Platform Pricing and Investment to Drive Third Party Value Creation in Two-Sided Networks

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Abstract

Many two-sided platforms (e.g., eBay, Google, iOS, Android, Twitter, Amazon) provide integration tools, such as modular interfaces, interactive development environments, application programming interfaces (APIs), and help desks to reduce the costs and improve the functionality of third party content developed for the platform. The need for such investment is increasing with the rise of major new markets such as the Internet of Things. While crucial to platform success, platform integration tools are costly to create. We develop an analytic model to explore the key trade-offs behind investment in integration tools and how that investment interacts with pricing decisions in a two-sided market. We model these decisions under various scenarios including monopoly and competitive platforms as well as symmetric and asymmetric platforms. Our results suggest that the consideration of integration investment can push the market into regimes in which the standard pricing results from extant platform literature no longer hold, in particular the tendency to reduce prices to one side of a market in response to increasing benefit of the network to the other side. Moreover, integration investments must be well-coordinated with developer and consumer pricing decisions and may have to be revised dynamically as the platform gains traction in the market. Higher levels of investment into integration become desirable when the platform (1) faces favorable expectations, (2) has access to a high-quality developer community, and (3) operates in a market where developers earn a high profit margin creating content that is highly valued by the consumer market. Finally, we also discuss a number of policy implications of this work.

Subject Classifications: Two-sided markets, Network externality, API, Application Programming Interface, Developers, Integration, Ecosystem

1 Introduction

In the last two decades, many industries have been transformed with the proliferation of two-sided platforms that bring together consumers and content providers. Platforms are everywhere in the information exchange and retail space, from shopping sites (e.g. Amazon.com, e-bay) and social media (e.g., Facebook, Twitter) to video-games (e.g., Xbox, Wii) and operating systems (e.g. iOS and Android). Now they are beginning to embed themselves even more deeply into our lives as home automation platforms begin to encompass sensors and actuators throughout the household to automate and control functions like thermostats, lighting, security, and home entertainment. Eventually, this "internet of things" (IoT) is forecast to extend even to urban functions such as traffic control and garbage collection (Barrie 2015, Shueh 2016), making the importance of platforms to society ever more pronounced (Evans and Annunziata 2012).

In areas where platforms have gained traction, the ability of a platform to encourage the development of a variety of content (such as games, productivity applications, and videos) and to integrate that content into a seamless user experience has become crucial in determining a platform's success. Thus, it is in the best interest of platform providers to make their platforms attractive and effective development environments for third party content providers. The problematic experience of mobile application development for electronic healthcare record platforms, such as EPIC, shows, however, that such a seamless environment for integrating the content and functionality of third-party developers is not automatic (Lim and Anderson 2016). For example, one digital healthcare entrepreneur described how his engineers "... tried valiantly to integrate (hack) antiquated databases in order to get our patient engagement software to speak securely to legacy systems" (Kim 2015). Another startup CEO said that "Lack of [tools for easy integration] for electronic healthcare records programs is killing mobile-health applications." (Lim and Anderson 2016). This difficulty suggests that, like any other technical product, platforms must invest resources and time in developing an environment that promotes the easy integration of third-party content, else their attractiveness to third-party developers, and ultimately to customers, will be stunted (Anderson and Parker 2013).

In the information exchange space, there are a number of tools to promote such product integration (Anderson, Chandrasekaran, Davis-Blake and Parker 2013), the most obvious examples being dedicated development environments, self-contained tasks with well-specified interfaces, standards,

organizational structures (such as help desks), software development kits (SDK), which create specialized development environments, and application programming interfaces (APIs), which improve platform modularity. Among these tools, APIs have gained significant traction in recent years (Figure 1). An API is a set of programming instructions for building software applications for a platform and gaining access to important data streams. Platforms ranging from Amazon and eBay to Youtube, Twitter, and Netflix have invested in providing powerful and user-friendly APIs (Kane 2010). Platform providers offer publicly available APIs to reduce third-party developers' cost of content development, which makes the platform more attractive to the developer community (Benzell, Lagarda and Alstyne 2016). A good API makes the platform more modular by providing well-defined interfaces for the application to the platform, hence reducing development costs for the third-party content provider. Furthermore, additional investment in "bullet-proofing" APIs can make the platform more reliable and provide users a more seamless user experience. Other integration tools, such as SDKs, also reduce costs to develop superior, well-integrated content by providing essential building blocks and development environments, which further improves the attractiveness of the platform for the developer community. When the content developers are on board, consumers are more likely to follow.

Platform investment in integration tools (as shown in Figure 1's depiction of the growth of public APIs over time) has been increasing rapidly over time. The need for integration investment will likely only accelerate with the arrival of IoT platforms. By 2020, as many as 30 billion "things" are expected to connect to each other over the IoT (IDC 2016). For an IoT platform to generate the benefits anticipated by industry experts (Reisinger 2015), physical device developers will need a low cost way to exchange data across the platform as well as give the platform the means to control these devices. For example a light-switch manufacturer, whose products generally cost less than two dollars, will need a wifi transmitter and software to hook up to a home IoT platform. It is also argued that a mature IoT will require common standards within and across literally hundreds to thousands of device types for communication and connectivity and that translators will be needed to bridge the gap between legacy devices and the ones designed with IoT in mind (IDC 2016). This will be expensive on the part of the platform firms. However, the reason they need to do this is that low margin developers, like the light-switch manufacturer discussed above, cannot afford to invest in mating up to multiple wifi and software protocol standards. This is where investing in

carefully crafted integration tools will be critical. With such tight developer margins, anything the platform can do to reduce developer costs is of the utmost importance, because an IoT platform is only be as powerful as the number of third-party sensors and actuators that integrate with the platform.

It is well known in the product development literature that the development of product integration tools and organizational structures, such as modularity, standards, and help desks, are expensive, yet of decisive importance for market success (Baldwin and Clark 2000). A notable example is Jeff Bezos's famous mandate at Amazon–"All teams will henceforth expose their data and functionality through service interfaces. All service interfaces, without exception, must be designed from the ground up to be externalizable. That is to say, the team must plan and design to be able to expose the interface to developers in the outside world. No exceptions" (Barrie 2011). Yet, despite these documented, remarkable investments in tools to facilitate third party content development, we are not aware of a significant body of work in the two-sided platforms literature that examines the optimal level of investment in integration tools such as APIs, SDKs, standards, specifications and help desks, nor how to coordinate that investment with pricing decisions. Our paper leverages the literature on product integration (Iansiti 1998, Anderson and Parker 2013) to attempt to close this gap. By doing so, we hope to provide a guide to platforms on how to better coordinate such decisions with other strategic decisions, particularly as platforms move out of the information exchange and retail industries into newer, less forgiving fields such as healthcare and, ultimately, the internet of things.

To investigate this crucial integration investment decision at a deeper level, we build a strategic model to analyze optimal investment into integration tools by two-sided platforms. We first examine decisions made by a monopolist platform by focusing on the interplay between integration tool investment and pricing decisions. A number of interesting insights emerge from this analysis. One important observation is that, when integration investment is considered, some standard results from the two-sided market literature are superseded. For example, a standard result from the two-sided market literature is that if the benefit of the platform's network externalities to one side of the two-sided market increases, then the price charged to the opposite side should *decrease* (Parker and Van Alstyne 2000*b*, Rochet and Tirole 2003, Parker and Van Alstyne 2005). However, our results suggest that it may be optimal to *increase* the developer participation fee when consumer utility
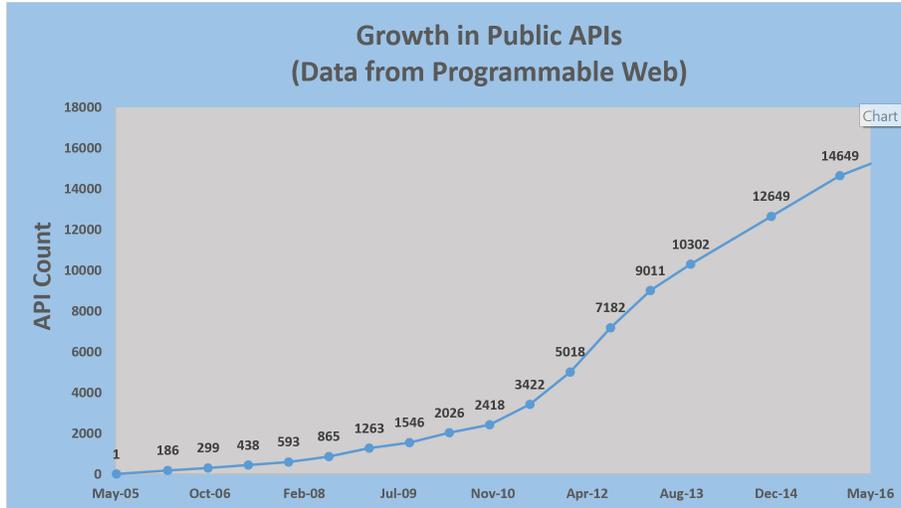
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Figure 1: Growth of the API Economy–data taken from ProgrammableWeb.com

from content goes up. The reason is that investing in integration tools and reducing the participation fee are partially substitutable actions in terms of attracting developers. When integration investment is very effective in reducing developers' fixed costs, the platform provider can increase both the participation fee and consumer price in response to increasing consumer utility from content, and still have higher participation across developers and consumers. Another departure from prior results is observed when developers' profit margins increase. The extant literature suggests that such an increase would result in a reduction in consumer price. However, our results show that this relation may not hold in the presence of integration investment. We also point out integration investment as an additional mechanism that could cause prices to both developers and consumers to go up simultaneously. For example, if consumer utility from the number of content developers increases, then it may be optimal for the platform to increase *both* the developer participation fee and the consumer price in the presence of integration investment. These observations highlight the importance of considering the effect of integration investment when making two-sided pricing decisions. The relation between integration investment and the developer participation fee deserves particular attention. Even though increasing integration investment and reducing participation fees may be partially substitutable, there is an important distinction between the two levers: integration investment is a non-rival strategy in the sense that it is a fixed cost that does not increase no matter how many developers join. In contrast, reducing participation fees is akin to a variable

cost, since the total impact increases with the number of developers joining the platform. Thus, the decision to increase integration investment versus to reduce developer participation fees is not entirely comparable. This paper aims to provide guidance around how to trade these decisions off, because not only is the level of integration investment a crucial decision, but it is also a decision that must be carefully coordinated with pricing decisions in order to obtain its maximum benefit for both consumers and developers.

Second, we analyze the role of consumer and developer expectations by focusing on the optimal decisions for a platform that faces unfavorable expectations in the market (such as a start-up platform, or a platform that enters a new industry). Under unfavorable expectations, which might result from a lack of widely accepted standards, the market may end up coordinating on the zero participation "ghost town" equilibrium (Parker, Van Alstyne and Choudary 2016). Thus the platform provider has to set the prices on both sides in a manner that will eliminate the zero-participation equilibrium. Because a platform under unfavorable expectations finds it more difficult to secure consumer participation, it lowers the consumer price and developer participation fees as one would expect. However, we also find, somewhat counterintuitively, that the platform also invests *less* in integration functionality. In other words, even though a platform facing unfavorable expectations would especially benefit from securing developer participation, this does not translate into a higher investment in integration tool functionality compared to a platform with favorable expectations. The reason lies in the fact that a platform facing unfavorable expectations obtains a smaller total surplus from integration investment compared with a platform facing favorable expectations, mainly because it charges lower prices. As a result, it cannot afford to invest in integration tools as much as a platform that faces favorable expectations.

The observation that unfavorable expectations forces a platform to invest less in integration has interesting dynamic implications. Specifically, when starting out, platforms often face less favorable expectations, which may change over time into more favorable expectations if consumers begin to believe in the viability of the firm. Hence, a dynamic strategy may be more appropriate for integration investment decisions, whereby the platform initially engages in a low level of integration investment and goes on to increase it over time as it builds its reputation.

Third, we analyze how competitive pressures shape the integration investment and the pricing decisions. We show that when competitive pressures exist, integration investment modifies pricing

decisions away from the results of the extant literature to a lesser extent. We also demonstrate that investing in better capabilities for facilitating third party development may be a significant success factor for a platform under competition. Specifically, if consumers value content highly and if integration tools are very effective in reducing developer costs, a platform that is able to create a more favorable integration environment can capture a larger market share than a platform with a higher standalone value but lower integration capability. Indeed, as we discuss in Section 4.1, better integration capabilities played an important role in Facebook's victory over Myspace, as the latter had an arcane architecture "hated by the developer community" (Gillette 2011). Based on our prior discussion of IoT's dependency on integrating numerous actuators and sensors, we would expect similar, but perhaps even greater magnitude, effects to play out in the IoT space.

Finally, we extend the base model to include heterogeneity in content quality. We assume there are two types of developers: high-type developers who create content with higher quality and low-types who develop content with lower quality. All else being equal, an increase in the average quality in the developer market would typically mean that more developers are likely to make a profit, and thus would be willing to join even with limited availability of integration tools. So, one could argue that optimal integration investment would be lower if the average quality in the developer market went up. Yet, we find that higher average developer quality (either because the percentage of high-type developers or the quality of low-types increases) *increases* platform's integration investment, so long as consumers' utility from content is sufficiently high. This is due primarily to network externalities: when the average quality of content is higher, the platform is more attractive to consumers, resulting in a bigger surplus from integration investment. However, if customers do not value content sufficiently, the optimal integration investment *decreases* with an increase in the quality of the low-type developers. The reason is that, in this scenario, a higher quality increases the average cost of the low-type developers without sufficiently increasing consumer utility. Thus, the surplus from integration investment goes down.

The remainder of the paper proceeds as follows. Section 2 reviews the related literature. In Section 3, we develop the base model for a monopolist platform and analyze the role consumer and developer expectations play in integration investment decisions. In Section 4, we consider two platforms that compete on the basis of their integration investments and pricing decisions. Section 5 extends the base model to incorporate heterogeneity in content quality. Finally, policy implications

of the results are discussed in Section 6, along with the limitations of the current analysis and possible extensions.

2 Literature Review

This paper contributes to the two-sided markets literature by analyzing the strategic choice of platform investment in integration tools and resources (e.g., APIs, SDKs, technical specification, help desks etc.) to facilitate third-party content development. The two-sided markets literature (e.g., Parker and Van Alstyne 2000b, Rochet and Tirole 2003, Parker and Van Alstyne 2005) explores novel strategies for two-sided platforms that leverage network externalities. In particular, two-sided markets exhibit a special form of indirect network effects (Katz and Shapiro 1985, Liebowitz and Margolis 1994) such that the participation on one side of the market depends on the number of users on the other side. For example, software developers will develop applications only for platforms that have a sufficiently broad installed base of users. Likewise, all else being equal, users prefer platforms that provide a greater variety of software. These *cross-side network effects* result in novel strategies that favor, and many times even subsidize, one side of the market in order to attract the other side (Eisenmann, Parker and Van Alstyne 2006).

The growing literature on two-sided markets has primarily focused on two-sided pricing strategies (Parker and Van Alstyne 2000a, Parker and Van Alstyne 2005, Armstrong 2006, Caillaud and Jullien 2003, Hagiu 2006, Rochet and Tirole 2003, Rochet and Tirole 2006, Weyl 2010). The key insight from this body of research is that platforms should charge lower prices to the side that cares less about the other. Either side of the market may be subsidized depending on the relative strengths of the cross-side network effects (Parker and Van Alstyne 2000a, Parker and Van Alstyne 2005, Armstrong 2006, Rochet and Tirole 2006). For example, search engines such as Google subsidize searchers while charging the advertisers, whereas Operating Systems such as Windows may subsidize application developers while charging consumers (Eisenmann et al. 2006). The two-sided pricing strategy also depends on other factors such as the fee structure determined by the platform (e.g., royalties versus participation fees), the users' ability to join more than one platform (Armstrong 2006), and the sequence of participation by the two sides (Hagiu 2006).

There is also a burgeoning stream of research in the two-sided markets literature that focuses on the use of non-price strategic levers by platforms (e.g., Gawer and Cusumano 2002, Boudreau

and Hagiu 2008, Parker and Van Alstyne 2013, Eisenmann, Parker and Van Alstyne 2011). For example, Bhargava and Choudhary (2004) analyze the product line design problem of an information intermediary. Zhu and Iansiti (2011) consider competition between an incumbent and an entrant on the basis of platform quality and installed base and show that installed base does not necessarily present barriers to entry. Hagiu and Spulber (2013) analyze the strategic use of first-party content by platform providers as a means to attract buyers to the platform and overcome unfavorable expectations. In a study that is closer to this paper, Bakos and Katsamakas (2008) analyze a platform's investment into increasing the strength of network effects. Although our paper is also looking at strategic investments to increase user participation, we treat the level of network effects as exogenous in our model. We instead analyze a platform's investment into integration tools that facilitate third party development and thereby increase participation on both sides of the market. Our paper is most closely related to Anderson, Parker and Tan (2014), who examine the choice of platform performance ("quality") level to invest in during a product development cycle. Their paper incorporates the possible negative effects of high platform performance on developers' fixed costs and discuss when it makes sense to curtail performance investment in order to avoid hindering third party content development. In contrast, we are not concerned with platform performance. Rather, the goal of this paper is to focus on the choice of *direct* investments into resources that facilitate third party development as a tool to increase participation on both sides of the market. To facilitate this examination, we expand beyond Anderson et al. (2014) by (1) directly considering investment in platform integration, (2) making developer payments to the platform endogenous, and (3) considering the impact of consumer and developer expectations upon investment strategy. Taken together, these departures provide a more comprehensive analysis of platform strategy that is focused upon the impact of integration investment upon pricing decisions.

Integration tools, whether APIs and other investments in increasing platform modularity, SDKs and other dedicated information systems, specialized organizational structures, or better specifications etc., all provide a means to facilitate the integration of third-party applications more effectively into the platform. There is a stream of research that focuses on the issues surrounding integration when "knowledge work" (such as product, process, or software development) is distributed across multiple organizations (see the review by Anderson and Parker 2013). Coordinating complex knowledge work projects that span organizational boundaries is more difficult than coordi-

nating those that remain within an organization's boundaries (Parker and Anderson 2002, Sosa, Eppinger and Rowles 2004, Amaral, Anderson and Parker 2011). The literature on integration suggests that investing in integration tools and capability increases a firm's overall performance (e.g. Iansiti 1995a, Iansiti 1995b, Iansiti 1998, Dyer and Singh 1998, Frohlich and Westbrook 2001, Gopal and Gosain 2010, Anderson and Parker 2013, Davies and Joglekar 2013). However, none of the papers in this literature focuses on quantifying the optimal amount of investment in these capabilities, nor do they examine these questions in a platform context. We attempt to bridge both gaps by analyzing how much a platform should optimally invest in integration tools in order to facilitate the integration of third-party applications.

Providing publicly available integration tools such as APIs is a common way to open a platform to the developer side (Parker and Van Alstyne 2009), thus the integration investment decision is a part of the platform's "openness" strategy. In addition to the vast literature on open-source software (e.g., Lerner and Tirole 2001, Johnson 2002, Lerner and Tirole 2002, von Hippel and von Krogh 2003, Lerner and Tirole 2005, Economides and Katsamakas 2006, Lee and Mendelson 2003), there is a growing stream of research that studies open platforms (Gawer and Cusumano 2002, West 2003, Gawer and Henderson 2007, Boudreau 2010, Eisenmann, Parker and Van Alstyne 2009, Parker and Van Alstyne 2013). Eisenmann et al. (2009) define openness of a platform as placing no restrictions on participation, development, or use across the platform's distinct roles, whether it involves the developer-side or the end-user side. A firm considering whether or not to open its platform faces a trade-off between adoption and appropriability (West 2003). One way to reconcile this trade-off is to "partially" open the platform; for example, publicly providing APIs partially opens a platform's source code but retains the concept of platform owner (Boudreau and Hagiu 2011). Parker and Van Alstyne (2013) build one of the few mathematical models that study the decision to partially open a platform. Specifically, in their dynamic model of platform openness and innovation, the platform provider chooses the percentage of code base to open and the length of the period of proprietary developer protection. Our paper is different from these studies because we do not focus on the trade-off between adoption and appropriability. Instead, we assume that the platform provider has already decided to grant access to application developers and examine the optimal level of integration investment to facilitate developer participation.

3 Monopoly

In this section, we analyze a monopolist platform's strategic investment in integration tools in coordination with its pricing decisions. In line with the two-sided markets literature (e.g., Armstrong 2006, Hagiu and Spulber 2013, Anderson et al. 2014), we first formulate the utility function for the consumers and the profit function for the developers. Then, we calculate the participation on both sides of the market for a given set of platform decisions.

3.1 The Base Model

Following Anderson et al. (2014), we adopt an additive form for the consumer utility function. Specifically, we divide the value a consumer obtains from purchasing a platform into two additive components: available content, and the base value of the platform before add-ons (V). For simplicity, we assume that each developer develops one unit of content; thus the number of developers that join the platform, N_D, is equivalent to the amount of content available on the platform. A consumer gains a net utility of α from an additional unit of content. In addition, the platform provides a standalone value V independent from the number of third party developers that join the platform. For example, a computer game console such as Sony PS3 or PS4 delivers some value to users through the utility of blu-ray DVD playback even in the absence of applications or games. The consumer utility function $U(N_D, p)$ is thus given by:

$$U(N_D, p) = V + \alpha N_D - p \tag{1}$$

where p is the consumer price. In line with the literature (e.g., Armstrong 2006, Anderson et al. 2014), α is conceived to be inclusive of content price; that is αN_D is the net benefit from content availability. We assume that the consumer market is homogenous for analytical tractability.[1] Later we relax this assumption when we study competing platforms.

Content developers are assumed to be profit maximizers. Again following Anderson et al. (2014), we assume that content developers have local monopolies for their titles and hence each set price at g; i.e. a developer earns g from each unit of content sold. Without loss of generality,

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[1]Hagiu and Spulber (2013) make the same assumption on the seller side in their study of first-party content investment. With three decisions to optimize, the monopoly model quickly becomes intractable without this simplifying assumption and one would have to resort to numerical analysis. Our preliminary analysis shows that if instead we assume heterogeneous consumers with different utility from the standalone value of the platform, we obtain similar qualitative results in terms of the directionality of the decision variables with respect to the market parameters.

we assume that consumers purchase every unit of content developed for the platform, though this assumption can easily be relaxed without directionally affecting the results by assuming each consumer on average buys a certain fraction of the available content. The platform provider charges the developers a participation fee of w to join the platform.[2] Note that in some cases, w may be negative indicating a direct subsidy. Content developers incur a development cost, which varies from developer to developer as a result of differences in engineering efficiency. Specifically, the fixed cost of development $\tilde{f}$ is assumed to be uniformly distributed on $[f - F/2, f + F/2]$ where $f_{min} = f - F/2 > 0$. To model the effect of platform investment in integration tools (e.g., APIs, SDKs), we assume that such investment reduces content development cost (in man-hours). Not all integration tools are equally effective in reducing developers' costs, though; the benefit depends on the functionality provided within the tool. Thus, in our model, the platform provider chooses the integration tool *functionality* level to invest in. Specifically, for an integration tool functionality level of x, a developer's fixed cost is reduced by βx, where β is integration tool effectiveness in cost reduction.[3] Realistically, even the highest possible level of integration tool functionality cannot completely eliminate the fixed cost of content development. For simplicity, we assume that the cost reduction benefit βx cannot exceed the minimum possible development cost, f_{min}. This implies that integration tool functionality x^* is bounded above by f_{min}/β. Consequently, the profit function of developer i is given by:

$$\pi_i(N_C, x, w) = gN_C - w - (f_i - \beta x) \tag{2}$$

where N_C is the number of consumers that join the platform, and f_i is developer i's fixed cost which is uniformly distributed on $[f - F/2, f + F/2]$, or equivalently in $[f_{min}, F + f_{min}]$. We normalize the opportunity cost of developers to zero. Assuming that there are a total of M_D developers in the developer community, the number of developers that join the platform as a function of consumer participation and platform decisions (p, w, x) is given by:

$$N_D(N_C, w, x) = max\{M_D(gN_C - w - f_{min} + \beta x)/F, 0\} \tag{3}$$

[2] In many industries, developers pay a royalty per each transaction instead of or in addition to a participation fee. Our major results still hold qualitatively if we switched to a framework with royalties. Please see Section 6 for further details.

[3] We assume that all developers obtain the same cost reduction benefit from integration tool functionality, even though in practice some developers may benefit more from integration tool functionality compared to others. It is straightforward to extend the current model to a setting where there are two types of developers such that high-types benefits more from integration investment (i.e. high β) compared to low-types (i.e. low β). Such an extension would not change the qualitative results and is thus omitted.

Similarly, assuming there are a total of N potential consumers in the market, the number of consumers that join the platform as a function of developer participation and platform decisions (p, w, x) is given by:

$$N_C = \begin{cases} N & \text{if } V + \alpha N_D - p \geq 0 \\ 0 & \text{if } V + \alpha N_D - p < 0 \end{cases} \tag{4}$$

The platform provider enjoys two revenue streams: Purchases of the platform by consumers at price p and the participation fee w charged to each developer that joins the platform. In addition to the pricing decisions, the platform provider has to decide how much to invest in integration tool functionality. We assume that it is increasingly costly to provide integration tools that have higher functionality. Thus, the fixed cost of providing integration tools is a convex increasing function of integration tool functionality x, specified as kx^2. The platform monopolist chooses price p, participation fee w, and integration tool functionality level x to maximize its profit given by:

$$\Pi(p, w, x) = (p - c)N_C + wN_D - kx^2 \tag{5}$$

where c is the marginal cost of production.

Table 1: Notation

	Decision Variables
x	Integration tool functionality level
p	Consumer price
w	Participation fee charged to developers
	Model Primitives
α	Consumers' net utility from an additional unit of content
V	Standalone value for the platform
N	Total number of consumers in the market
g	Developers' marginal profit per consumer
β	Fixed cost reduction per unit of integration tool functionality
f_{min}	Minimum possible fixed cost incurred by developers in the absence of integration tools, defined as $f - F/2$
F	The range of fixed cost incurred by developers, the fixed cost being uniform in $[f_{min}, F + f_{min}]$
M_D	Total number of developers in the market
k	Platform's cost per unit of integration tool functionality squared
c	Platform's variable cost of production
t	Degree of platform differentiation on the consumer market

3.2 Integration Investment Strategy for a Monopolist Platform

The platform provider chooses p such that all consumers join the platform. Assuming an opportunity cost of zero for the consumers and developers, the platform provider's optimization problem

becomes:

$$\max_{p,w,x} \Pi(p,w,x) = (p-c)N + wM_D \max\{\frac{gN - w - f_{min} + \beta x}{F}, 0\} - kx^2$$

$$s.t. \ \ V + \alpha M_D \max\{\frac{gN - w - f_{min} + \beta x}{F}, 0\} - p \geq 0 \tag{6}$$

$$\frac{f_{min}}{\beta} \geq x \geq 0 \tag{7}$$

Constraint (6) is binding at optimality. By solving the first-order conditions for w and x, we obtain the optimal decisions for the platform provider, stated in Lemma 1.

LEMMA 1. *Suppose* $f_{min} \leq N(g + \alpha)$. *If* $\beta \leq \sqrt{\frac{4f_{min}Fk}{M_D N(g+\alpha)}}$, *then the optimal decisions for a monopolist platform are given by:*

$$x_f^* = \frac{\beta M_D(N(g+\alpha) - f_{min})}{4Fk - M_D\beta^2}$$

$$w_f^* = \frac{2kF(N(g-\alpha) - f_{min}) + M_D N\alpha\beta^2}{4Fk - M_D\beta^2}$$

$$p_f^* = V + \frac{2k\alpha M_D(N(g+\alpha) - f_{min})}{4Fk - M_D\beta^2}$$

whereas if $\beta > \sqrt{\frac{4f_{min}Fk}{M_D N(g+\alpha)}}$, *then the optimal decisions are:*

$$x_f^* = \frac{f_{min}}{\beta}$$

$$w_f^* = \frac{(g-\alpha)N}{2}$$

$$p_f^* = V + \frac{M_D N\alpha(g+\alpha)}{2F}$$

We note that if the fixed cost of even the most efficient developers, f_{min}, is still much higher than a developer's total possible revenue Ng (i.e. $f_{min} > N(g+\alpha)$), then the platform provider cannot profitably attract third party developers. Under that scenario, the platform fails to build a developer ecosystem, but as long as the standalone value of the platform, V, is higher than the production cost of the platform ($V > c$), the platform provider can still serve the consumer side by setting the consumer price as V.

Next, in Lemma 2, we analyze the effect of important market parameters on the optimal decisions to better understand the role of the integration investment strategy. Some of the results from the lemma are highlighted in Table 2.

LEMMA 2. *Assuming $f_{min} < N(g + \alpha)$ to ensure developer participation, the following hold:* [4]

i) *When consumers' utility from additional content (α) increases, integration investment and consumer price always increase, whereas the participation fee increases if and only if $M_D\beta^2 > 2Fk$.*

ii) *If developer marginal profit per consumer (g), increases, integration investment, consumer price, and participation fee all increase.*

iii) *If integration tool effectiveness (β) increases, integration investment, consumer price, and participation fee all increase.*

iv) *integration investment decreases with the variability in developers' fixed costs, (F), if and only if $f \leq N(g + \alpha) + \frac{M_D\beta^2}{8k}$. Consumer price and developer participation fee may decrease or increase with F.*

Lemma 2 presents interesting observations about the interplay between integration investment and two-sided pricing decisions. In particular, integration investment may result in two-sided pricing policies that are not seen in the extant literature, as explained in the Introduction. For example, an increase in consumers' utility from additional content, α, implies that consumers now care more about developer adoption. When this is the case, the previous two-sided markets literature suggests that the platform provider should cut the developer participation fee in order to increase content availability (e.g., Parker and Van Alstyne 2005, Armstrong 2006). However, we find that it may be optimal to *increase* the participation fee instead. This is because in our model the platform provider has an extra lever: integration investment. Investing in integration tool functionality and *reducing* the participation fee are partially substitutable actions in terms of attracting developers. When integration investment is very effective in reducing developers' fixed costs (i.e. β is high) or there are many potential developers in the market (M_D is large), the platform provider can *increase both the participation fee and consumer price* in response to increasing consumer utility from content and still have higher participation across developers and consumers.

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[4] Unless otherwise stated, we use the words increasing and decreasing to refer to *weakly* increasing and decreasing functions throughout the paper.

Table 2: Comparative Statics under Monopoly

	Integration Investment	Developer Fee	Consumer Price
Consumer Utility from Content, α	↑	↑ or ↓	↑
Developer Profit Margin, g	↑	↑	↑
Integration Tool Effectiveness, β	↑	↑	↑

Similarly, the extant literature would suggest that an increase in developer marginal profit g would always result in a lower consumer price. Lemma 2 (ii) shows that this is not true for a monopolist platform in the presence of integration investment. The reason lies in the fact that an increase in developer profit margin triggers an increase in integration investment, which is somewhat surprising on its own. One could argue that since developers are already doing better because of the higher marginal profit, there is less need to invest in integration tool functionality, but by increasing the integration investment the platform provider can not only charge an even higher participation fee but also can increase the consumer price.

We also find that when the effectiveness of integration investment, β, increases, the platform provider invests more to increase integration tool functionality. This increased investment makes it possible to increase prices charged on both sides.

Finally, we find that if the variability in developers' fixed cost increases, the platform provider invests less in integration tool functionality as long as the average cost is not prohibitively high $(f \leq N(g+\alpha)+\frac{M_D\beta^2}{8k})$. This is mainly because with a smaller variance in the cost distribution, a unit increase in integration tool functionality results in a larger increase in the developer participation rate. Thus, the return on integration investment is higher when the variability in developers' costs is lower. When the average cost is very high, though, an increase in cost variability puts the platform in a tough spot in terms of attracting developers. Thus, the platform provider is better off increasing the integration investment to guarantee developer participation, and then rely more on the consumer side to make money by increasing the consumer price.

3.3 The Effect of Unfavorable Expectations

The analysis in Section 3.2 implicitly assumes that for a given set of decisions (p, w, x), consumers and developers always coordinate on the equilibrium with the highest rate of participation on

both sides. This is a common assumption in the two-sided markets literature (e.g., Parker and Van Alstyne 2005, Rochet and Tirole 2003, Armstrong 2006); yet it does not reflect the full range of possible demand correspondences. Indeed, if they hold unfavorable expectations (or beliefs) for the platform, users may in practice coordinate on the equilibrium with the lowest participation rates instead. A start-up platform would be more likely to face such unfavorable expectations compared to an established platform. Similarly, a new entrant into a market dominated by strong incumbents would be more likely to face unfavorable expectations. For example, the mobile application development market is dominated by Android and iOS. New entrants into this market such as Windows Phone and Samsung's Tizen received lukewarm reactions from the developer community since developers did not expect these platforms to obtain a significant installed base (Tibken 2013, VisionMobile 2014). In this section, we analyze the effect of unfavorable expectations on a platform provider's integration and pricing strategies.

In the presence of network effects, for any vector (p, w, x) of platform choices there can be multiple, self-fulfilled participation equilibria. In our model, (similar to Hagiu and Spulber 2013) the linearity of developer benefits in consumer participation and the step function shape of consumer benefits in developer participation narrow the possible stable equilibria to two: zero participation and high participation. We denote the zero participation equilibrium as the "unfavorable expectations" equilibrium and the high participation equilibrium as the "favorable expectations" equilibrium. In line with the literature (Hagiu 2006, Hagiu and Spulber 2013, Caillaud and Jullien 2003), we focus on two polar types of platforms, which are characterized by these distinct types of expectations.[5]

DEFINITION 1. *A platform is said to be facing unfavorable expectations (UE platform) if for a given set of (p, w, x), consumers and developers always coordinate on the equilibrium with the lowest rate of participation on both sides. In contrast, a platform is said to be facing favorable expectations (FE platform) if for a given set of (p, w, x), consumers and developers always coordinate on the equilibrium with the highest rate of participation on both sides.*

Note that the type of expectations is exogenous in our model for simplicity. In practice, different expectations may arise from users' uncertainty about a platform's quality (Hagiu 2006).

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[5] In theory, between these extremes, there are infinitely many demand configurations. We have chosen to contrast the two extreme cases of user expectations in order to better highlight the effect of user expectations on integration investments strategy.

To have a chance of making positive profits, a platform facing unfavorable expectations must set its prices so as to eliminate the unfavorable expectations equilibrium. This requires prices to be such that an individual consumer finds it profitable to join even when he or she expects the platform will attract no consumers. Note that in that scenario, the developer participation is given by $M_D \max\{\frac{-w-f_{min}+\beta x}{F}, 0\}$; thus the platform provider has to set p such that $V + \alpha M_D \max\{\frac{-w-f_{min}+\beta x}{F}, 0\} - p \geq 0$. This condition should be binding at optimality. As a result, there are two possible solutions to the platform's optimization problem: Either $w > -f_{min} + \beta x$ or $w < -f_{min} + \beta x$.[6] If both of these solutions are feasible, the platform chooses the one with the highest profit.

Case 1: Consumer Attraction Strategy The first possible solution involves making the platform attractive to consumers by setting a very low consumer price. Specifically, when $w > -f_{min} + \beta x$, $\max\{\frac{-w-f_{min}+\beta x}{F}, 0\} = 0$, implying that consumers expect zero cross-side benefits. Thus to ensure consumer participation, the platform sets the consumer price as $p^* = V$; i.e. equal to the standalone value of the platform. With the consumer opportunity cost normalized to zero, the entire consumer market joins the platform at this price point, despite their unfavorable expectations about the platform. Thus, the platform provider's optimization problem becomes

$$\max_{w,x} \Pi(w,x) = (V-c)N + wM_D \frac{gN - w - f_{min} + \beta x}{F} - kx^2$$

$$s.t. \quad \frac{f_{min}}{\beta} \geq x \geq 0 \tag{8}$$

Note that at a price of V, consumers enjoy a surplus utility as long as *some* developers join the platform. Thus, this strategy is designed to attract consumers. The solution (w, x) is defined by the following first-order conditions:

$$\frac{\partial \Pi}{\partial w} = M_D \frac{gN - 2w - f_{min} + \beta x}{F} = 0 \tag{9}$$

$$\frac{\partial \Pi}{\partial x} = \frac{M_D w \beta}{F} - 2kx = 0 \tag{10}$$

and must satisfy $w > -f_{min} + \beta x$ to be viable. Specifically, assuming $f_{min} \leq Ng$ [7], the optimal

---

[6]We prove under Case 1 why $w = -f_{min} + \beta x$ would never hold.

[7]Similar to the proof of Lemma 1, we can show that when $f_{min} \geq Ng$, the platform provider does not find it profitable to attract the developer side.

decisions under this *consumer attraction* strategy are given by:

$$x_{ue1}^* = \min\{\frac{M_D\beta(Ng - f_{min})}{4kF - M_D\beta^2}, \frac{f_{min}}{\beta}\} \tag{11}$$

$$w_{ue1}^* = \min\{M_D\frac{2Fk(Ng - f_{min})}{4kF - M_D\beta^2}, \frac{gN}{2}\}$$

$$p_{ue1}^* = V$$

To satisfy the viability condition $w > -f_{min} + \beta x$, the following has to hold:

$$\beta < \sqrt{\frac{2Fk(f_{min} + gN)}{gNM_D}} \tag{12}$$

Finally, if $\beta > \sqrt{\frac{4f_{min}Fk}{gNM_D}}$, then the unconstrained solution x exceeds the upper bound, which implies $x_{ue1} = f_{min}/\beta$.

To complete the analysis, note that $w = -f_{min} + \beta x$ would still require setting $p^* = V$ but would never be optimal. When $w = -f_{min} + \beta x$, $\max\{\frac{-w - f_{min} + \beta x}{F}, 0\} = 0$, which requires $p^* = V$ in order to attract the consumers. But above we show that when $p^* = V$, the participation fee is strictly positive ($w^* > 0$), as long as it is profitable to attract the developer side (i.e. $f_{min} < Ng$). Thus, at optimality $w = -f_{min} + \beta x \leq 0$ would never hold.

Case 2: Developer Attraction Strategy In this case, $w < -f_{min} + \beta x \leq 0$. Note that this strategy is designed to attract developers since the participation fee is negative. In other words, the platform pays developers to develop content. Similar strategies have been adopted, for example, by smartphone operating systems that face unfavorable expectations, such as Tizen and Windows Phone. Specifically, Microsoft reportedly paid more than $100,000$ to bring apps to Windows Phone (Vance 2013), while Tizen by Samsung launched "Tizen App Challenge", offering a total of $4 million to developers to create new apps for the platform (Reuters 2014). Similarly, Google invested $10M to pay developers to create applications for Android when it first launched.

When $w < -f_{min} + \beta x \leq 0$, the resulting consumer price is given by $p = V + \alpha M_D(-w - f_{min} + \beta x)/F$. So, the platform's optimization problem becomes

$$\max_{w,x} \Pi(w, x) = (V - c)N + \alpha NM_D\frac{-w - f_{min} + \beta x}{F} + wM_D\frac{gN - w - f_{min} + \beta x}{F} - kx^2$$

$$s.t. \ V + \alpha M_D\frac{gN - w - f_{min} + \beta x}{F} - p \geq 0 \tag{13}$$

$$\frac{f_{min}}{\beta} \geq x \geq 0 \tag{14}$$

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This will give the same w and x as in the favorable platform case; but the consumer price p is lower than p_f^*. Specifically, assuming $f_{min} < N(g + \alpha)$,

$$
\begin{aligned}
x_{ue2} &= \min\{\frac{M_D\beta(N(g+\alpha) - f_{min})}{4Fk - M_D\beta^2}, \frac{f_{min}}{\beta}\} \\
w_{ue2} &= \min\{\frac{2kF(N(g-\alpha) - f_{min}) + M_DN\alpha\beta^2}{4Fk - M_D\beta^2}, \frac{(g-\alpha)N}{2}\} \\
p_{ue2} &= \max\{V - \frac{gM_DN\alpha}{F} + \frac{2kM_D\alpha(N(g+\alpha) - f_{min})}{4Fk - M_D\beta^2}, V + M_D\frac{N\alpha(\alpha - g)}{2F}\}
\end{aligned}
\tag{15}
$$

Note that the solution $\{w_{ue2}, x_{ue2}\}$ is viable only if $w_{ue2} < -f_{min} + \beta x_{ue2}$; or equivalently

$$
\beta > \sqrt{\frac{2Fk(f_{min} + N(g-\alpha))}{gM_DN}}
\tag{16}
$$

Finally, similar to the platform with favorable expectations, when $\beta > \sqrt{\frac{4f_{min}Fk}{M_DN(g+\alpha)}}$, then $x_{ue2} = f_{min}/\beta$.

Next we develop the condition under which the UE platform should choose developer attraction strategy over consumer attraction strategy.

PROPOSITION 1. *Assuming an interior solution to the optimization problems under both strategies, a monopolist platform facing unfavorable expectations chooses the developer attraction strategy defined in (15) if $\beta > \sqrt{\frac{Fk(2f_{min} + N(2g - \alpha))}{gM_DN}}$ and chooses the consumer attraction strategy defined in (11) otherwise.*

When the effectiveness of integration investment in cost reduction (β) is relatively high, a monopolist platform with *unfavorable expectations* would prefer the developer attraction strategy to the consumer attraction strategy. This is because the developer attraction strategy relies on heavier investment in integration tool functionality as well as a lower participation fee compared to the consumer attraction strategy. Note that the threshold for β is smaller if the strength of network effects (α) is higher. In other words, when consumers derive a higher benefit from the presence of developers, the developer side is more likely to experience a reduced price. In contrast, the threshold for β increases with developer marginal profit g (as long as $N\alpha > 2f_{min}$), implying that when *developers* derive a higher benefit from the presence of consumers, the consumer side is more likely to be subsidized. Note that these findings are consistent with the previous literature on two-sided markets (e.g., Parker and Van Alstyne 2005, Armstrong 2006, Hagiu and Spulber 2013).

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Finally, note that the threshold for β is higher when the minimum possible developer fixed cost f_{min} or when the range of fixed cost distribution, F, is high. This may seem counterintuitive at first – one could think that if the average fixed cost in the developer market is higher, that would trigger a higher integration investment, thus favoring the developer attraction strategy over the consumer attraction strategy. However, high fixed costs imply a lower return on integration investment; that is, when f_{min} or F is high, for the same investment on integration tool functionality, the platform provider will recruit a smaller number of developers. Thus, the developer attraction strategy becomes less effective under such market conditions.

An important result in this section is that the UE platform invests less in integration tool functionality compared to the FE platform as stated in the following proposition. The proof is straightforward and is omitted.

PROPOSITION 2. *A monopolist platform facing unfavorable expectations invests weakly less in integration tool functionality than a platform with favorable expectations.*

Even though a platform facing unfavorable expectations has a more challenging task of securing market participation, this does not translate into a higher investment in integration tool functionality than a platform with favorable expectations. The reason is that the platform with favorable expectations always extracts more total surplus from consumers and developers; and thus it is able to invest more. To see this, first consider the consumer attraction strategy. For a given x, the optimal consumer price for the FE platform is $p_f(x) = V + \frac{M_D \alpha(N(g+\alpha) - f_{min} + \beta x)}{2F}$ whereas for the UE platform it is $V < p_f(x)$. The resulting gap in surplus from consumers due to unfavorable expectations is $\frac{M_D \alpha(N(g+\alpha) - f_{min} + \beta x)}{2F}$, which is increasing in x. While the optimal developer participation fee for the FE platform $w_f(x) = \frac{N(g-\alpha) + x - f_{min}}{2}$ is smaller than that for the UE platform $w_{ue1}(x) = \frac{gN + x - f_{min}}{2}$, the total profit gap $\delta(x)$ specified below is increasing in x:

$$
\begin{aligned}
\delta(x) &= N_D^f(x)w_f(x) + Np_f(x) - N_D^{ue1}(x)w_{ue1}(x) - Np_{ue1}(x) \\
&= \frac{M_D N\alpha(N(2g+\alpha) - 2f_{min} + 2x\beta)}{4F}
\end{aligned}
$$

where $N_D(x) = \frac{gN - w(x) - f_{min} + \beta x}{F}$. Thus, the FE platform extracts a higher surplus from a given x compared to the UE platform choosing the consumer attraction strategy. That is why under this strategy, the UE platform sets a lower level of integration tool functionality x compared to the

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FE platform. Now consider the developer attraction strategy. In this case, both the FE and the UE platform charge the same participation fee for a given x, $w(x) = \frac{N(g-\alpha)+x-f_{min}}{2}$ and therefore extract the same surplus from the developer side. On the consumer side, the UE platform charges a lower price $p_{ue2}(x) = V + \frac{M_D\alpha(N(\alpha-g)-f_{min}+\beta x)}{2F} < p_f(x) = V + \frac{M_D\alpha(N(\alpha+g)-f_{min}+\beta x)}{2F}$. The resulting gap in surplus caused by unfavorable expectations is $\delta(x) = \frac{gM_DN^2\alpha}{F}$. Note that even though the gap is positive, it does not depend on x: an increase in x will yield the same additional surplus for both the F and the UE platforms. That is why under this strategy the UE platform sets exactly the same level of integration tool functionality as the FE platform.

We see an example of lower investment by a platform facing unfavorable expectations in the case of *Tizen* operating system. Tizen was developed by Samsung as an alternative to Android. The developer community does not hold high expectations for the platform (Tibken 2013, VisionMobile 2014). Despite this big challenge to overcome, Tizen's SDK falls short compared to that of Android and iOS, as evaluated in the report "Developer Economics Q1 2014" by VisionMobile (VisionMobile 2014):

> "Our own initial assessment of the platform in Q3 2013 indicated that the Tizen SDK
> was still a long way from being ready for mainstream developer adoption, lacking the
> polish and ease of use that developers now take for granted in iOS and Android SDKs."

Similarly, when Best Buy launched its e-marketplace in 2009, it faced unfavorable expectations from the market, especially compared to Amazon, which already had a well-developed e-marketplace (Schroeder 2009). In line with our results, Best Buy started off with very limited integration investment (a single API called Remix that provides access to the product catalog) as opposed to the wide range of APIs offered by Amazon Marketplace.

Note that this disparity in investment between a platform that faces favorable expectations and one that faces unfavorable expectations may have interesting dynamic implications. A start-up or a new entrant in the market is likely to face unfavorable expectations initially and is advised to invest a smaller amount into integration tool functionality. As the start-up matures and gains credibility, however, one can speculate that it should increase its investment in integration tool functionality, since firms facing favorable expectations have a higher return on integration investment. Thus, integration investment decisions must not only be well-coordinated with the two-sided pricing

decisions, but also be revised dynamically if the platform's credibility in the market changes.

Finally, to better understand changes in optimal decisions driven by unfavorable expectations, we carry out a comparative statics analysis in Lemma 3 and compare the results to those obtained for the FE platform in Lemma 2. Table 3 summarizes some of these results and highlights the differences from Lemma 2 in red.

LEMMA 3. *Assuming $f_{min} < Ng$ to ensure developer participation under both developer attraction and consumer attraction strategies, the following holds:*

i) *If integration tool effectiveness (β) increases, integration investment, consumer price, and participation fee increase. However, the rate of increase in integration tool functionality investment is less than the rate under favorable expectations.*

ii) *If developer marginal profit per consumer (g) increases, the optimal integration investment, and participation fee increase. However, consumer price may increase or decrease.*

iii) *Under the developer attraction strategy, when consumers' utility from content (α) increases, integration investment always increases, whereas the participation fee and consumer price may increase or decrease.*

iv) *Integration investment increases with the variability in developers' fixed cost, (F), if $f \leq gN + \frac{M_D \beta^2}{8k}$ under the consumer attraction strategy, and if $f \leq N(g + \alpha) + \frac{M_D \beta^2}{8k}$ under the developer attraction strategy. Consumer price and developer participation fee may decrease or increase with F.*

Not surprisingly, when integration investment is more effective in reducing developer fixed costs, more is invested in third party facilitation even under unfavorable expectations. However, it is important to note that *a platform increases integration investment at a higher rate under favorable expectations than under unfavorable expectations*, since it can extract a higher total surplus from the investment.

The FE platform always increases the consumer price in response to an increase in developer marginal profit, g. This is not necessarily true when it comes to platforms facing unfavorable expectations. Under the consumer attraction strategy, consumer price does not depend on developer marginal profit. Under the developer attraction strategy, consumer price would only increase if

Table 3: Comparative Statics under Unfavorable Expectations (*)

	Integration Investment	Developer Fee	Consumer Price (***)
Consumer Utility from Content, α (**)	↑	$\uparrow$ or $\downarrow$	$\Uparrow$ or $\Downarrow$
Developer Profit Margin, g	↑	↑	$\Uparrow$ or $\Downarrow$
Integration Tool Effectiveness, β	↑	↑	↑

(*) Differences from favorable expectations are highlighted in red double arrows.
(**) Under the consumer attraction strategy, α does not have any effect on decision variables.
(***)Applies only to the developer attraction strategy. Under the consumer attraction strategy, consumer price is insensitive to all the parameters in the table (since $p^* = V$).

integration tool effectiveness is very high ($M_D \beta^2 > 2Fk$). The reason is that the UE platform has to overcome a bigger hurdle in securing participation. Only when investment in third party integration tools is very effective, can the platform afford to increase consumer prices, because only then it can secure a large enough developer participation to compensate for the increase in price. Note that an increase in consumer price in response to increasing g would contradict the extant literature. Thus, Lemma 3 shows that when the platform faces unfavorable expectations, integration investment is more likely to create pricing policies in line with the extant literature.

Finally, under the developer attraction strategy, a platform under unfavorable expectations may increase the developer participation fee in response to increased consumer utility from additional content α, similar to a platform under favorable expectations. This happens if integration investment is very effective in reducing developers' fixed costs. However, unlike the FE platform, the UE platform cannot always increase the consumer price in α, as the UE platform must set prices in a way that eliminates the low participation equilibrium.

4 Competition

In this section, we study competition between two platforms building on the model concepts developed in Section 3. We assume that content developers may choose to affiliate with more than one platform, or "multihome," whereas consumers join at most one platform, or "singlehome." This scenario fits a number of important industries. For example, for smartphones, app developers typically release their applications on both Android and iOS (VisionMobile 2014), whereas most consumers have access to only one of these platforms. Similarly, in the videogame industry;

developers tend to develop for multiple consoles (Corts and Lederman 2009), but a majority of consumers choose one console in a given generation.

Content developers decide whether or not to join a platform independently from their participation decision for the other platform (ignoring any budget constraints) because they are able to multihome. Thus, the developer demand is derived the same way as in Section 3.

$$N_D^i(x_i, p_i, w_i, N_C^i) = \frac{M_D(gNN_C^i - f_{min} + \beta x_i - w_i)}{F} \tag{17}$$

Consumers, on the other hand, must decide which platform to join, and thus create competition between the platforms to attract them. Depending on the consumer prices (p_1, p_2), participation fees (w_1, w_2), and integration tool functionality (x_1, x_2) set by platforms 1 and 2, platform i gets N_C^i consumers and N_D^i developers $(i = 1, 2)$. The prospect of these market sizes plays a major role in the platform choice of consumers.

In this section, we relax the assumption of homogeneous consumer market. Specifically, we assume that consumers have different preferences for each platform. These preferences can arise from multiple sources that include having a library of compatible content or belonging to a community that has adopted a specific platform. In other words, keeping prices and content availability the same, each platforms would still have a different appeal to each consumer. Specifically, we use a common competitive market model, Hotelling's linear city, to capture this effect. Individual consumers have different tastes for the platform; which are modeled as uniformly distributed along a unit interval and the platforms are located at the opposite ends of the interval. The higher the distance between a consumer's location and a platform, the bigger the disutility of unmatched preferences. Let t be the "transportation cost" parameter in the Hotelling model, which represents the degree of horizontal product differentiation between the platforms in attracting consumers. Note that low t implies less product differentiation, and thus a higher degree of competition. Without loss of generality, assume that Platform 1 is located at point 0 whereas Platform 2 is located at point 1. Accordingly, the net utility from joining Platform 1 for the consumer y with taste $y \in [0, 1]$ is $U_1(y) = V + \alpha N_D^1 - p_1 - ty$.

By locating the marginal consumer who is indifferent between the two platforms and using the fact that consumers are uniformly distributed on a unit interval, the number of consumers who join

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platform i $(i = 1, 2)$ can be calculated as

$$N_C^i(x_i, p_i, w_i, x_{-i}, p_{-i}, w_{-i}, N_D^i, N_D^{-i}) = N\left(1/2 + \frac{u_i - u_{-i}}{2t}\right) \tag{18}$$

We substitute (17) into (18) to get

$$N_C^i(x_i, p_i, w_i, x_{-i}, p_{-i}, w_{-i}) = \frac{F(t - p_i + p_{-i}) - M_D\alpha(gN + w_i - w_j - \beta(x_i - x_j))}{2(Ft - gM_DN\alpha)} \tag{19}$$

Accordingly, platform sponsor i's $(i = 1, 2)$ decision problem is as follows:

$$\max_{x_i, p_i, w_i} \Pi_i(x_i, p_i, w_i; x_{-i}, p_{-i}, w_{-i}) = (p_i - c)N_C^i + rN_D^i - kx_i^2;$$

$$s.t. \ \frac{f_{min}}{\beta} \geq x_i \geq 0. \tag{20}$$

We assume that platforms enter the market simultaneously such that both platforms make their decisions without observing the competitor's decisions. The resulting equilibrium is symmetric with both platforms setting the integration tool functionality level, price and participation fee specified in Lemma 4.

LEMMA 4. *Suppose $f_{min} \leq N(g + \alpha)/2$ and $c \leq V + \frac{gM_DN\alpha}{2F} + \frac{M_Dk(g+\alpha)(N(g+\alpha)-2f_{min})}{4Fk-M_D\beta^2} - 3t/2$ to ensure developer participation and consumer side market coverage, respectively. Then, in a symmetric duopoly with developers multihoming and consumers singlehoming, the platforms choose the following integration tool functionality and price levels.*

$$x_C = \frac{M_D\beta(N(g+\alpha) - 2f_{min})}{2(4Fk - M_D\beta^2)}$$

$$p_C = c + t - \frac{gM_DN\alpha}{2F} - \frac{gkM_D(N(g+\alpha) - 2f_{min})}{4Fk - M_D\beta^2}$$

$$w_C = \frac{N\alpha(M_D\beta^2 - 2Fk) + 2Fk(Ng - 2f_{min})}{2(4Fk - M_D\beta^2)}$$

The integration investment chosen at equilibrium in a symmetric duopoly is qualitatively similar to the choice of a monopolist: It increases with consumers' utility from content α, integration tool effectiveness β, and developer marginal profit g. Table 4 summarizes these results. The pricing decisions of a duopolist, however, present some interesting differences from those of a monopolist. One distinction, for example, lies in the response to an increase in developer marginal profit, g.

COROLLARY 1. *In a symmetric duopoly with developers multihoming and consumers singlehoming, when developer marginal profit, g, increases, platforms reduce consumer price p, whereas a monopolist platform with favorable expectations always increases the price.*

A monopolist platform can increase the consumer price in response to increasing developer marginal profit g. With the additional tool of third party facilitation, the monopolist platform is able to attract more consumers simply by attracting more developers to the market. However, as shown in Corollary 1, this is not possible in a symmetric duopoly due to competitive pressures, even though the competing platforms also increase their integration investment in response to an increase in developer marginal profit, g. Note that the cross-side subsidy rule would indeed suggest a reduction in consumer price when developer profit margin increases. Thus, the fact that a competing platform always reduces the consumer price with an increase in g is in line with the previous literature. In other words, Corollary 1 shows that integration investment is *less likely* to create pricing policies that contradict the cross-side subsidy rule if the platform operates in a competitive market.

Table 4: Comparative Statics in a Symmetric Duopoly (*)

	Integration Investment	Developer Fee	Consumer Price
Consumer Utility from Content, α	↑	↑ *or* ↓	⇓
Developer Profit Margin, g	↑	↑	⇓
Integration Tool Effectiveness, β	↑	↑	⇓

(*) Differences from monopoly are highlighted in red double arrows.

COROLLARY 2. *In a symmetric duopoly with developers multi-homing and consumers singlehoming, when consumers' utility from additional content, α, increases, platforms reduce consumer price p, whereas a monopolist platform with favorable expectations increases the consumer price.*

Another difference from the monopoly model is that consumer price actually goes down when consumers' utility from content (α) increases as highlighted in Corollary 2. To understand this, first note that in response to an increase in consumers' utility from content, the monopolist increases its integration investment at a faster rate compared to the duopolist (since the former has a higher surplus from integration investment compared to the latter) and *if* the participation fee is reduced, the monopolist again reduces it more than the duopolist. In other words, when α increases, competing platforms fail to ramp up developer participation as much as a monopolist would do. Thus, they engage in a price war to stay competitive in attracting the consumers. The result is a reduced

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consumer price.

COROLLARY 3. *In a symmetric duopoly with developers multi-homing and consumers singlehoming, when integration tool effectiveness, β, increases, platforms reduce consumer price p, whereas a monopolist platform with favorable expectations increases the consumer price.*

Interestingly, an increase in integration tool effectiveness, β, also results in a lower consumer price when symmetric platforms compete. This is again due to platforms engaging in a price war to stay competitive in attracting the consumers. With higher integration tool effectiveness, the platforms increase their integration investment and are able to charge a higher developer participation fee. This potential upside in profitability allows them to reduce consumer price in an effort to secure a higher share of the consumer market.

Finally, similar to the monopoly case, expectations from the extant literature may not hold when consumers' utility from content, α, increases. Specifically, the participation fee w increases when consumers' utility from content, α increases as long as $M_D\beta^2 > 2Fk$. This is again due to the partial substitutability of integration investment and participation fee reduction.

4.1 Asymmetric Platforms

In this section, we extend the analysis to asymmetric platforms. When platforms are differentiated, we observe richer market segmentation scenarios. However, the model quickly becomes intractable; thus we resort to numerical analysis to gain insights. Figure 2 illustrates an example with two platforms that have different costs for providing integration tool functionality (k) and different standalone values (V). The disparity between integration tool capabilities may stem from previous experience in providing and managing these tools, from having a better software development team, or from having a more amenable platform architecture. For example, one of the reasons Myspace failed to keep up with Facebook was its arcane architecture that was based on *.NET*, which contributed to its inability to rely on third party developers for features or other content. As David Siminoff of the dating website JDate puts it (Gillette 2011):

> "Using .NET is like Fred Flintstone building a database. The flexibility is minimal. It
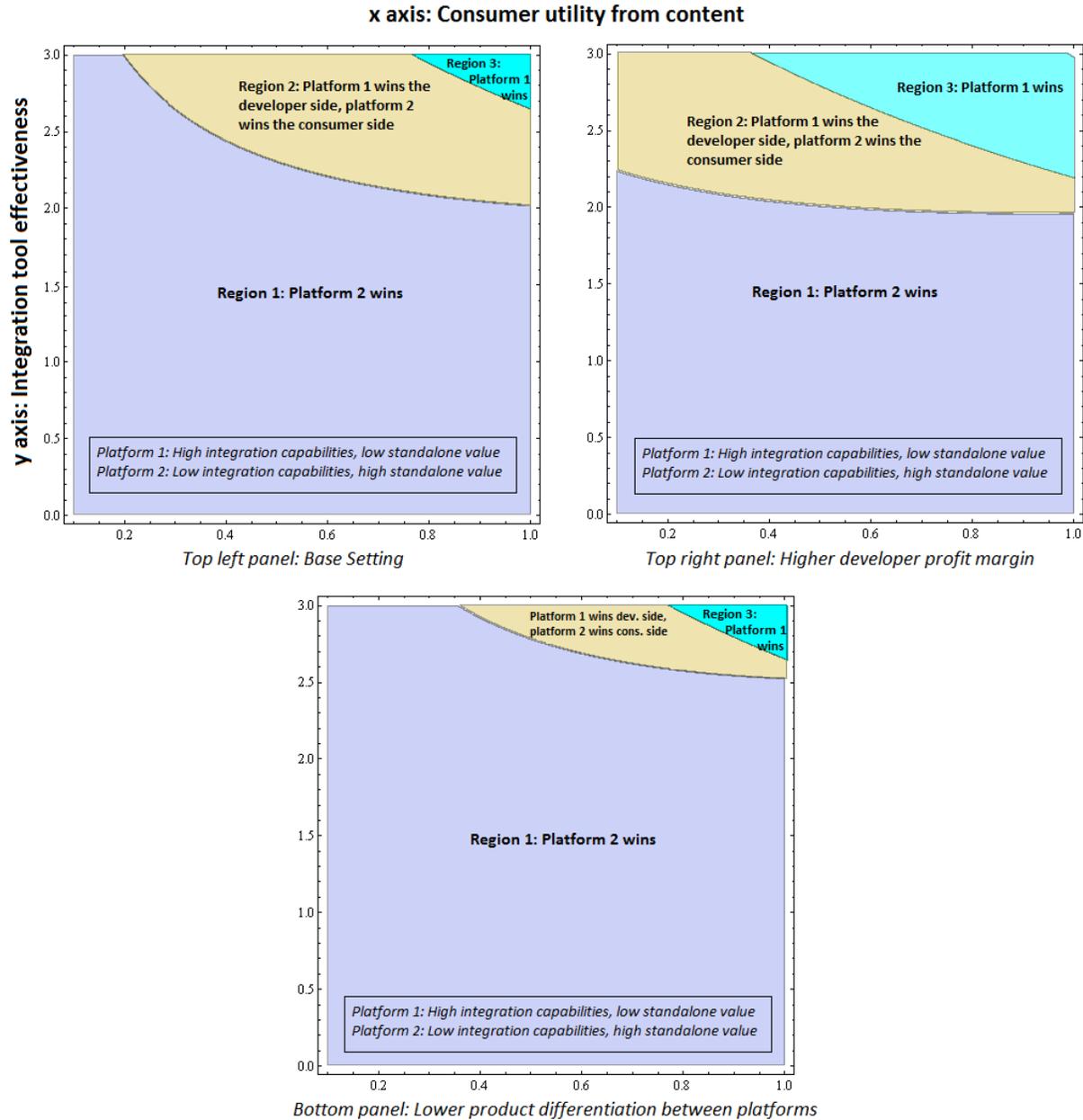> is hated by the developer community."

While Facebook reaped the benefits of opening its platform to outside developers, Myspace ended up doing everything itself, as explained by Chris DeWolfe, co-founder of Myspace (Gillette 2011):

> " We tried to create every feature in the world and said, 'O.K., we can do it, why should we let a third party do it?' "

Intuitively, the platform with higher integration capabilities has an advantageous position in attracting developers all else being equal. Similarly, the platform with higher standalone value has an advantage in attracting consumers. Suppose Platform 1 has a higher integration capability but a lower standalone value than Platform 2. We analyze which platform is the market leader under different parameter settings. The horizontal axis on Figure 2 represents consumers' utility from additional content (α), while the vertical axis represents integration tool effectiveness in reducing developers' fixed costs (β).

In the absence of integration investment as an additional lever, Platform 1 would never gain a bigger market share on both sides of the market. However, Figure 2 illustrates that Platform 1 is the market leader when α and β are very high; that is, when consumers highly value content availability and when integration tools are very effective in reducing developer costs. This is because, in markets with high α, content availability becomes the key. Since Platform 1 can afford to provide more integration tool functionality, it has an edge in such cases as long as integration investment is effective enough. For moderate-to-high values of α and β, we observe that Platform 1 gets a bigger share of the developer market due to its advantage in providing integration tool functionality, whereas Platform 2 gets a bigger share of the consumer market due to its higher standalone value. Finally, for low-to-moderate values of α and β, Platform 2 is the market leader, since Platform 1's higher integration capability does not give him an edge in these market settings.

On the top right panel, developers' profit margin is higher compared to the base setting on the left. With higher profit margins, more developers are likely to join the platform for a given integration investment level; thus, all else being equal, the return on integration investment is higher. As a result, we observe that the platform with better integration capabilities (Platform 1) becomes the market leader for a wider range of parameter values.

x axis: Consumer utility from content

Top left panel: Base Setting

Top right panel: Higher developer profit margin

Bottom panel: Lower product differentiation between platforms

Notes. $k_1 = 2.8$, $k_2 = 6$, $V_1 = 1.16$, $V_2 = 1.2$, $M_D = 2$, $N = 1$, $t = 0.75$, g=1, $f_{min} = 0.5$, $F = 5$, $c = 0.05$. On the top right panel $g = 1.4$, on the bottom panel $t = 0.5$.

Figure 2: An example of market segmentation in a duopoly with multihoming developers and singlehoming consumers

Finally, on the bottom panel, the degree of product differentiation is lower compared to the base case, implying more intense competition to attract consumers – a situation that puts Platform 1 at a disadvantage since the standalone value it offers is lower than that of Platform 2. Even though

the parameter region in which Platform 1 is the market leader does not change between the top left and the bottom panels, the region where Platform 1 wins only the developer side is significantly smaller on the bottom panel. This is because if Platform 1 has a hard time attracting consumers, it will also have a hard time attracting developers. Indeed, Platform 1 is able to secure a bigger share of the developer market only when integration tool effectiveness is very high.

5   Extension: Incorporating Developer Content Quality

In the base model, we assume that the quality of content is the same across the developer community and thus consumers gain the same utility from each additional content regardless of the developer who provides it. In practice, though, content quality varies. For example, among the million applications in Google Play Store, some provide many user-friendly features, while some are not useful. Likewise, some applications operate smoothly, while some suffer from bugs that hinder functionality. In this section, we extend the monopoly model by incorporating the heterogeneity in content quality in order to see how the average quality in the developer market affects a platform's integration investment strategy [8].

For simplicity, we assume that there are two types of developers: those who produce high quality content (i.e. high-type) and those who produce low quality content (i.e. low-type). Specifically, a fraction ρ of the developer market is high-type and the remaining $1 - \rho$ is low-type. We assume that consumers enjoy a higher utility from high quality content (αq_H) compared to their utility from low quality content (αq_L). We normalize high-type's quality q_H to 1 whereas low-type's quality is $q_L < 1$. We assume high (low) types charge g_H (g_L) where $g_H \geq g_L$ and that with these price points, the consumers would purchase all the content developed by both types. The modified utility function for consumers is given by:

$$U = V + \alpha N_D^H + \alpha q_L N_D^L - p$$

where N_D^H is the number of high-types that join the platform and N_D^L is the number of low-types that join the platform. Finally, the profit function for the two types of developers are given by

$$\pi_D^H = g_H N_G - w - (\tilde{f}_H - \beta x)$$

$$\pi_D^L = g_L N_G - w - (\tilde{f}_L - \beta x)$$

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[8]We obtain similar results (qualitatively) when we extend the duopoly model in Section 4 instead. The analysis is available from the first author upon request.

where $\tilde{f}_H$ ($\tilde{f}_L$) represent the fixed cost distribution for the high-type (low-type) developers respectively. Note that developers are heterogeneous not only in terms of the quality of content they provide but also in terms of their fixed costs. We analyze two versions of this problem. In the first version, we assume that high quality content is on average more expensive to develop (e.g., requiring more man-hours, or higher technological investment). In the second version, we assume that high-type content developers are the more experienced developers. Thus they not only develop higher quality content but also are able to do it in fewer man-hours.

5.1 High-Type Developers with Higher Costs

In this version, we assume that high-type developers' fixed cost is on average higher than that of the low-types. This would be true for example in the video-game industry where games with superior graphics are also more expensive to develop. In line with this argument, we assume that high-types' fixed cost is uniformly distributed in $[f - F/2, f + F/2]$ whereas low-types' is in $[fq_L - F/2, fq_L + F/2]$. Note that while the minimum and the maximum possible fixed cost for the low-types are lower than those for the high-types, the variance of the cost distribution is the same. We analyze this problem for a monopolist facing favorable expectations. By solving the first-order conditions, we obtain the following optimal integration tool functionality level:

$$x_{ex1}^* = \min\{\frac{M_D\beta\big(N(\rho(g_H + \alpha) + (1 - \rho)(\alpha q_L + g_L)) - f(\rho(1 - q_L) + q_L)\big) + F/2}{4Fk - M_D\beta^2}, \frac{fq_L - F/2}{\beta}\} \quad (21)$$

Lemma 5 demonstrates that integration tool functionality investment increases with the average quality in the developer market as long as consumer utility from content is sufficiently high.

LEMMA 5. *The following holds for a monopolist platform:*

- *Optimal integration investment increases with the fraction of high-type developers in the market, ρ, if $\alpha \geq f/N$.*

- *Optimal integration investment increases in the quality of the low-type developers, q_L, if and only if $\alpha \geq f/N$.*

For platforms, an increase in the average quality in the developer market would typically mean that more developers are likely to make a profit, and thus would be willing to join even with limited availability of third-party development tools. So, in the absence of network externalities, one could

argue that optimal integration investment would go down with the average quality in the developer market. However, we see that this intuition does not generally hold when cross-side network effects come into the picture. This is mainly because of the fact that high-type developers attract more consumers to the platform. Accordingly, when the fraction of high-types in the market increases, the platform provider obtains a bigger surplus from the integration investment as long as consumer utility from additional high quality content, α, is high enough. This higher surplus triggers higher investment in integration tool functionality. Similarly, if the low-type's quality q_L increases, low-type developers are able to attract more consumers; thus the platform provider can afford to invest more in integration tool functionality. Note that if consumers' utility from content is relatively small ($\alpha < f/N$), then integration investment *decreases* with an increase in q_L. The reason is, a higher q_L increases the average cost of low-type developers without sufficiently increasing consumer utility when α is small enough.

5.2 Low-Type Developers with Higher Costs

In this version we assume that high-type developers are on average more efficient than the low-types. This would generally be true when we compare professional application developers with hobbyists: hobbyists tend to produce applications with fewer features in more man-hours while professional developers tend to produce better applications more efficiently.

We assume that high-type's fixed cost is uniformly distributed in $[f_{min}, f_{min} + F]$ while low-type's is in $[f_{min}/q_L, f_{min}/q_L + F]$ where $f_{min} = f - F/2$. The resulting optimal integration tool functionality level is given by:

$$x_{ex2}^* = \min\Big\{\frac{M_D\beta\big(-f(1 - \rho(1 - q_L)) + F/2 + N(\rho(g_H - g_L + (1 - q_L)\alpha) + q_L\alpha + g_L)\big)}{4Fk - M_D\beta^2}, \frac{fq_L - F/2}{\beta}\Big\} (22)$$

Similar to Section 5.1, we see that the optimal integration investment increases in the fraction of high-type developers in the market, and the quality of the low-types. For example, a significant number of app developers that prioritise Android are hobbyists because of lower barriers to entry compared to iOS (VisionMobile 2014). Our results would imply that Android should invest less in integration tool functionality compared to iOS since its potential developer market has a larger fraction of "low-type" developers.

LEMMA 6. *The following holds for a monopolist platform:*

- *Optimal integration investment always increases with the fraction of high-type developers in the market, ρ.*

- *Optimal integration investment increases in the quality of the low-type developers, q_L, if and only if $\alpha \geq \frac{f\rho}{N(1-\rho)}$.*

When high-types are also more efficient, the surplus from integration investment increases even faster with an increase in the fraction of high-type developers in the market. Thus, the optimal integration tool functionality level always increases with ρ. Note that this result is stronger than that in Lemma 5 because it holds even if $f > N\alpha$ and $g_L > g_H q_L$ as long as $g_L < g_H$. The result for the effect of q_L is akin to the analogous result in Lemma 5: If the low-type's quality q_L increases, then low-type developers are able to attract more consumers; thus the platform provider can afford to invest more in integration tool functionality, on the condition that consumer utility from additional high quality content, α is high enough ($\alpha \geq \frac{f\rho}{N(1-\rho)}$).

To summarize, in this extension we find that higher average quality in the developer market (i.e. higher percentage of high-type developers or higher relative quality of low-types) typically triggers a larger integration investment, under the assumption that both types have uniform fixed cost distributions with the same variance. This is mainly because higher average quality attracts more consumers to the platform, thus the platform provider tends to obtain a bigger surplus from the integration investment. One exception comes from markets that exhibit low consumer utility from content. If consumers' utility from content is relatively low, an increase in the quality of the low-types increases the average cost of low-type developers without sufficiently increasing consumer utility. Thus, the return on integration investment goes down, which triggers a lower integration investment.

6   Discussion and Limitations

It is well known in the product development literature that investment in integration tools that reduce the costs of third-party content developers and provide a more seamless user experience decisively influences the success of products in the market place (Iansiti 1998). Information platforms (e.g., eBay, Google, Facebook, Nintendo, Android, etc.) are no exception. Some integration tools, particularly APIs, have been used to create thousands of applications. So much so that more than

half of the traffic to major platforms like Twitter and eBay come through APIs (Woods 2011), and now *API as a business strategy* has become part of the platform vocabulary (Jacobson, Brail and Woods 2011). Platforms that fail to invest in such integration tools, such as the majority of current electronic healthcare records platforms, deter complementary content application development by third-parties (Lim and Anderson 2016). Integration investment will almost certainly impact the success of the growing IoT because of IoT's dependence on third-party developers. Yet a formal analysis of investment in integration tools by platforms remains, to the best of our knowledge, absent in the literature.

The key insight from our study is that investment into tools that facilitate content development is not only of crucial importance, but must be well-coordinated with pricing decisions to both sides of the market in order to obtain the maximum benefit. Moreover, the possibility for integration investment may create regimes that depart from traditional results in the platform literature. Specifically, the standard result obtained from strengthening the network benefit to one side of the market is to increase the price charged by the platform to that side, and *reduce* the price charged to the opposite side. However, our results suggest that under many market conditions, prices to *both sides* of the market should optimally increase. For example, when consumer utility from content goes up, it may be optimal to *increase* the developer participation fee in addition to increasing the consumer price. The reason underlying this and many other non-standard results is that investing in integration tools and reducing developer participation fees are *partially* substitutable actions in terms of attracting developers. There is an important distinction between the two levers, though. Integration investment is a fixed cost that does not increase as more developers join. In contrast, reducing participation fees is akin to a variable cost, since the burden increases with the number of developers joining the platform. Thus, the decision to increase integration investment versus to reduce developer participation fees is not entirely comparable. Guidance around how to trade these decisions off is critical to both senior managers who must make the decisions and investors who must evaluate these decisions.

Investing in integration tools is crucial to creating a developer ecosystem, yet must be timed appropriately. One could think that a start-up platform, or a platform that enters a new industry, would especially benefit from securing developer participation, and thus should make a significant integration investment. While this is partially true, our results suggest that a platform facing

unfavorable expectations in the market, such as would be typical of a market entrant, should invest *less* in integration compared with a platform facing favorable expectations, such as an established incumbent. This is because a platform that faces unfavorable expectations obtains a lower total surplus from integration investment due to its inability to set high prices like the one that faces favorable expectations. We see such an example with Tizen, the operating system developed by Samsung. Even though Tizen faced unfavorable expectations from the developer market and could benefit from a well-regarded API program (Tibken 2013, VisionMobile 2014), its investment into API functionality was small compared to Android or iOS (VisionMobile 2014). We see a similar example with Best Buy, who faced unfavorable expectations relative to Amazon Marketplace. Note that this result has dynamic implications in the sense that while a start-up or a new entrant in the market should start with a relatively low level of investment in integration capabilities, it may be optimal to increase that level over time if the platform succeeds to build a strong reputation.

Our study also highlights the role of integration investment under competition. Specifically, we illustrate that a platform that offers a lower core value to consumers than its competitor may become the market leader if it better facilitates third party content development. This happens in a market in which integration investment is very effective in reducing developer fixed costs, consumers highly value content availability, and the developer profit margin is high. As discussed in Section 4.1, better integration investment indeed played a role in Facebook's victory over Myspace, as the latter had an arcane site architecture "hated by the developer community" (Gillette 2011).

Finally, quality heterogeneity in the developer market also affects the level of integration investment. Our analysis in Section 5 shows that the relation between content quality and developers' fixed cost distribution plays a critical role in determining the effect of quality heterogeneity on the optimal integration investment. For example, under regimes of at least moderately high utility from third party content, optimal integration investment can increase with the percentage of high quality developers in the market.

To summarize, our results suggest that higher levels of integration investment become optimal if the platform has a strong reputation in the market, has access to a "high-quality" developer community and operates in a market where developers earn a high profit margin creating content that is highly valued by the consumer market. Further, the possibility of integration investment may push markets into different regimes than those that have been observed under the standard

results from the platform literature.

The study of platform integration investment has numerous policy implications. For example, one reason that the current generation of electronic healthcare record systems has became so widespread was because of the "meaningful use" section of the Affordable Care Act of 2010, which mandated electronic health record systems be installed beginning in 2011-12. Unfortunately, the current systems are highly non-modular (Glaser, Halvorson, Ford, Heffner and Kastor 2007) and do not facilitate large developer communities. Because of switching costs and network effects, the current generation is likely to maintain market share, delaying the hoped-for revolution in patient electronic record interchange and accessibility. This suggests the importance of avoiding premature lock-in of IoT platforms because of their dependence on third party content development. Instead, legislation that encourages the formation of common, developer-friendly integration tools and other standards in desirable markets may be desirable in the presence of multiple new entrants or high competition to encourage ecosystem development. Moreover, because many third-party developers, such as light-switch manufacturers with razor-thin margins, do not have extensive resources to invest in adapting to fully take advantage of even a single platform, it may behoove the government to directly invest in tax credits for integration investment under certain regimes. Finally, as others have noted, competition authorities may wish to tread lightly in emerging platform markets lest they prevent platforms from achieving favorable expectations and thus reducing welfare enhancing platform integration investments.

There are a number of limitations to our study. Throughout the paper, we assume that developers pay a participation fee to join the platform. In many industries, however, developers pay a per-transaction royalty to the platform provider instead of, or in addition to, participation fees. The major results in this paper still hold qualitatively if the platform providers collect royalties instead of participation fees. Specifically, for the monopolist platform, the optimal integration investment level stays the same under the two pricing regimes. Similar interplay between integration investment and pricing decisions also obtains. For example, the optimal royalty may increase with consumers' utility from content, because of the additional lever provided by the integration investment. More importantly, we can show that if the monopolist faced unfavorable expectations, it would still invest less in integration tools compared with a platform that faces favorable expectations. The difference under the royalty pricing regime is that the platform with unfavorable expectations always

adopts the equivalent of the consumer attraction strategy.[9] Finally, under competition, the model becomes intractable if we replace the participation fee with royalties. A preliminary numerical analysis suggests that the directionality of comparative statics remain qualitatively the same. A more comprehensive analysis is left as future research.

In our model of multihoming developers, we make a simplifying assumption that developers do not experience decreasing fixed cost when transplanting content to a different platform. Although this simplification is done for mathematical convenience, spreading fixed costs across both platforms does not change our results qualitatively. When platforms are symmetric, a developer who develops for one platform also develops for the other. Thus, if developers experience decreasing fixed cost when they multihome, in effect their overall fixed cost is reduced. This reduction would change the optimum levels of the decision variables, but it does not change the structure of the optimum strategy for integration investment.

Finally, we consider a single-period model. Future work might analyze the interplay between integration investment and pricing in a dynamic framework as suggested by our analysis of favorable versus unfavorable expectations. For example, an initial investment in integration may enable the platforms to charge higher prices in multiple periods, which would create a stronger case for investing in the integration investment to facilitate third-party developer participation.

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[9]The details of this analysis are available upon request.

References

Amaral, J., Anderson, E. G. and Parker, G. G. (2011), 'Putting it together: How to succeed in distributed product development.', *Sloan Management Review* **2**(52), 51–58.

Anderson, E. G., Chandrasekaran, A., Davis-Blake, A. and Parker, G. G. (2013), Managing distributed product development projects: Integration strategies for language and geographic barriers. Working Paper, University of Texas at Austin, Austin, Texas.

Anderson, E. and Parker, G. (2013), 'Integration of global knowledge networks', *Production and Operations Management* **22**(6), 1446–1463.

Anderson, E., Parker, G. and Tan, B. (2014), 'Platform performance investment with network externalities', *Information Systems Research* **25**(1), 152–172.

Armstrong, M. (2006), 'Competition in two-sided markets', *RAND Journal of Economics* **37**(3), 668–691.

Bakos, Y. and Katsamakas, E. (2008), 'Design and ownership of two-sided networks: Implications for internet platforms', *Journal of Management Information Systems* **25**(2), 171–202.

Baldwin, C. Y. and Clark, K. B. (2000), *Design rules: The power of modularity*, MIT Press.

Barrie, J. (2011), 'Jeff bezos "makes ordinary control freaks look like stoned hippies," says former engineer'. Retrieved on August 8 2016 from BusinessInsider.com. `http://www.businessinsider.com/jeff-bezos-makes-ordinary-control-freaks-look-like-stoned-hippies-says-former-engineer-20`

Barrie, J. (2015), 'Here's how the internet of things will solve traffic jams and take the stress out finding a parking space'. Retrieved on August 8 2016 from BusinessInsider.com. `http://www.businessinsider.com/ofcom-report-on-internet-of-things-2015-1`.

Benzell, S., Lagarda, G. and Alstyne, M. V. (2016), The role of apis in the economy.

Bhargava, H. K. and Choudhary, V. (2004), 'Economics of an information intermediary with aggregation benefits', *Information Systems Research* **15**(1), 22–36.

Boudreau, K. (2010), 'Open platform strategies and innovation: Granting access vs. devolving control', *Management Science* **56**(10), 1849–1872.

Boudreau, K. and Hagiu, A. (2008), Platform rules: Multi-sided platforms as regulators. SSRN: `http://papers.ssrn.com/abstract=1269966`.

Boudreau, K. and Hagiu, A. (2011), Platform rules: Multi-sided platforms as regulators, *in* A. Gawer, ed., 'Platforms, markets and innovation', Edward Elgar Publishing Inc, London, UK.

Caillaud, B. and Jullien, B. (2003), 'Chicken and egg: Competition among intermediation service providers', *RAND Journal of Economics* **34**(2), 309–328.

Corts, K. and Lederman, M. (2009), 'Software exclusivity and the scope of indirect network effects in the u.s. home video game market', *International Journal of Industrial Organization* **27**, 121–136.

Davies, J. and Joglekar, N. (2013), 'Supply chain integration, product modularity, and market valuation: Evidence from the solar energy industry.', *Production and Operations Management* **22**(6), 1494–1508.

Dyer, J. and Singh, H. (1998), 'The relational view: Cooperative strategy and sources of interorganizational competitive advantage.', *"Academy of Management Review"* **23**(4), 660–679.

Economides, N. and Katsamakas, E. (2006), 'Two-sided competition of proprietary vs. open source technology platforms and the implications for the software industry', *Management Science* **52**(7), 1057–1071.

Eisenmann, T. R., Parker, G. and Van Alstyne, M. (2006), 'Strategies for two-sided markets', *Harvard Business Review* **October**.

Eisenmann, T. R., Parker, G. and Van Alstyne, M. (2009), Opening platforms: how, when and why?, *in* A. Gawer, ed., 'Platforms, markets and innovation', Edward Elgar Publishing Inc, London, UK.

Eisenmann, T. R., Parker, G. and Van Alstyne, M. (2011), 'Platform envelopment', *Strategic Management Journal* **32**.

Evans, P. and Annunziata, M. (2012), Industrial internet: Pushing the boundaries of minds and machines, Technical report, General Electric.

Frohlich, M. and Westbrook, R. (2001), 'Arcs of integration: an international study of supply chain strategies.', *Journal of Operations Management* **19**, 185–200.

Gawer, A. and Cusumano, M. (2002), *Platform leadership: How Intel, Microsoft, and Cisco drive industry innovation*, Harvard Business School Publishing, Boston.

Gawer, A. and Henderson, R. (2007), 'Platform owner entry and innovation in complementary markets: Evidence from intel.', *Journal of Economics and Management Strategy* **16**(1), 1–34.

Gillette, F. (2011), 'The rise and inglorious fall of myspace', *Business Week* **June 22, 2011**.

Glaser, J. P., Halvorson, G. C., Ford, M., Heffner, R. and Kastor, J. A. (2007), 'Too far ahead of the it curve', *Harvard Business Review* **7**(8), 29–39.

Gopal, A. and Gosain, S. (2010), 'Research note—the role of organizational controls and boundary spanning in software development outsourcing: Implications for project performance', *International Statistical Review* **21**(4), 960–982.

Hagiu, A. (2006), 'Pricing and commitment by two-sided platforms', *RAND Journal of Economics* **37**(3), 720–737.

Hagiu, A. and Spulber, D. (2013), 'First-party content and coordination in two-sided markets', *Management Science* **59**(4), 933–949.

Iansiti, M. (1995*a*), 'Science based product development: An empirical study of the mainframe computer industry', *POM* **4**(4), 335–359.

Iansiti, M. (1995*b*), 'Technology integration: Managing technological evolution in a complex environment', *"Research Policy"* **24**(4), 521–542.

Iansiti, M. (1998), *Technology Integration: Making Critical Choices in A Dynamic World*, Harvard Business Press, Boston, MA.

IDC (2016), 'Worldwide internet of things forecast update: 2015 – 2019'. Released on February 2016.

Jacobson, D., Brail, G. and Woods, D. (2011), *APIs: A Strategy Guide*, O'Reilly Media, California, US.

Johnson, J. P. (2002), 'Open source software: Private provision of a public good', *Journal of Economic Management Strategy* **11**(4), 637–662.

Kane, S. (2010), '5 predictions for apis in 2011.'. Retrieved June 13, 2014. `http://gigaom.com/2010/12/31/5-predictions-for-apis-in-2011/`.

Katz, M. L. and Shapiro, C. (1985), 'Network externalities, competition, and compatibility', *American Economic Review* **75**(3), 424–440.

Kim, J. S. (2015), 'What's really killing digital health startups', *TechCrunch* .

Lee, D. and Mendelson, H. (2003), 'Divide and conquer: Competing with free technology under network effects', *Production and Operations Management* **17**(1), 12–28.

Lerner, J. and Tirole, J. (2001), 'The open source movement: Key research questions', *European Economic Review* **45**(4), 819–826.

Lerner, J. and Tirole, J. (2002), 'Some simple economics of open source', *Journal of Industrial Economics* **50**(2), 197–234.

Lerner, J. and Tirole, J. (2005), 'The economics of technology sharing:open source and beyond.', *Journal of Economic Perspectives* **19**(2), 99–120.

Liebowitz, S. and Margolis, S. E. (1994), 'Network externality: An uncommon tragedy', *Journal of Economic Perspectives* **8**(2), 133–150.

Lim, S. Y. and Anderson, E. G. (2016), 'Institutional barriers against innovation diffusion: From the perspective of digital health startups.', *49th Hawaii International Conference on System Sciences (HICSS)* pp. 3328–3337.

Parker, G. and Anderson, E. (2002), 'From buyer to integrator: The transformation of the supply chain manager in the vertically disintegrating firm', *Production and Operations Management* **11**(1), 75–91.

Parker, G. G. and Van Alstyne, M. W. (2000*a*), Information complements, substitutes, and strategic product design. mimeo, Tulane University and University of Michigan.

Parker, G. G. and Van Alstyne, M. W. (2000*b*), Internetwork externalities and free information goods, *in* 'Proceedings of the 2nd ACM Conference on Electronic Commerce', ACM, pp. 107–116.

Parker, G. G. and Van Alstyne, M. W. (2005), 'Two-sided network effects: A theory of information product design', *Management Science* **51**(10), 1494–1504.

Parker, G. G. and Van Alstyne, M. W. (2013), Innovation, openness and platform control. Available at SSRN: http://ssrn.com/abstract=1079712.

Parker, G. and Van Alstyne, M. (2009), 'Six challenges in platform licensing and open innovation', *Communications & Strategies* (74), 17.

Parker, G., Van Alstyne, M. and Choudary, S. (2016), *Platform Revolution: How Networked Markets Are Transforming the Economy—And How to Make Them Work for You SP Choudary, MW Van Alstyne, GG Parker - 2016 - New York:*, WW Norton & Company.

Reisinger, D. (2015), 'Here's why internet of things really is the next frontier for businesses'. Retrieved from fortune.com on August 16, 2016. `http://fortune.com/2015/09/30/internet-of-things-businesses/`.

Reuters (2014), 'Tizen app challenge announces winners of 4+ million in prizes.'. Retrieved November, 2014 from `http://www.reuters.com/article/2014/02/23/idUSnMKW6vR8Ca+1ca+MKW20140223`.

Rochet, J. C. and Tirole, J. (2003), 'Platform competition in two-sided markets', *J. Eur. Econom. Assoc.* **1**(4), 990–1029.

Rochet, J. C. and Tirole, J. (2006), 'Two-sided markets: A progress report', *RAND Journal of Economics* **37**(3), 645–667.

Schroeder, S. (2009), 'Bestbuy launches api; can it stack up to amazon?'. Retrieved September 24, 2015, from Mashable. `http://mashable.com/2009/01/27/best-buy-api`.

Shueh, J. (2016), ''smart garbage' startup cuts city trash costs by 40 percente'. Retrieved on August 8 2016 from govtech.com. `http://www.govtech.com/civic/Smart-Garbage-Startup-Cuts-City-Trash-Costs-by-40-Percent.html`.

Sosa, M., Eppinger, S. and Rowles, C. (2004), 'The misalignment of product architecture and organizational structure in complex product development.', *Management Science* **50**(12), 1674–1689.

Tibken, S. (2013), 'Tizen makes stealth pitch to samsung's android acolytes.'. Retrieved November, 2014 from `http://www.cnet.com/news/tizen-makes-stealth-pitch-to-samsungs-android-acolytes/`.

Vance, A. (2013), 'Apple flatters microsoft with imitation', *Bloomberg Businessweek* **June 11, 2013**.

VisionMobile (2014), 'Developer economics q1 2014 state of the developer nation.'. Retrieved November, 2014 from `http://www.developereconomics.com/reports/q1-2014/`.

von Hippel, E. and von Krogh, G. (2003), 'Open source software and the "private-collective" innovation model', *Organization Science* **14**(2), 209–223.

West, J. (2003), 'How open is open enough?: Melding proprietary and open source platform strategies', *Research Policy* **32**(7), 1259–1285.

Weyl, E. G. (2010), 'A price theory of multi-sided platforms', *The American Economic Review* **100**(4), 1642–1672.

Woods, D. (2011), 'Explaining the api revolution to your ceo.'. Retrieved June 4, 2014. `http://www.forbes.com/sites/danwoods/2011/12/15/explaining-the-api-revolution-to-your-ceo/2/`.

Zhu, F. and Iansiti, M. (2011), 'Entry into platform-based markets', *Strategic Management Journal* **33**(1), 88–106.

7 Appendix of Proofs

PROOF OF LEMMA 1. We solve for the optimal decisions (x, w) by taking the respective first order conditions. Assuming positive developer participation, the first order condition with respect to w is given by:

$$\frac{\partial \Pi}{\partial w} = M_D \frac{(g - \alpha)N - 2w - f_{min} + \beta x}{F} = 0 \tag{23}$$

where $f_{min} = f - F/2$. At optimality, the following holds:

$$w_f(x) = \frac{(g - \alpha)N - f_{min} + \beta x}{2} \tag{24}$$

We first solve for the unconstrained solution, x_f. The optimal solution x_f^* will be given by $x_f^* = \max\{\min\{x_f, \frac{f_{min}}{\beta}\}, 0\}$. The first order condition with respect to x is:

$$\frac{M_D \beta(\alpha N + w)}{F} - 2kx_f = 0 \tag{25}$$

Solving the first order conditions simultaneously yields:

$$x_f = \frac{M_D \beta(N(g + \alpha) - f_{min})}{4Fk - M_D \beta^2} \tag{26}$$

$$w_f = \frac{2kF(N(g - \alpha) - f_{min}) + M_D N \alpha \beta^2}{4Fk - M_D \beta^2} \tag{27}$$

where $f_{min} = f - F/2$. To ensure $x_f \geq 0$, $f_{min} = f - F/2 \leq N(g + \alpha)$ has to hold. If $f_{min} > N(g + \alpha)$, then $x_f = 0$. In that case,

$$w_f(x = 0) = \frac{(g - \alpha)N - f_{min}}{2} < 0 \tag{28}$$

But this developer subsidy is not enough to attract developers because $N_D(x = 0) = M_D(-f_{min} + N(g + \alpha))/2F < 0$. Thus, if $f_{min} > N(g + \alpha)$, then the firm should only serve the consumer side of the market. Specifically, assuming $V > c$ the firm charges consumers V, in which case all consumers join the platform despite zero participation from the developer side.

Note that when integration tool effectiveness for cost reduction β satisfies $\beta \leq \sqrt{\frac{4 f_{min} F k}{M_D N (g+\alpha)}}$, then the optimal integration tool functionality x_f^* trivially satisfies the upper limit constraint. If $\beta > \sqrt{\frac{4 f_{min} F k}{M_D N (g+\alpha)}}$, the platform provider chooses the highest possible integration tool functionality level given by $x_f^* = f_{min}/\beta$. For the latter, the resulting w_f^* and p_f^* can easily be calculated as $\frac{(g-\alpha)N}{2}$ and $V + \frac{M_D N \alpha (g+\alpha)}{2F}$, respectively.

Finally, for the second order conditions we need

$$\frac{\partial^2 \Pi}{\partial w^2} = -2M_D/F < 0 \tag{29}$$

$$\frac{\partial^2 \Pi}{\partial x^2} = -2k < 0 \tag{30}$$

which are trivially satisfied. We also need the determinant of the Hessian to be positive.

Hessian=

$$\begin{pmatrix} -2M_D/F & M_D\beta/F \\ M_D\beta/F & -2k \end{pmatrix}$$

$$Det[Hessian] = M_D \frac{4Fk - M_D\beta^2}{F^2} \tag{31}$$

$\square$

Thus, throughout the section, we assume that $4Fk - M_D\beta^2 > 0$.

PROOF OF LEMMA 2. First, note that we assume $N(g + \alpha) - f_{min} \geq 0$ to ensure developer participation and $4Fk - M_D\beta^2 \geq 0$ to satisfy the second order conditions, where $f_{min} = f - F/2$. Also, note that integration investment level given by kx_f^2 is an increasing function of integration tool functionality x_f; thus, any parameter change that affects the optimal level of functionality affects the optimal investment in the same direction.

i) We first analyze the change in the optimal participation fee w_f^* in response to an increase in α. It suffices to check the sign of the following derivative.

$$\frac{\partial w_f^*}{\partial \alpha} = \frac{N(M_D\beta^2 - 2Fk)}{4Fk - M_D\beta^2}$$

Under the assumption $4Fk - M_D\beta^2 \geq 0$, if $M_D\beta^2 \geq 2Fk$, then the participation fee w_f^* increases with α. It is straightforward to see that the optimal integration tool functionality

level x_f^* and the consumer price p_f^* always increases with α:

$$\frac{\partial x_f^*}{\partial \alpha} = \frac{M_D N \beta}{4Fk - M_D \beta^2}$$

$$\frac{\partial p_f^*}{\partial \alpha} = \frac{2k M_D (N(g + 2\alpha) - f_{min})}{4Fk - M_D \beta^2}$$

ii) Under the assumption $4Fk - M_D\beta^2 \geq 0$, the following derivatives are trivially positive.

$$\frac{\partial w_f^*}{\partial g} = \frac{2FkN}{4Fk - M_D \beta^2}$$

$$\frac{\partial x_f^*}{\partial g} = \frac{M_D N \beta}{4Fk - M_D \beta^2}$$

$$\frac{\partial p_f^*}{\partial g} = \frac{2k M_D N \alpha}{4Fk - M_D \beta^2}$$

iii) Under the assumptions $4Fk - M_D\beta^2 \geq 0$ and $N(g + \alpha) - f_{min} \geq 0$, the following derivatives are trivially positive, concluding the proof.

$$\frac{\partial x_f^*}{\partial \beta} = \frac{M_D(N(g + \alpha) - f_{min})(4Fk + M_D\beta^2)}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial w_f^*}{\partial \beta} = \frac{4Fk M_D \beta(N(g + \alpha) - f_{min})}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial p_f^*}{\partial \beta} = \frac{4k M_D^2 \alpha \beta(N(g + \alpha) - f_{min})}{(4Fk - M_D\beta^2)^2}$$

iv) Recall that developers' fixed cost is uniformly distributed in $[f - F/2, f + F/2]$; thus, F determines the variance of the distribution. It is easy to see that $\frac{\partial x_f^*}{\partial F} \leq 0$ if and only if $f \leq N(g + \alpha) + \frac{M_D \beta^2}{8k}$.

$$\frac{\partial x_f^*}{\partial F} = -\frac{M_D \beta(8k(N(g + \alpha) - f) + M_D\beta^2)}{2(4Fk - M_D\beta^2)^2}$$

Similarly, $\frac{\partial p_f^*}{\partial F} \leq 0$ if and only if $f \leq N(g + \alpha) + \frac{M_D\beta^2}{8k}$ as can be seen from the following derivative:

$$\frac{\partial p_f^*}{\partial F} = -\frac{M_D \alpha k(8k(N(g + \alpha) - f) + M_D\beta^2)}{(4Fk - M_D\beta^2)^2}$$

Finally,

$$\frac{\partial w_f^*}{\partial F} = -\frac{Fk(4Fk - M_D\beta^2) - 2k M_D \beta^2(N(g + \alpha) - a + F/2)}{(4Fk - M_D\beta^2)^2}$$

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which implies that developer participation fee increases in F if and only if $Fk(4Fk - M_D\beta^2) \geq 2kM_D\beta^2(N(g+\alpha) - a + F/2)$. Note that $4Fk - M_D\beta^2 \geq 0$ in order to satisfy the second order conditions, and $N(g + \alpha) - a + F/2 \geq 0$ to ensure developer participation. Thus, developer participation fee may indeed decrease or increase with respect to changes in the variability in fixed cost distribution.

<div align="right">□</div>

PROOF OF LEMMA 3. First, note that we assume $Ng - f_{min} \geq 0$ to ensure developer participation and $4Fk - M_D\beta^2 \geq 0$ to satisfy the second order conditions, where $f_{min} = f - F/2$.

i) It is straightforward to see that under both strategies, the decision variables weakly increase with β. Specifically, under the developer attraction strategy:

$$\frac{\partial x_{ue2}^*}{\partial \beta} = \frac{M_D(N(g + \alpha) - f_{min})(4Fk + M_D\beta^2)}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial w_{ue2}^*}{\partial \beta} = \frac{4FkM_D\beta(N(g + \alpha) - f_{min})}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial p_{ue2}^*}{\partial \beta} = \frac{4kM_D^2\alpha\beta(N(g + \alpha) - f_{min})}{(4Fk - M_D\beta^2)^2}$$

Under the consumer attraction strategy:

$$\frac{\partial x_{ue1}^*}{\partial \beta} = \frac{M_D(Ng - f_{min})(4Fk + M_D\beta^2)}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial w_{ue1}^*}{\partial \beta} = \frac{4FkM_D\beta(Ng - f_{min})}{(4Fk - M_D\beta^2)^2}$$

$$\frac{\partial p_{ue1}^*}{\partial \beta} = 0$$

Note that $\frac{\partial x_f^*}{\partial \beta} = \frac{\partial x_{ue2}^*}{\partial \beta}$ and $\frac{\partial x_f^*}{\partial \beta} - \frac{\partial x_{ue1}^*}{\partial \beta} = \frac{M_D N\alpha(4Fk + M_D\beta^2)}{(4Fk - M_D\beta^2)^2} > 0$, indicating that the UE platform increases its integration tool functionality at a slower rate than the FE platform when β increases.

ii) Under the consumer attraction strategy,

$$\frac{\partial w_{ue1}^*}{\partial g} = \frac{2FkN}{4Fk - M_D\beta^2}$$

$$\frac{\partial x_{ue1}^*}{\partial g} = \frac{M_D N\beta}{4Fk - M_D\beta^2}$$

$$\frac{\partial p_{ue1}^*}{\partial g} = 0$$

Trivially, all the decision variables are weakly increasing in g. Under the developer attraction strategy:

$$\frac{\partial w^*_{ue2}}{\partial g} = \frac{2FkN}{4Fk - M_D\beta^2}$$

$$\frac{\partial x^*_{ue2}}{\partial g} = \frac{M_DN\beta}{4Fk - M_D\beta^2}$$

$$\frac{\partial p^*_{ue2}}{\partial g} = M_DN\alpha\frac{M_D\beta^2 - 2Fk}{4Fk - M_D\beta^2}$$

The first two are trivially positive. However, the consumer price increases in g only if and only if $M_D\beta^2 - 2Fk \geq 0$.

iii) Under the consumer attraction strategy, none of the decision variables depend on α. Under the developer attraction strategy:

$$\frac{\partial w^*_{ue2}}{\partial \alpha} = \frac{N(M_D\beta^2 - 2Fk)}{4Fk - M_D\beta^2}$$

$$\frac{\partial x^*_{ue2}}{\partial \alpha} = \frac{M_DN\beta}{4Fk - M_D\beta^2}$$

$$\frac{\partial p^*_{ue2}}{\partial \alpha} = M_D\frac{gM_DN\beta^2 - 2Fk(f_{min} + N(g - 2\alpha))}{F(4Fk - M_D\beta^2)}$$

It is easy to see that w^*_{ue2} increases with α if $M_D\beta^2 \geq 2Fk$ and decreases with α otherwise. Similarly, the consumer price increases with α if $gM_DN\beta^2 - 2Fk(f_{min} + N(g - 2\alpha)) \geq 0$ and decreases with α otherwise.

iv) Under the consumer attraction strategy:

$$\frac{\partial x^*_{ue1}}{\partial F} = -\frac{M_D\beta(8k(Ng - f) + M_D\beta^2)}{2(4Fk - M_D\beta^2)^2}$$

which is clearly negative when $f \leq gN + \frac{M_D\beta^2}{8k}$. Under the developer attraction strategy, $x_{ue2} = x_f$, thus the sign of the derivative will be the same as given in Lemma 2(iv).

Under the consumer attraction strategy,

$$\frac{\partial w^*_{ue1}}{\partial F} = -\frac{Fk(4Fk - M_D\beta^2) - 2kM_D\beta^2(Ng - a + F/2)}{(4Fk - M_D\beta^2)^2}$$

which implies that developer participation fee increases in F if and only if $Fk(4Fk - M_D\beta^2) \geq 2kM_D\beta^2(Ng - a + F/2)$. Note that $4Fk - M_D\beta^2 \geq 0$ in order to satisfy the second order

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conditions, and $Ng - a + F/2 \geq 0$ to ensure developer participation. Thus, developer partic-ipation fee may indeed decrease or increase with respect to changes in the variability in fixed cost distribution. The result under the developer attraction strategy can be proven similarly.

Finally, under the consumer attraction strategy, $p = V$; thus consumer price does not depend on F. Under the developer attraction strategy,

$$\frac{\partial p^*_{ue2}}{\partial F} = \frac{M_D\alpha(8F^2k^2(f + N(g - \alpha)) - FkM_D\beta^2(F + 8gN) + gM_D^2N\beta^4}{F^2(4Fk - M_D\beta^2)^2}$$

which, clearly, can be positive or negative.

$\square$

PROOF OF PROPOSITION 1. We compare the profits under the two strategies, assuming an interior solution; that is the unconstrained optima x_{ue1} and x_{ue2} satisfy $0 < x_{ue1} < f_{min}/\beta$ and $0 < x_{ue2} < f_{min}/\beta$.

$$\Pi_{UF1} - \Pi_{UF2} = \frac{M_DN\alpha\big(Fk(2f_{min} - \alpha N) + gN(2Fk - M_D\beta^2)\big)}{F(4Fk - M_D\beta^2)} \tag{32}$$

where $f_{min} = f - F/2$. Given the assumption $4Fk - M_D\beta^2 \geq 0$, Strategy 1 yields a higher profit if

$$\beta < \sqrt{\frac{Fk(2f_{min} + 2gN - N\alpha))}{gM_DN}} \tag{33}$$

Note that if (33) holds (i.e. Strategy 1 gives a higher profit), the viability condition for Strategy 1 (which is $\beta < \sqrt{\frac{Fk(2f_{min}+2gN)}{gM_DN}}$) is automatically satisfied. Similarly, if $\beta \geq \sqrt{\frac{Fk(2f_{min}+2gN-N\alpha))}{gM_DN}}$ (i.e. Strategy 2 gives a higher profit), the viability condition for Strategy 2 (which is $\beta > \sqrt{\frac{Fk(2f_{min}+2gN-2N\alpha)}{gM_DN}}$), concluding the proof. $\square$

PROOF OF LEMMA 4. At equilibrium, $\{x_1^*, x_2^*, p_1^*, p_2^*, w_1^*, w_2^*\}$ satisfy the following first order conditions

$$\frac{\partial\Pi_1}{\partial x_1}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) = \frac{\partial\Pi_1}{\partial p_1}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) =$$
$$\frac{\partial\Pi_1}{\partial w_1}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) = \frac{\partial\Pi_2}{\partial x_2}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) =$$
$$\frac{\partial\Pi_2}{\partial p_2}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) = \frac{\partial\Pi_2}{\partial w_2}(x_1^*, p_1^*, w_1^*; x_2^*, p_2^*, w_2^*) = 0 \tag{34}$$

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By solving (34) simultaneously, we obtain x_C^*, p_C^*, and w_C^*, given in Lemma 4. To ensure optimality, second order conditions require the Hessian to be negative definite. That is, the first leading principal minor (LPM) has to be negative, the second LPM has to be positive, and the third LPM has to be negative.

$$First\ LPM = \frac{\partial^2 \Pi}{\partial x^2} = -2k < 0$$

$$Second\ LPM = \begin{vmatrix} \frac{\partial^2 \Pi}{\partial x^2} & \frac{\partial^2 \Pi}{\partial x \partial p} \\ \frac{\partial^2 \Pi}{\partial p \partial x} & \frac{\partial^2 \Pi}{\partial p^2} \end{vmatrix}$$
$$= N \frac{8Fk(Ft - gM_D N\alpha) - NM_D^2 \alpha^2 \beta^2}{4(Ft - gM_D N\alpha)^2} > 0$$

A necessary but not sufficient condition to satisfy this requirement is

$$Ft - gM_D N\alpha > 0 \tag{35}$$

$$Third\ LPM = \begin{vmatrix} \frac{\partial^2 \Pi}{\partial x^2} & \frac{\partial^2 \Pi}{\partial x \partial p} & \frac{\partial^2 \Pi}{\partial x \partial w} \\ \frac{\partial^2 \Pi}{\partial p \partial x} & \frac{\partial^2 \Pi}{\partial p^2} & \frac{\partial^2 \Pi}{\partial p \partial w} \\ \frac{\partial^2 \Pi}{\partial w \partial x} & \frac{\partial^2 \Pi}{\partial w \partial p} & \frac{\partial^2 \Pi}{\partial w^2} \end{vmatrix}$$
$$= M_D N \frac{(2Ft - gM_D N\alpha)(M_D \beta^2 - 4Fk) + FkM_D N(g+\alpha)^2}{2F(Ft - gM_D N\alpha)^2} < 0$$

The first term in the numerator is positive by (35), and the third term is trivially positive. Thus, to satisfy the requirement the following must hold:

$$4Fk - M_D \beta^2 > 0 \tag{36}$$

Finally, to ensure market coverage on the consumer side, the utility of consumer located at $N_C^i = 1/2$ should be nonnegative. In other words, $c \leq V + \frac{gM_D N\alpha}{2F} + \frac{M_D k(g+\alpha)(N(g+\alpha) - 2f_{min})}{4Fk - M_D \beta^2} - 3t/2$, where $f_{min} = f - F/2$. Similarly, to ensure developer participation, we assume $f_{min} \leq N(g+\alpha)/2$. $\quad\square$

PROOF OF COROLLARY 1. Note that we assume $f_{min} = f - F/2 < N(g+\alpha)/2$ to ensure developer participation and $4Fk - M_D \beta^2 \geq 0$ to satisfy second order conditions. Under these assumptions, the following derivative is trivially negative, proving that consumer price p_C^* decreases with g.

$$\frac{\partial p_C^*}{\partial g} = -\frac{M_D N\alpha}{2F} - \frac{M_D k(N(2g+\alpha) - 2f_{min})}{4Fk - M_D \beta^2}$$

In Lemma 2, we have shown that p_f^* always increases with g, concluding the proof. $\square$

PROOF OF COROLLARY 2. Note that we assume $4Fk - M_D\beta^2 \geq 0$ to satisfy second order conditions. Under this assumption, the following derivative is trivially negative, proving that consumer price p_C^* decreases with α.

$$\frac{\partial p_C^*}{\partial \alpha} = -\frac{gM_DN}{2F} - \frac{gM_DkN}{4Fk - M_D\beta^2}$$

In Lemma 2, we have shown that p_f^* always increases with α, concluding the proof. $\square$

PROOF OF COROLLARY 3. Note that we assume $f_{min} = f - F/2 < N(g+\alpha)/2$ to ensure developer participation. Under this assumption, the following derivative is trivially negative, proving that consumer price p_C^* decreases with β.

$$\frac{\partial p_C^*}{\partial \beta} = -\frac{2gM_D^2k(N(g+\alpha) - 2f + F)}{(4Fk - M_D\beta^2)^2}$$

In Lemma 2, we have shown that p_f^* always increases with β, concluding the proof. $\square$

PROOF OF LEMMA 5. It suffices to check the signs of the following derivatives

$$\frac{\partial x_{ex1}^*}{\partial \rho} = \frac{M_D\beta(N(g_H - g_L) + (N\alpha - f)(1 - q_L))}{4Fk - M_D\beta^2}$$

$$\frac{\partial x_{ex1}^*}{\partial q_L} = \frac{M_D\beta(N\alpha - f)(1 - \rho))}{4Fk - M_D\beta^2}$$

which are trivially positive if $f \leq N\alpha$ under the assumptions $g_H \geq g_L$ and $4Fk - M_D\beta^2 \geq 0$. $\square$

PROOF OF LEMMA 6. It suffices to check the signs of the following derivatives

$$\frac{\partial x_{ex2}^*}{\partial \rho} = \frac{M_D\beta(N(g_H - g_L) + (N\alpha + f)(1 - q_L))}{4Fk - M_D\beta^2}$$

$$\frac{\partial x_{ex2}^*}{\partial q_L} = \frac{M_D\beta(N\alpha(1 - \rho) - f\rho)(1 - q_L)}{4Fk - M_D\beta^2}$$

The first is always positive under the assumptions $g_H \geq g_L$ and $4Fk - M_D\beta^2 \geq 0$. The second is positive if and only if $\alpha \geq \frac{f\rho}{N(1-\rho)}$. $\square$