacity, appearance, and presence of hardware features like GPS receivers and accelerometers. At the time of entry, all of the handsets using Apple’s OS are very similar to each other (except for storage capacity) while simultaneously being quite distinct from the handsets available for other OSes.
(dropped calls, signal coverage, bandwidth, etc.) is better in a particular market. Therefore, in our setting, while OSes are horizontally differentiated, carriers are vertically differentiated. Moreover, users differ in their horizontal preference for an OS and their vertical willingness-to-pay for quality. Some developers’ ideas are easier to realize with one OS’s software development kit than another’s, so we model developers with horizontal preferences. Developers are essentially indifferent to the quality of carriers.

We model horizontal differentiation as x positions along a Hoteling line of unit length with OSes located at the endpoints. Users and developers are each uniformly distributed along the line. We model vertical differentiation of users as willingness-to-pay for quality parameter θ that is uncorrelated with the horizontal index and uniformly distributed between [2θ, 3θ], and following Tirole (1988) we assume $\bar{\theta} \geq 2\theta$ and scale willingness to pay such that $\bar{\theta} = \theta + 1$. The locations of OSes and the quality levels of carriers are publicly observable and the distributions of x and θ are public knowledge, but each user’s and developer’s indices are private knowledge. For ease of exposition, we model user utility and developer value that are in excess of the cost of delivering them. In other words, we normalize the marginal costs of carriers and OSes to zero.

The four potential bundles of carrier and OS are {C₀, M₀}, {Cₙ, M₀}, {C₀, M₁} and {Cₙ, M₁}, although all four carrier-OS bundles may not be available due to exclusive contracts between carriers and OSes. The multilayer platform and industry structure are shown in Figure 1. Following prior horizontal differentiation literature [Bakos, 1997; Salop, 1979], we model preferences of developers and users as transport costs from their location to the location of the chosen OS. Moreover, the payoffs to users and developers are additively separable in utility from quality, disutility from transport cost, and disutility from price. More specifically, the payoff to users consists of positive utility from the chosen bundle’s carrier quality, disutility due to distance from the OS in the bundle and negative payoff due to the price of the bundle. And the payoff to developers consists of value received from homing with an OS, disutility from distance from the OS and the price charged by the OS.

Developers as well as users benefit from same-side as well as cross-side network effects. A developer (user) gets same-side network benefit of $n_D (n_U)$ from being connected to a unit mass of developers (users) using the same firm. Similarly, a developer (user) gets a cross-side network benefit of $N_D (N_U)$ from being connected to a unit mass of users (developers) on the other side. The transport cost for developers and users along x axis (OS) axis are denoted by $t_D$ and $t_U$ respectively. The payoff to a user of {x, θ} type, where x is his location along the Hoteling line and θ is his willingness to pay for quality, when he chooses the bundle {C₀, M₀} is given as:

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6 An exclusive contract between OS i and carrier j means that OS i is available to users only through carrier j. The carrier is not excluded from offering bundles from the other OS.
\[ U(C_M; x, \theta) = \theta q_{C0} - x t_{C1} + n_u Q_{U(C0)} + N_n Q_{D(M0)} - p_{C0} \]  

Note that \( \theta q_{C0} \) denotes utility from carrier \( C_0 \)'s quality \( q_{C0} \) (which is either \( q \) or \( \bar{q} \) depending on the outcome of an investment); \( x t_{C1} \) denotes disutility from transport cost related to operating system \( M_0 \); \( n_u Q_{U(C0)} \) denotes same side networks effect where \( Q_{U(C0)} \) is the mass of users on the carrier \( C_0 \)'s network; \( N_n Q_{D(M0)} \) denotes cross-side network effect where \( Q_{D(M0)} \) is the mass of developers on the OS \( M_0 \); and \( p_{C0} \) denotes the price charged by the carrier \( C_0 \) for the bundle \( \{C_0, M_0\} \).

Similarly, the payoff to a user of \( \{x, \theta\} \) type, when he chooses the bundle \( \{C_1, M_0\} \), \( \{C_0, M_1\} \) or \( \{C_1, M_1\} \) is given as:

\[ U(C_M; x, \theta) = \theta q_{C0} - (1-x) t_{C1} + n_u Q_{U(C1)} + N_n Q_{D(M0)} - p_{C0} \]  

\[ U(C_M; x, \theta) = \theta q_{C1} - x t_{C0} + n_u Q_{U(C1)} + N_n Q_{D(M0)} - p_{C0} \]  

\[ U(C_M; x, \theta) = \theta q_{C1} - (1-x) t_{C0} + n_u Q_{U(C1)} + N_n Q_{D(M1)} - p_{C1} \]  

The payoff to a developer depends on her homing decision between OSes. Note that in our setting developers are uniformly distributed along the Hoteling line of unit length with OSes located at the endpoints. The payoff of a developer, located at \( x \) along the Hoteling line who chooses OS \( M_0 \) as her home, is given as:

\[ V(M_0; x) = v - x t_{D} + n_D Q_{D(M0)} + N_D (Q_{U(C0)} + Q_{U(C1)}) - p_{M0} \]  

Here \( v \) is the exogenous value received by a developer for homing with an OS (such as access to software development kits and sample code). Furthermore, \( x t_{D} \) denotes disutility from transport cost related to operating system \( M_0 \), and \( n_D Q_{D(M0)} \) denotes same side networks effect where \( Q_{D(M0)} \) is the mass of developers on the OS \( M_0 \). \( N_D (Q_{U(C0)} + Q_{U(C1)}) \) denotes cross-side network effect where \( Q_{U(C0)} + Q_{U(C1)} \) is the mass of users on the OS \( M_0 \); and \( p_{M0} \) denotes the price charged by the OS \( M_0 \).

Similarly, the payoff of a developer \( \{s\} \) who chooses OS \( M_1 \) as her home, is given as:

\[ V(M_0; x) = v - (1-x) t_{D} + n_D Q_{D(M1)} + N_D (Q_{U(C0)} + Q_{U(C1)}) - p_{M1} \]
Figure 1 illustrates multilayer platform and market structure. OS’s all development cost is sunk and we normalize cost of serving developers to zero. Hence, profit function of OS $M_0$ is:

$$\pi_{M_0} = Q_{d(M_0)} \cdot p_{M_0}$$

(7)

where $Q_{d(M_0)}$ is the mass of developers who choose $M_0$ as their home OS and $p_{M_0}$ is the price charged by $M_0$. Similarly, the profit function of $M_1$ OS is:

$$\pi_{M_1} = Q_{d(M_1)} \cdot p_{M_1}$$

(8)

The carriers’ payoff function is more complex. Each carrier sells two different bundles and also might incur a cost $k$ to undertake a risky investment to increase quality. We use $I_{ci}$ as an indicator function to write the payoff functions as:

$$\pi_{c0} = Q_{u(com0)} \cdot p_{com0} + Q_{u(com1)} \cdot p_{com1} - k \cdot I_{c0}$$

(9)

$$\pi_{c1} = Q_{u(clm0)} \cdot p_{clm0} + Q_{u(clm1)} \cdot p_{clm1} - k \cdot I_{c1}$$

(10)

$$I_{ci} = \begin{cases} 1 & \text{if Carrier } i \text{ makes investment } k \\ 0 & \text{if Carrier } i \text{ does not make investment } k \end{cases}$$

where $i \in [0,1]$

(11)

We summarize notations in Table 1. Within the above model setup, we make the following three assumptions for tractability and expositional clarity.
A1: The outside option for carriers and users are “feature phones” that do not use a platform-style OS. We normalize the profits and utility for “feature phones” to zero. This assumption implies that feature phones are perfectly competitive. This establishes them as a uniform outside option.

A2: Users have unit demand and therefore do not multihome. This assumption simplifies our exposition; a person with a “work phone” and a “personal phone” is effectively two different users. Depending on the use-cases, these two users might have quite different indices.

A3: Neither carriers nor OSes participate as developers. This assumption simplifies the exposition of our model. This type of “neutral platform” provides a lower bound for firm profitability and social welfare (Yoo et al., 2007). Alternatively, $M_0$ can be the developer at precisely at $x = 0$ and $M_1$ can be the developer at precisely $x = 1$ without qualitatively changing our results.\(^7\) For example, we observe that Google writes apps for Android, but they do not write a significant share of the apps.

In the next Section we analyze the responses of the strategic players carriers when they take the actions of the other players as exogenous. The following section uses these results as building blocks to explain the strategic interactions of all players in the following section.

3. **Market Outcome with No Strategic Interaction**

We first consider carrier competition if OS actions are considered exogenous (or non-strategic), and then OS competition if carrier actions are considered non-strategic.

3.1 **Carrier Competition for Users**

In this subsection we develop a baseline case of carrier competition for users prior to the introduction of platform-style smartphone. Two carriers $C_0$ and $C_1$ compete vertically because users have differing willingness-to-pay for quality, and all users agree on the quality level for each firm. Each firm has inherent quality $q$ and the opportunity to make a costly investment that may increase its quality. An investment succeeds with probability $\lambda$, and if successful, increases quality by a set amount to $\tilde{q}$. The sequence of events for our baseline model where carriers compete for users is summarized in Figure 2.

![Figure 2: Sequence of events for carrier competition](image)

\(^7\) Each OS firm would improve its profits by $V(\cdot)$ by developing for its own platform. In the extreme case of the other firm fully covering the developer market, the focal firm is indifferent to developing for the rival platform because it would be the marginal developer.
Since the outcome of the investment is stochastic, with probability $\lambda^2$ both carriers end up with high quality ($\bar{q}$) and with probability $(1-\lambda)^2$ both carriers fail in improving quality and continue with low quality ($\bar{q}$). Hence with probability $\lambda^2 + (1-\lambda)^2$ both the carriers end up with the same quality level. If both carriers end up at the same quality level, Bertrand competition ensues and firms earn zero profits from sales. In fact, since both the carriers have made the investment ($k$), the payoff to both the carriers would be net negative.

If the difference in willingness to pay for quality is large enough, the firms would find it profitable to serve only part of the user market. This is in spite of the fact that the firms forgo some network effects by doing so. Specifically, partial user market coverage is optimal if $\bar{q} > \theta \left[ 3q + 2\Delta q + n_p \cdot (\theta + 5\Delta \theta) / 3 \right]$. To focus momentarily on the zero-sum-market-share case of full user market coverage, we derive in (12) and (13) the profit maximizing prices when $\bar{q} \leq \theta \left[ 3q + 2\Delta q + n_p \cdot (\theta + 5\Delta \theta) / 3 \right]$, followed by the associated market shares and profits. These values are analogous to a standard vertical differentiation model [Tirole, 1988; Wang & Yang, 2001], except that we allow for same-side network effects.

$$\pi^*_{c_0} = \left( \Delta \theta - \bar{\theta} \right) \left( \Delta q + \frac{n_p \cdot \Delta \theta}{3} \right)$$  \hspace{1cm} (12)

$$\pi^*_{c_1} = \left( \Delta \theta + \bar{\theta} \right) \left( \Delta q + \frac{n_p \cdot \Delta \theta}{3} \right)$$  \hspace{1cm} (13)

$$Q^*_{c_0} = \frac{\Delta \theta - \bar{\theta}}{3}$$  \hspace{1cm} (14)

$$Q^*_{c_1} = \frac{\Delta \theta + \bar{\theta}}{3}$$  \hspace{1cm} (15)

Note that conditional on investments being made, both firms are better off when quality levels are different. This result is not novel because it is equivalent to Griva & Vettas (2011) under the condition that firms cannot pre-commit to prices,\(^8\) but it a useful benchmark for analyzing the firms’ investment decisions.

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\(^8\) It is relatively easy for cellular carriers to change their prices, so posted prices do not affect users’ expectations of market share. That is, users infer that Carriers will adjust prices as needed to optimize their profits.
For the case of different quality levels, we assume that the high-quality firm is \( C_1 \) (a high-quality \( C_0 \) involves only switching subscripts). This means that the firm \( C_1 \) is successful in its quality investment and offers high quality (\( \bar{q} \)) while the firm \( C_0 \) is unsuccessful in its quality investment and offers low quality (\( q \)). Overall, the expected profit conditional on investment and full user market coverage is:

\[
E[\pi_{C0}] = E[\pi_{C1}] = (\lambda - \lambda^2) \left[ \frac{(2\bar{q} - \bar{\theta})^2}{3} \right] \left[ \frac{q - q + n_C^C (\bar{q} - \bar{\theta})}{3} \right] + (\lambda - \lambda^2) \left[ \frac{(\bar{q} - 2\bar{\theta})^2}{3} \right] \left[ \frac{\bar{q} - q + n_C^C (\bar{q} - \bar{\theta})}{3} \right] - k \tag{18}
\]

The first term of the RHS is the expected payoff of being the “high quality” firm, the second term is the expected payoff to being the “low quality” firm, and \( k \) is the sunk cost of the investment. To simplify our exposition, we define a notation \( \Lambda = \left( \Delta q + \frac{n_C^C \cdot \Delta \theta}{3} \right) \cdot \left( 5\bar{q}^2 - 8\bar{\theta}q + 5\theta^2 \right) \) which is always positive.\(^9\) Then each firm will independently decide to undertake the investment if (27) is greater than zero, or equivalently \( \lambda - \lambda^2 \geq 3k/\Lambda \). This occurs if and only if \( 0 < k < \Lambda/12 \) and \( 1/2 - \sqrt{(\Lambda - 12k)/4\Lambda} \leq \lambda \leq 1/2 + \sqrt{(\Lambda - 12k)/4\Lambda} \).

There is a critical range of probability of success of investment, \( \lambda \), that balances the likelihood of ending up at the same quality level and ending up at different quality levels. If \( \lambda \) is in this range then both firms are interested in making quality enhancement investment, otherwise neither is. This is equivalent to the mixed strategy equilibrium in Wang & Yang (2001), although our richer model yields a range of values rather than a single \( \lambda^* \). Because the firms are symmetric, it is unsurprising that either both will invest or neither will. The surprising aspect is that the range is bounded from above. That is, the probability of success can be “too high” to be of use to the carriers because Bertrand competition ensues if both carriers succeed. The conditions under which investment is optimal (i.e., investment has a higher expected value than non-investment) are described in Proposition 1.

**PROPOSITION 1:** The range of \( \lambda \) that leads to investment is an open interval centered on \( \lambda = \frac{1}{2} \). For a given cost of investment, this range becomes wider in response to an increase in (1) same-side network effect, (2) difference between high and low quality outcomes, or (3) difference in highest and lowest willingness-to-pay for quality. The maximum feasible cost of investment increases in response to the same three exogenous factors.

Proofs of all Propositions and Corollaries are located in the Appendix.

\(^9\) The first factor is unambiguously positive. Rewrite the second factor as \( \left( 4\bar{q}^2 - 8\bar{\theta}q + 4\theta^2 \right) + \left( \bar{q}^2 + \theta^2 \right) \). The first sub-expression factors to \( 4\left( \bar{q} - \bar{\theta} \right)^2 \), so both sub-expressions are strictly positive for any nonzero real values of \( \bar{q} \) and \( \bar{\theta} \).
The intuition behind an interval centered on ½ is that a “too high” probability of success makes it likely that both firms will succeed, and surprisingly this is an outcome worse than doing nothing. The intuition behind widening the interval is that all three factors tend to shift marginal users from the low-quality firm to the high-quality firm. The high-quality firm extracts more profit from these users, so these factors help the high-quality firm more than they harm the low-quality firm. Each firm has an equal probability of being the high- or low-quality firm, so the expected payoff from investing increases.

Consider now the entry of a mobile OS into this market. We will analyze specific modes of market entry in detail in §4, but one thing that every mode has in common is that it introduces cross-side network effects that raise the utility of smartphones relative to feature phones. The effective increase in quality increases coverage of the user market as described in Proposition 2.

**PROPOSITION 2:** The addition of one or more mobile OSes with cross-side network effects increases coverage of the user market for any \( \overline{\theta} \leq \theta \left[ \frac{3q + 2\Delta q + n_v \cdot (\theta + 5\Delta \theta)}{3} \right] \). Otherwise, the user market is fully covered under same-side network effects and remains covered with cross-side network effects.

The intuition behind this result is that in a user market that is less than fully covered, the additional utility from OSes (i.e., cross-side network effects) entices some additional users to purchase. This also expands the range of parameter values under which the user market is fully covered, which benefits all parties. The introduction of OSes also introduces competition for another group of customers, the developers.

### 3.2 OS Competition for Developers

Because developers can multihome costlessly, mobile OSes \( M_0 \) and \( M_1 \) each operate as a local monopoly even if the markets intersect. For the moment, we ignore carriers but will re-introduce them at the end of the subsection. The sequence of events for this subsection is very simple: OSes simultaneously and uncooperatively set prices, then developers purchase.

The market for developers is a simple Hotelling model with (same-side) network effects, so it is straightforward to determine the strategies of the OSes.

**LEMMA 1:** In the presence of same-side network effects and no cross-side network effects, an OS firm \( i \) sets its price at \( \overline{v}_i/2 \) if \( v_i \leq 2(t_D - n_D) \), and at \( v_i + n_D - t_D \) otherwise.

**Proof:** Because multihoming is costless for developers, each OS behaves as a monopolist. The firm extracts the full surplus from the marginal developer on its platform, so from (5) and (6) we have the price for OS \( i \) as:

\[
p_{i0} = v_i + (n_D - t_D) \cdot Q_{D(i)}
\]

Solving the first-order conditions for (7) and (8) yields:
Substituting (20) into (19) results in a price of \( \frac{v_i}{2} \). However, the corner solution of \( Q_{D(M)} = 1 \) obtains if \( v_i \geq 2(t_D - n_D) \). In this case, plugging 1 in for the market size in (19) yields a price of \( v_i + n_D - t_D \). Note that the price function is continuous for all values of the same-side network effect and misfit cost, although the slope may change at \( Q_{D(M)} = 1 \). Q.E.D.

Up until this point we have simplified our exposition by ignoring the impact of carriers and users upon the developer market. Similar to Proposition 2 in the previous subsection, cross-side network effects from users raise the effective value of an OS to developers regardless of whether OSes enter exclusively or not. The general effect of users upon the developer market is outlined in Proposition 3. The detailed effects contingent upon the mode of OS market entry will be discussed in the next section.

**PROPOSITION 3:** The introduction of cross-side network effects into the developer market (i) strictly increases the prices charged to developers, and (ii) strictly increases the mass of developers on an OS unless the OS already fully covered the market.

Propositions 2 and 3 demonstrate that the mere presence of another side of the market affects market outcomes. In the next Section we explore the behavior of carriers and OSes if we allow their actions to affect each other’s decisions. Although each firm can easily decide its best response to a given configuration of the market, the configuration of the market itself depends crucially on how firms expect each other to respond to their decisions.

4. **Market Outcome with Strategic Interaction**

In this Section we bring together the decisions of carriers and the decisions of OSes to investigate their interactions in a multi-layer platform market. The sequence of events (see Figure 3) is the same as in subsection 3.1 except that two stages of contract negotiation are appended to the front to incorporate the interactions of firms’ strategies. We model the OSes as taking the lead in negotiations because their persistent differentiation gives them a stronger bargaining position relative to carriers [Sharma et al., 2007].

![Figure 3: Sequence of events when carriers and OSes interact strategically](image)

The magnitude of cross-side network effects on each side of the market now depends on the availability of bundles negotiated between the carriers and OSes in Stage 2. For the moment, let us assert
that \( \lambda < 1/2 - \sqrt{(\Lambda - 12k)/4\Lambda} \) (see Proposition 1) and thus carrier inherent quality is deterministically \( q \).

To keep the proof of Proposition 4 tractable, we introduce three lemmas first then assemble them in the Proposition’s proof. Each lemma describes a particular combination of bundle availability depending on any exclusive contracts negotiated in Stage 2. Proposition 4 then analyzes the OSes’ incentives to choose among these combinations.

The first market configuration we analyze is both OSes signing exclusively with the same carrier. Although such a configuration would almost certainly be blocked by regulators, it is a useful benchmark case because it creates essentially a monopoly integrated platform. Without loss of generality, we will assume that both OSes contract exclusively with \( C_1 \). The utility of a user located at \( \{x, \theta\} \) depends upon the bundle chosen. Recall that the prices for feature phones are normalized to zero, leading to the following utilities.

\[
U(C_0; x, \theta) = \theta q + n_u Q_{c(c_0)}
\]  
(21)

\[
U(C_1; x, \theta) = \theta q + n_u Q_{c(c_1)}
\]  
(22)

\[
U(C_1M_0; x, \theta) = \theta q + n_u Q_{c(c_1)} + N_u Q_{d(M_0)} - xt_u - p_{CIM_0}
\]  
(23)

\[
U(C_1M_1; x, \theta) = \theta q + n_u Q_{c(c_1)} + N_u Q_{d(M_1)} - (1-x)t_u - p_{CIM_1}
\]  
(24)

**LEMMA 2:** In the absence of quality investments, if both OSes enter exclusively on the same carrier then (1) the exclusive carrier forecloses the entire user market and (2) if \( t_d - n_d \leq (2v + N_o)/4 \); the profits for OSes and the exclusive carrier are \( v + N_o/2 - (t_d - n_d) \) and \( 2(N_u - n_u)/(t_u - 4n_u) \) respectively. Otherwise \( t_d - n_d > (2v + N_o)/4 \), and the profits for the OSes and the exclusive carrier are \( (2v + N_o)^2/16(t_d - n_d) \) and \( N_oN_u/4(t_d - n_d) - (t_u - 4n_u)/2 \) respectively.

**Proof:** With symmetric OSes, the exclusive carrier \( C_1 \) finds that its profit is increasing in prices until the developer market is maximized by bringing half of the users onto each OS.\(^{10}\) Therefore, all firm payoffs hinge on OSes’ success in covering the developer market. Fixing the user market share for an OS at \( \frac{1}{2} \), the marginal developer is located at \( x^* = (v + N_o)/2 - p_{M_0}/(t_d - n_d) \) resulting in an optimal price of \( p_{M_0}^* = (2v + N_o)/4 \) and a payoff of \( \pi_{M_0}^* = (2v + N_o)^2/16(t_d - n_d) \) if the developer market is not fully covered. Such partial coverage occurs when \( t_d - n_d \geq (2v + N_o)/4 \). Otherwise, the developer market is

\(^{10}\)Note that if any users purchase \( \{C_1, M_0\} \) or \( \{C_1, M_1\} \), then all users will prefer \( C_1 \)'s feature phones to \( C_0 \)'s feature phones due to superior same-side network effects. This is an artifact of abstracting away all horizontal differences between carriers, but it does not affect our results because \( C_1 \) prices its smartphone bundles to squeeze the feature phone segment out of existence.
fully covered and the OS charges \( p^*_m = v + N_D/2 - (t_D - n_D) \). Since this price is charged to a unit mass of developers, the OS firm’s payoff is also \( \pi^*_m = v + N_D/2 - (t_D - n_D) \).

Turning to \( C_1 \), the price \( p^*_{C1M0} = p^*_{C1M1} = N_D N_U / 4(t_D - n_D) - (t_U - 4n_U) / 2 \) is optimal if the developer market cannot be fully covered by each OS; otherwise \( p^*_{C1M0} = p^*_{C1M1} = 2(N_U - n_U) / (t_U - 4n_U) \) is optimal if \( C_1 \) can induce all developers onto both OSes. In general, the pricing function is discontinuous between these two cases. The payoff to \( C_1 \) is identical to the price since it is charged to a unit mass of users; the payoff to \( C_0 \) is zero. \textbf{Q.E.D.}

The intuition behind this result is that the exclusive carrier functions almost like a single-party platform: it is in the carrier’s interest to set prices for users that maximize developer participation. If developer misfit cost \( t_D \leq (2v + N_D) / 4 + n_D \) then each OS firm can profitably capture the entire developer market with monopoly pricing (recall that multihoming is costless, so each OS ignores the “competing” OS). The exclusive carrier wants maximal developer participation because it can use bundle pricing to extract some of the cross-side network effect enjoyed by users.

The next configuration we analyze is each OS contracting exclusively with a different carrier. This is similar to, but distinct from, the competing integrated platforms of prior literature [Katz & Shapiro, 1985; Rochet & Tirole, 2006; Griva & Vettas, 2011; Yoo et al., 2007]. Without loss of generality, we will assume that \( M_0 \) contracts with \( C_0 \) and \( M_1 \) contracts with \( C_1 \). A user’s utility from homing with each bundle is thus

\[
U(C_0M_0; x, \theta) = \theta q_{c0} - x t_{c0} + n_U Q_{U(c0)} + N_U Q_{D(M0)} - p_{c0M0}
\]

\[
U(C_1M_1; x, \theta) = \theta q_{c1} - (1-x) t_{c1} + n_U Q_{U(c1)} + N_U Q_{D(M1)} - p_{c1M1}
\]

Including the outside option of a feature phone normalized to zero price and utility, the user market is segmented by three indifference lines (users along an indifference line derive the same net utility from two different options). The indifference line between \( \{C_0M_0\} \) and a feature phone will slope upwards because at any given price the users close to \( x = 0 \) gain more utility from that bundle. Likewise, the indifference line between \( \{C_1M_1\} \) and a feature phone will slope downwards. The indifference line between the two smartphone segments will be a vertical line because users’ taste for quality is met equally by either platform. The end result is depicted in Figure 4.
LEMMA 3: In the absence of quality investments, if each OS enters exclusively on a different carrier then each carrier’s profit is $t_c/2$. The OS profits are identical to those in Lemma 2.

Proof: Conditional on each OS contracting exclusively with a different carrier, the market shares are symmetric and resemble Figure 4. The vertical divider between the symmetric bundles will of course be at $x = 1/2$.

The outside option region will be squeezed out of existence if the user at $\{1/2, \theta\}$ is induced to purchase, and carriers always find it profitable to do so. With full user market coverage the problem reduces to a Hotelling linear city model with market density $\tilde{\theta} - \check{\theta}$ (which is identically 1) and the standard payoff of $\pi_{c1} = t_c/2$. Equilibrium carrier profits are indifferent to network effects because these are competed away. The OSes’ decisions, prices and payoffs are identical to those in Lemma 2. Q.E.D.

The intuition behind this result is that the horizontal competition between carriers benefits OSes by fully covering the user market which attracts more developers through cross-side network effects. The final configuration we analyze is non-exclusive entry by both OSes. Under this configuration both the OSes, $M_0$ and $M_1$, are available on both the carriers, $C_0$ and $C_1$. In this configuration, a user can choose from all possible bundles.

LEMMA 4: In the absence of quality investments, if both OSes enter on both carriers then carrier profits are zero. OS decision and payoffs are the same as in Lemma 2.

Proof: The carriers offer identical “differentiated” bundles at the same quality level and therefore forced to offer the OSes under Bertrand competition. Carriers’ prices and payoffs are identical to those in §3.1, namely zero. Since the user market is fully covered under Lemma 3 with positive prices, it must also be fully covered here with prices set to zero. The OS firms’ decisions and prices are again identical to those in Lemma 2. Q.E.D.
The intuition behind these results is that OS firms are indifferent to why the user market is covered; their interest is in covering the developer market.

With the results of Lemmas 2, 3 and 4 in hand, we can now model the OS firms’ entry decisions via reverse induction. That is, the OS firms rationally expect the outcomes described above and choose the entry mode that benefits them most. The overall decision is described in Proposition 4.

**PROPOSITION 4:** In the absence of quality investments by carriers, OSes are indifferent to entering exclusively on a single carrier or entering non-exclusively on all carriers.

The intuition behind this result is that OS decisions and payoffs are unchanged by exclusivity because, in the absence of quality investments, users are always distributed equally on the two OSes. Under the conditions examined thus far, exclusive contracts do not benefit OSes, although they do have impacts on carriers as detailed in the following corollary.

**COROLLARY 1:** The entry of mobile OSes increases carrier industry profits if and only if the OSes enter the market exclusively. Carrier industry profits are unchanged if both OSes enter non-exclusively (are available on both carriers).

The intuition behind this result is that carriers benefit from market power due to having a quality advantage, an exclusive OS, or both. The cross-side network effects from non-exclusive OSes are competed away to users, so exclusivity is valuable to carriers. Just as OS entry decisions can affect carrier firms, carrier investment decisions can affect OS firms’ payoffs and even manipulate their entry decisions.

Taking this strategic interaction one step further, there are conditions under which OSes prefer carriers to invest – possibly forcing the OSes to enter exclusively – when the carriers themselves prefer not to invest. Proposition 5 shows that under certain conditions, OS firms offer to subsidize these investments that carriers otherwise would not make. Generalizing the results from Lemma 2 to asymmetric market coverage yields an optimal price for OS i of

\[ p_{i0} = \left[ v + N_D \left( Q_{i(\text{COM})} + Q_{i(\text{CLM})} \right) \right] / 2 \]

with a payoff of

\[ \left[ v + N_D \left( Q_{i(\text{COM})} + Q_{i(\text{CLM})} \right) \right]^2 / 4 (t_D - n_D) \]

if the developer market is not fully covered. If the developer market is fully covered, then OS i’s optimal price is

\[ p_{i0} = v + N_D \left( Q_{i(\text{COM})} + Q_{i(\text{CLM})} \right) (t_D - n_D) \]

charged to a unit mass of developers.

When the developer market is fully covered even in a worst-case scenario (exclusively available on a low-quality carrier that is competing against a high-quality carrier), OSes are ex-ante indifferent to the zero-sum game of moving users between carriers. OSes become interested in quality investments if there is any possibility that the developer market will be partially covered; under these conditions OS payoffs are strictly convex in the OS’s user market share. The parameter values under which these
conditions hold are illustrated in Figure 5. An OS would be willing to pay up to a fraction \( \lambda^2(1-\lambda)^2 \) of the difference between the expected value with quality investments and the known payoff without quality investments. This payment would be made to the carrier(s) to offset \( k \) with payment conditional on the investment being made.

Under exclusive entry, the OS benefits fully from its proxy investment through the carrier. Under non-exclusive entry, the OS gets deterministically half of the users served by carriers, which yields revenues identical to those in Proposition 4. Since identical revenues are available to OS firms without investment, there is no incentive for OS firms to subsidize the carriers’ investments. We formally present this result in the following Proposition.

**PROPOSITION 5:** An OS firm would be willing to pay an exclusive carrier to offset a fraction \( 2(\lambda - \lambda^2) \) of quality investment cost, \( k \), if developers’ cross-side network effects are sufficiently weak \( N_d < 3[2(t_d - n_d) - v]/(\Delta \theta - \theta) \). Otherwise \( N_d \geq 3[2(t_d - n_d) - v]/(\Delta \theta - \theta) \), and OS firms will not subsidize carrier quality investment, and they are indifferent to entering exclusively or non-exclusively.

The intuition behind this result is that when the developer market is not fully covered, additional users on an OS are very valuable for attracting additional developers. If the condition \( N_d < 3[2(t_d - n_d) - v]/(\Delta \theta - \theta) \) is met then the developer market is less than fully covered in at least one potential outcome (namely, exclusive entry on a carrier that turns out to be the low-quality firm). Such a potential guarantees that the OS payoffs are convex in users, making the risk-neutral OS firms prefer risky exclusive entry. Exclusive entry is risky because exclusivity and side-payments are contracted before investment outcomes are determined. Rather than deterministically splitting the user market 50-50, quality investments allow a winner-take-most outcome for carriers with equal probability of being the high-quality or low-quality firm. Figure 5 shows the parameter values for which the OS firms find risky exclusive entry preferable ex-ante. The horizontal axis measures the lowest willingness-to-pay for quality; with larger values indicating a smaller relative spread in WTP among users and higher market share for the high-quality carrier. The vertical axis measures cross-side network effects received by developers. The driver behind Figure 5 is shown in Figures 6 and 7 which illustrate the convex payoff possibilities. The curved thicker blue portion of the graph representing partial developer coverage, and the linear thinner red portion representing full developer coverage. The expected value of a winner-take-most market is the midpoint of the dashed line,\(^{11}\) whereas the value of a 50-50 user market is the point on the red-blue graph at \( Q_U = 1/2 \). If the dashed line is above the red-blue graph, firms rationally prefer the risky option to the deterministic one. That is, OS firms strictly prefer risky exclusive entry whenever (1)

\(^{11}\) It is the midpoint because the OS has an equal probability of finding itself exclusive with the higher quality carrier or the lower quality one.
the developer market would be partially covered in any feasible market state and (2) carriers are not sufficiently motivated to invest on their own.

![Diagram showing exclusive entry regions for various parameter values](image)

**Figure 5: OS exclusive entry for various model parameter values**

This figure shows the regions in which the OS will decide to enter exclusively with $n_D = 1/8$ and several values of $t_D$ and $v$. The OS firm prefers exclusive entry when parameters are below and to the right of the curve.

We chose specific parameter values in Figures 6 and 7 to illustrate three important cases. We fix $\theta$ at $1/2$ and $N_D$ at 1 in each case to set up the possibility of a significant winner-take-most outcome; the high-quality carrier attracts 5/6 of the users and the low-quality carrier is left with only 1/6 of the users. In Figure 6, an OS exclusive on a low-quality carrier is in the blue portion of the graph while an OS exclusive on a high-quality carrier is in the red portion. A non-exclusive OS always has 1/2 of the users between the two carriers. Here the convex nature of the payoff is pronounced: a low-quality outcome is slightly worse than a 50-50 split, but a high-quality outcome is much better. The expected payoff of unequal quality carriers (indicated by the midpoint of the dashed line) is significantly higher than the expected payoff of equal qualities and/or non-exclusive entry (indicated by the point of the red-blue graph at a user market share of 1/2). This difference, shown in green, gives the OS firm an incentive to subsidize an exclusive carrier’s quality investment. Since the quality investment only yields unequal carrier qualities with probability $\lambda^2(1-\lambda)^2$, OS firms are willing to pay up to a fraction $\lambda^2(1-\lambda)^2$ of the difference.
Figure 6: OS payoff for different levels of user market share

This figure shows the OS firm’s payoff (vertical axis) in terms of the OS’s total share of users (horizontal axis). Although the payoff function is continuous, the only possible outcomes are “lower quality,” “higher quality” and “split market evenly.” OS entry decisions depend on the distance between the known value of equal qualities and the expected value of unequal qualities.

The difference is less pronounced in either panel of Figure 7. In the left panel, all possible outcomes are in the blue portion. The expected value to an OS firm of unequal quality exclusive carriers is strictly higher than the expected value of a 50-50 split, but not by much. In this case, an OS firm would prefer exclusive entry but would offer little or no assistance to the carrier for quality investment. Transferring this result to Figure 5, the parameter values are only slightly below and to the right of the curve. In the right panel, all possible outcomes are in the red portion. The expected value of unequal quality exclusive is exactly the same as the expected value of a 50-50 split. An OS firm is therefore indifferent to exclusive or non-exclusive entry, representing a point above and to the left of the curve in Figure 5. Note that carriers still prefer exclusive entry and may be willing to pay OS firms to sign such contracts.
Figure 7: OS payoffs when developer market partially covered (left) and fully covered (right)

Left panel: All feasible outcomes result in partial coverage of developers, and the expected value of unequal qualities is only slightly above the known value of equal qualities. Right panel: All potential outcomes resulting in full coverage of developers, and ex-ante the OS firm is indifferent to carrier quality investment.

5. Discussion and Conclusion

When a single strategic firm controls a platform in a two-sided market, it is often in this firm’s interest to subsidize customers on one of the sides. However, the economically important smartphone market that links app developers and end users requires the coordination of two strategic firms to enable a platform. Importantly, each firm controls prices on only one side of the market. Many of the characteristics of the smartphone market identified in our study originate from the lack of price coordination between OSes and carriers. If a single firm was able to make pricing decisions on both sides of the market, it could create the positive effects identified by Choi (2010). The lack of coordination in the smartphone market is a version of the double marginalization often seen in vertical supply chains. Existing two-sided network models cannot address this very important problem because they implicitly assume that the platform partners are perfectly cooperative. Even the limited cooperation of an exclusive contract usually requires revenue sharing [Cai et al., 2012], but our model demonstrates that cross-side network effects can substitute for revenue sharing by giving each firm some ability to affect the revenue of the other.

This coordination emerges endogenously in a smartphone market modeled as a multilayer platform with two mobile operating system vendors and two mobile wireless carriers. Users have horizontally differentiated preferences for OSes but have vertically differentiated willingness-to-pay for carrier quality, creating a Hotelling square of user preferences. On the other hand, developers have only horizontal preferences for OSes, creating a Hotelling line of developers. Users as well as developers experience positive same-side and cross-side network effects. The locations of carriers and OSes and quality levels are publicly observable as are the distributions of developer and user preferences, but the specific locations of developers and users are their private information. Moreover, OS firms have the
bargaining power to choose to enter the market exclusively or non-exclusively while carriers have an opportunity to make risky quality enhancing investments.

In the absence of a platform-style smartphone, wireless carriers make quality enhancing investments (for example, upgrading towers to the next “G” of service) only when the probability of success is moderate (in this example, success concerns speed rather than whether the technology works). This is so because if the probability of success is too high or too low then both wireless carriers are more likely to end up with same quality level, leading to Bertrand competition and net negative payoffs (in this example, rushed deployment yet no first-mover advantage). If the market on the user side is not fully covered, then the introduction of mobile OSes increases the market coverage on the user side. When OSes offer apps on smartphone-style platforms, prices charged to developers increase due to cross-side network effects and market coverage on developer side increases (if it is not already fully covered without the mobile platform).

We show that exclusive contracting changes the basis of competition in multilayer mobile platforms. Wireless carrier firms prefer (have higher expected payoffs) if OS firms enter into exclusive contracts with them, but our model shows that for many parameter values the OS firms are indifferent to exclusive or non-exclusive entry. On the other hand, under many parameter values OS firms prefer for wireless carriers to make risky quality investments even if the carriers themselves do not find the investment attractive. Limited cooperation arises endogenously in our model wherein OS firms agree to enter exclusively on a carrier and subsidize that carrier’s quality investment.

In our model, the user’s outside option is a feature phone at competitive prices. Another outside option that has emerged recently is the tablet. A tablet with mobile data service is equivalent to a smartphone for the purposes of market structure, but a user purchasing a feature phone and a separate Wi-Fi tablet has effectively contacted the app developer side of the market without a wireless carrier intermediary. The economic impact of this option would be to give the OS more bargaining power in its negotiations with carriers. Since our model gives the OS significant bargaining power already, the inclusion of Wi-Fi tablets would not change our results materially.

Another potential change is that a regulator may believe that exclusive contracts between OS firms and wireless carriers are not socially optimal. Such a regulator might be able to restrict the length of exclusivity, perhaps to zero as in the case of courts in several countries disallowing exclusivity altogether [Bougette et al., 2012]. An important consideration is the regulator’s objective function.

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12 Evidence of OS firms’ superior bargaining is also seen in the inclusion of “over-the-top” apps that compete directly with wireless carriers’ services, e.g. iMessage and Skype.
Actions to maximize end user welfare [Bougette et al., 2012; Chen & Fu, 2012] might not maximize social welfare by ignoring firm profits and app developer welfare.

Like all models, ours is a stylized representation of reality that has limitations. First, in the smartphone ecosystem, handset makers form a layer joining OSes and carriers. Our model implicitly treats these handset makers as non-strategic providers of commodities. Apple is vertically integrated with the sole handset maker for its OS, Microsoft is vertically integrated with one of several handset makers for its OS, and Google has not integrated with any handset maker. If handset makers are neutralized by competition in their layer then our model is unchanged. Our model does not address how a strategic handset maker (e.g., Samsung for the Google’s Android OS) might affect strategies, although we expect that adding layers would exacerbate the coordination issues already present with two layers.

The primary distortion introduced by a multilayer network is double marginalization. The set of “optimal” prices that would maximize total profits for the platform is never achieved unless self-enforcing contracts can be written to coordinate the firms’ actions. Such coordination may take the form of side payments or subsidies for the partner firm’s customers. Future work in this area may be able to identify self-enforcing contract mechanisms that improve industry profits beyond the case we identified involving quality investments. Existing two-sided network models cannot address this very important problem because they implicitly assume that the platform partners are perfectly cooperative.

Other fruitful avenues for future research can address the contracting issues when OSes are asymmetric in their strategies. One OS moves first and makes an irreversible decision, and the second OS makes its decision based on what the first did. This could also be visualized as a “Penguin effect” [Choi, 1997] problem because the model parameters would involve uncertainty for the first mover. It appears that Apple perceived the market to be similar to the left panel of Figure 7. This perception led them to enter exclusively on AT&T but not to commit any significant resources toward upgrading AT&T’s infrastructure.

References


Appendix 1: Analytic Proofs

PROPOSITION 1: The range of \( \lambda \) that leads to investment is an open interval centered on \( \lambda = \frac{1}{2} \). For a given cost of investment, this range becomes wider in response to an increase in (1) same-side network effect, (2) difference between high and low quality outcomes, or (3) difference in highest and lowest willingness-to-pay for quality. The maximum feasible cost of investment increases in response to the same three exogenous factors.

Proof: Because the firms are symmetric, either both will invest or neither will. The outcome for non-investment is zero profits for each firm due to Bertrand competition. This is the outside option against which investment is compared. Conditional on investment, the investment cost \( k \) is sunk. There is a probability equal to \( \lambda^2 + (1 - \lambda)^2 \) that both the carriers end up with high quality or low quality. In this case both carriers have equal quality and Bertrand competition ensues with zero revenue and payoffs to each firm of \(-k\). Otherwise the focal firm will earn “high quality” profits or “low quality” profits with equal probability. Overall, the expected profit conditional on investment and full user market coverage is:

\[
E[\pi_{e0}] = E[\pi_{e1}] = (\lambda - \lambda^2) \left[ \frac{(2\overline{\theta} - \theta)^2}{3} \left( q - \frac{n_v \cdot (\theta - \overline{\theta})}{3} \right) + (\lambda - \lambda^2) \left[ \frac{(\overline{\theta} - 2\theta)^2}{3} \left( q - \frac{n_v \cdot (\theta - \overline{\theta})}{3} \right) \right] - k \right] \tag{27}
\]

The first term of the RHS is the expected payoff of being the “high quality” firm, the second term is the expected payoff to being the “low quality” firm, and \( k \) is the sunk cost of the investment. To simplify our exposition, we define a notation \( \Lambda = \left( \Delta q + \frac{n_v \cdot \Delta \theta}{3} \right) \cdot \left( 5\overline{\theta}^2 - 8\overline{\theta}\theta + 5\theta^2 \right) \) which is always positive.\(^{13} \) Then each firm will independently decide to undertake the investment if (27) is greater than zero, or equivalently \( \lambda \cdot (1 - \lambda) \geq \frac{3k}{\Lambda} \). This occurs if and only if \( 0 < k < \Lambda/12 \) and \( 1/2 - \sqrt{(\Lambda - 12k)/4\Lambda} \leq \lambda \leq 1/2 + \sqrt{(\Lambda - 12k)/4\Lambda} \).

\(^{13} \)The first factor is unambiguously positive. Rewrite the second factor as \( \left( 4\overline{\theta}^2 - 8\overline{\theta}\theta + 4\theta^2 \right) + \left( \overline{\theta}^2 + \theta^2 \right) \). The first sub-expression factors to \( 4(\overline{\theta} - \theta)^2 \), so both sub-expressions are strictly positive for any nonzero real values of \( \overline{\theta} \) and \( \theta \).
It is clear from these conditions that the admissible range for $\lambda$ is centered on $\frac{1}{2}$. The strict inequality for $k$ guarantees that the final solution will be an open set. For fixed $k$, the range is widening in $\Lambda$. Also, the maximum feasible cost for the investment is increasing in $\Lambda$. It remains to be shown that $\Lambda$ is increasing in (1) same-side network effect, (2) difference between high and low quality outcomes, and (3) difference in highest and lowest willingness-to-pay for quality. Now we rewrite $\Lambda$ as

$$\Lambda = \left(\Delta q + \frac{n_U \cdot \Delta \theta}{3}\right) \left[5(\theta + \Delta \theta)^2 - 8(\theta + \Delta \theta)\theta + 5\theta^2\right].$$

Because the term in square brackets is always positive, it is clear that $\Lambda$ is increasing in (1) same-side network effect $n_U$ and (2) difference between high and low quality outcomes $\Delta q$. For factor (3), it is sufficient that the derivative

$$\frac{\partial \Lambda}{\partial (\Delta \theta)} = \left(\Delta q + \frac{n_U \cdot \Delta \theta}{3}\right) \left[10(\theta + \Delta \theta)\Delta \theta - 8(\theta + \Delta \theta)\theta + 5\theta^2\right]$$

is unambiguously positive. All three marginal effects work in the same direction under partial coverage of the user market. Q.E.D.

**PROPOSITION 2:** The addition of one or more mobile OSes with cross-side network effects increases coverage of the user market for any $\bar{\theta} \leq \theta \left[3q + 2\Delta q + n_U \cdot (\theta + 5\Delta \theta)/3\right]$. Otherwise, the user market is fully covered under same-side network effects and remains covered with cross-side network effects.

**Proof:** The user market is fully covered under same-side network effects if $\bar{\theta} \leq \theta \left[q + 2\bar{q} + n_U \cdot (5\bar{q} - 4\theta)/3\right]$. Under partial user market coverage, coverage is decreasing in the amount by which $\bar{\theta}$ exceeds the upper bound. The introduction of cross-side network effects introduces a positive additive term to the upper bound, decreasing the excess (perhaps eliminating it entirely), and therefore increasing the market coverage of users. Q.E.D.

**PROPOSITION 3:** The introduction of cross-side network effects into the developer market (i) strictly increases the prices charged to developers, and (ii) strictly increases the mass of developers on an OS unless the OS already fully covered the market.

**Proof:** The cross-side network effect is a function of the OS’s market share, effectively increasing the same-side network effect. Depending on the OS-carrier bundles available in the market, the increase in effective same-side network effects may be symmetric or asymmetric. Inspection of (20) reveals that increasing $n_D$ will strictly increase each OS’s market share unless it was already at the corner solution of 1. Inspection of (19) shows that an effectively higher $n_D$ has a first-order positive impact on the price and a second-order positive effect on the price from the weakly larger market share. Q.E.D.
PROPOSITION 4: In the absence of quality investments by carriers, OSes are indifferent to entering exclusively on a single carrier, entering exclusively on different carriers, or entering non-exclusively on all carriers.

Proof: If both carriers are of the same quality, any entry regime by OSes leads to full user market coverage with exactly one-half of users using each OS. Although entry regimes affect which carrier serves which user, OS firm payoffs are driven by developer market coverage which depends on the quantity of that OS’s users, not which carrier is serving them. Q.E.D.

COROLLARY 1: The entry of mobile OSes increases carrier industry profits if and only if the OSes enter the market exclusively. carrier industry profits are unchanged if both OSes enter non-exclusively (are available on both carriers).

Proof: Comparing carrier profits under Lemmas 3 and 4, the market power from exclusive entry leads to higher profits for carriers if no quality investments are made. This effect generalizes to the case of quality investments: In a differentiated market with same-side network effects, each firm can charge positive prices whether they have the same or different quality levels [Griva & Vettas, 2011].

If both OSes are available on both carriers, then the carriers are offering identical “differentiated” products. Carriers offer the OSes under Betrand competition, and firm profits derive entirely from investment decisions and quality differences. Q.E.D.

PROPOSITION 5: An OS firm would be willing to pay an exclusive carrier to offset a fraction $2(\lambda - \lambda^2)$ of quality investment cost, $k$, if developers’ cross-side network effects are sufficiently weak.

$N_d < 3[2(t_d - n_d) - v]/(\Delta \theta - \theta)$. Otherwise $N_d \geq 3[2(t_d - n_d) - v]/(\Delta \theta - \theta)$; OS firms will not subsidize carrier quality investment, and they are indifferent to entering exclusively or non-exclusively.

Proof: When quality investment is feasible, an OS firm has three choices upon entering the market.

1. Enter exclusively with a carrier that will make a risky quality investment
2. Enter exclusively with a carrier that will not make a risky quality investment
3. Enter non-exclusively on both carriers

Option 2 yields payoffs consistent with Lemma 3 while option 3 yields payoffs consistent with Lemma 4 (which are identical to Lemma 3 for the OS firm). These are risk-free options for the OS firm, and it would be indifferent between them. If the conditions of Proposition 1 are met, then both carriers will always invest removing option 2.

The potential payoffs for the OS firm are three points along an underlying piecewise function:
\[
\pi_{M_1}^* = \begin{cases} 
\frac{v + N_D \left( Q_U(C_{OM}) + Q_U(C_{MI}) \right)^2}{4(t_D - n_D)} & \text{if } Q_{D(M)} < 1 \\
 v + N_D \left( Q_U(C_{OM}) + Q_U(C_{MI}) \right) - (t_D - n_D) & \text{if } Q_{D(M)} = 1
\end{cases}
\]

(29)

Specifically the points are a “low” outcome at \((Q_U(C_{OM}) + Q_U(C_{MI})) = (\Delta \theta - \bar{\theta})/3\), “medium” outcome at \((Q_U(C_{OM}) + Q_U(C_{MI})) = 1/2\) and “high” outcome at \((Q_U(C_{OM}) + Q_U(C_{MI})) = (\Delta \theta + \bar{\theta})/3\). Entering the market with option 1 gives the OS firm a lottery over all three possible outcomes. That is, the OS firm has some non-zero probability of obtaining each outcome; it is convenient to consider the lottery to have probability \(2(\lambda - \bar{\lambda}^2)\) of being in the “low” or “high” outcome and probability \(1 - 2(\lambda - \bar{\lambda}^2)\) of being in the “middle” outcome. Entering with option 2 or 3 always yields the “middle” outcome with probability 1. Thus, option 1 yields a payoff identical to option 2 with probability \(1 - 2(\lambda - \bar{\lambda}^2)\). The OS firm has a higher expected value from option 1 if the lottery, conditional on not being in the “middle” outcome, is strictly convex (see Figure 6).

The overall function in (29) is convex because the first piece is strictly convex as it is quadratic and the second piece is convex (but not strictly convex) as it is linear. The lottery is always convex and it is strictly convex if at least one outcome is in the strictly convex piece of (29). We must show that the “low” outcome is in the strictly convex piece; i.e., the developer market is partially covered in the low-quality condition. Substituting the low-quality user market share (14) into the developer market share, this condition becomes

\[
1 > \frac{v + N_D \Delta \theta - \theta}{2(t_D - n_D)}
\]

(30)

\[
N_D < \frac{2(t_D - n_D) - v}{\Delta \theta - \bar{\theta}}
\]

If the lottery is strictly convex yet the conditions of Proposition 1 are not met, the OS firm would be willing to make a side-payment to an exclusive carrier to subsidize the cost of investment. The OS firm’s willingness to pay is the lesser of (1) the shortfall between what the carrier is willing to pay and the actual \(k\) required, and (2) the difference in expected value between the option 1 lottery and the certain payoff of option 2 or 3. Writing the payoffs in the pattern of (18), that difference simplifies to
\[ E[\text{Option}_1 - \text{Option}_2] = [\lambda^2 \cdot \pi_{\text{High}} + (\lambda - \lambda^2) \cdot \pi_{\text{Low}} + (1 - 2(\lambda - \lambda^2)) \cdot \pi_{\text{Low}}] - \pi_0 \]

\[ = 2(\lambda - \lambda^2) \left( \frac{\pi_{\text{High}} + \pi_{\text{Low}}}{2} - \pi_0 \right) \]  

where \( \pi_0 \) is the payoff for options 2 and 3, and \( \pi_{\text{High}} \) and \( \pi_{\text{Low}} \) are the payoffs of being exclusive with the high- and low-quality firms, respectively. The difference is equal to the vertical difference between Figure 6’s dashed line and the underlying function at \( Q_{U(COM0)} + Q_{U(C1M0)} = \frac{1}{2} \) multiplied by the probability of not being in the middle state under option 1.

The OS firms have no incentive to subsidize investments if all three outcomes are in the linear piece of the underlying function (that is, if the developer market is fully covered in any potential outcome). The lottery’s expected value from option 1 is exactly equal to the known payoff of options 2 and 3,\(^\text{14}\) yielding a willingness to pay of zero. \( \text{Q.E.D.} \)

\(^{14}\) In this case, \( (\pi_{\text{High}} + \pi_{\text{Low}})/2 = \pi_0 \).
## Appendix 2: Summary of Notation

### Table 1: Summary of notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_0$, $C_1$</td>
<td>Mobile carriers</td>
</tr>
<tr>
<td>$\Delta a$</td>
<td>Difference between the maximum and minimum values of “$a$,” that is, $\bar{a} - \underline{a}$</td>
</tr>
<tr>
<td>$I_j$</td>
<td>Investment decision by $j$ equal to 1 for investment and 0 otherwise</td>
</tr>
<tr>
<td>$k$</td>
<td>Cost for a carrier to undertake the uncertain investment</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Probability of success for carrier’s uncertain investment</td>
</tr>
<tr>
<td>$\Lambda$</td>
<td>Constant calculated from exogenous parameters (see page 14)</td>
</tr>
<tr>
<td>$M_0$, $M_1$</td>
<td>Mobile OS vendors located at $x = 0$ and $x = 1$, respectively</td>
</tr>
<tr>
<td>$n_D$</td>
<td>Same-side network effect benefit from a unit mass of developers</td>
</tr>
<tr>
<td>$n_U$</td>
<td>Same-side network effect benefit from a unit mass of users</td>
</tr>
<tr>
<td>$N_D$</td>
<td>Cross-side network effect benefit from a unit mass of users, received by a developer</td>
</tr>
<tr>
<td>$N_U$</td>
<td>Cross-side network effect benefit from a unit mass of developers, received by a user</td>
</tr>
<tr>
<td>$p_j$</td>
<td>OS $j$’s price to developers</td>
</tr>
<tr>
<td>$p_{ij}$</td>
<td>Carrier $i$’s price to users for the bundle including OS $j$</td>
</tr>
<tr>
<td>$\pi_j$</td>
<td>Payoff (profit or surplus) for $j$</td>
</tr>
<tr>
<td>$q_j$</td>
<td>Quality of carrier $j$</td>
</tr>
<tr>
<td>$\underline{q}$</td>
<td>Minimum and maximum values for users’ $\theta$</td>
</tr>
<tr>
<td>$\bar{q}$</td>
<td>Possible quality levels for a carrier with $\bar{q} &gt; q &gt; 0$</td>
</tr>
<tr>
<td>$Q_{i(j)}$</td>
<td>Quantity of $i$ meeting condition $j$. For example, $Q_{U(C_1,M_1)}$ are users of $M_1$ on $C_1$’s service.</td>
</tr>
<tr>
<td>$t_D$, $t_U$</td>
<td>Transport cost for developers and users to “travel” one unit in the $x$ direction</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Users’ willingness to pay for quality parameter</td>
</tr>
<tr>
<td>$\underline{\theta}$, $\bar{\theta}$</td>
<td>Minimum and maximum values for users’ $\theta$</td>
</tr>
<tr>
<td>$U(ij;x,\theta)$</td>
<td>Payoff for user located at $x$ and WTP $\theta$ who homes with bundle ${i,j}$</td>
</tr>
<tr>
<td>$v$</td>
<td>Inherent value received by a developer for homing with an OS</td>
</tr>
<tr>
<td>$V(j;x)$</td>
<td>Payoff for developer located at $x$ who homes with OS $j$</td>
</tr>
<tr>
<td>$x$</td>
<td>Location indices for developers and users for preference between OSes</td>
</tr>
</tbody>
</table>