Innovation, Openness & Platform Control

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14-January-2013

We examine how exercising control rights over a technology platform can increase profits and innovation. By choosing how much to open and when to bundle enhancements, platform sponsors can influence choices of ecosystem partners. Platform openness invites developer participation but sacrifices direct sales. Bundling enhancements early destroys developer profits but bundling late delays R&D spillovers that promote platform growth. Interestingly, developers can prefer sponsored platforms to unmanaged open standards despite giving up rights to their applications. Results can inform innovation strategy, choice of organizational form, antitrust and intellectual property law, and the management of competition.

Keywords: Open Innovation, Sequential Innovation, Platforms, R&D Spillovers, Intellectual Property, Network Effects, Network Externalities, Bundling, Two Sided Networks, Two Sided Markets, Vertical Integration.

Acknowledgments: This work has benefited from thoughtful comments by Marcel Canoy, Thomas Eisenmann, Jovan Grahovic, Josh Lerner, Sadao Nagaoka, Marc Rysman, Jens Prüfer, Tushar Shanker, Ekundayo Shittu, Patrick Waelbroeck, Thomas Weber, and Ken Younge. Xiaoyue Jiang provided key analytic simplifications and Nico Savva provided guidance for our model of technological uncertainty. Seminar participants from Cambridge University, IDEI / Bruegel, Imperial College, Kansai University, Law and Economics Consulting Group, MIT, Stanford Institute for Economic Policy Research, Tilburg Law & Economics Center, University of California-San Diego, and University of Washington also helped shape this research. The National Science Foundation provided support via grant SES-0925004. We also thank executives from AT&T, Cisco Systems Inc., the member organizations of the International Post Corporation, Microsoft Corporation, and SAP who generously gave of their time to help us understand key tradeoffs in platform business models.

1 Introduction

Improved computing and communications technologies have promoted open innovation and platform business models (Chesbrough, 2003). Platform economics are distinctly powerful because they allow firms to harness a global network of partners who can extend a core offering to create a vibrant and appealing ecosystem. We believe this trend will continue and that we are likely to see the "platformization" of sectors of the economy previously served by vertically organized firms. For example, on-premises enterprise software firms face significant competition from hosted services ecosystems as a result of widely available browser and mobile-device clients that easily connect to remote resources. Similarly, device manufacturers for cameras, MP3 players, global positioning systems, and phones now court numerous developers in an effort to crowdsource innovation around their products. As cover stories in The Economist (2012) and Wall Street Journal (2012) show, the call for understanding platforms extends to the popular press.

Despite considerable research on prices, quantities, and network effects, however, Yoo et al. (2010) note that little formal analysis has investigated the building blocks of successful platform business models. This paper addresses that gap. Our thesis is that to manage open innovation, a platform firm must carefully set parameters for openness, developer property rights, and vertical integration. It should choose openness to balance growth and profitability; it should appropriate third party innovation so as to manage participation and R&D spillovers; and platform firms have rational criteria for choosing vertical integration over platforms and platforms over open standards. We build and explore a formal model to examine these tradeoffs.

Openness we analyze as the degree to which firms expose platform technologies to developers who, on the one hand, expand the platform's utility to users and thus boost platform profits, but who, on the other hand, divert profits to themselves if the platform does not absorb their innovations. Openly sharing technology affects the innovative capacity of developers but also the rents available to platform sponsors.

Developer property rights we analyze as the decision to bundle downstream innovations into the platform, thus essentially competing with developers by entering their markets. On the one hand, a decision not to bundle developer innovations increases their output but, on the other hand, this prolongs monopoly distortions and prevents valuable new features from becoming standards available to the community. Bundling innovations together with open sharing has the potential to profitably regulate R&D spillovers.

Numerous firms have foreseen the benefits of vertically integrating into their developers' innovations yet this also carries costs. Whether through internal development or acquisition, coercive or not, platform firms such as Apple, Facebook, Google, Intel, Microsoft, and SAP have routinely absorbed valuable features developed by ecosystem partners. Microsoft, for example, aggressively absorbed innovations such as disk defragmentation, encryption, streaming media, and web browsing (Jackson, 1999). The danger is that bundling developers' innovations reduces their efforts, induces their exit, and subsequently retards ecosystem innovation. It can even lead to antitrust investigation. Google and Intel have both faced FTC scrutiny for favoring their versions of others' products while Microsoft was convicted of antitrust violation for anticompetitive bundling (Jackson, 1999).

Given the importance of openness and bundling, it is not surprising that executives disagree over the best ways to manage such tradeoffs. At one end of the spectrum, Tivo used provisions of the Digital Millennium Copyright Act to lock out industry players who sought to attach to its proprietary systems (Slater and Schoen, 2006). This allowed Tivo to charge more for its innovations yet closure kept its ecosystem small. At the other end of the spectrum, UNIX firms lost all control over Application Programming Interfaces (APIs) to committees (West, 2003). RedHat uses licensing terms, standard under the GNU Public License, that give anyone who receives their code the right to modify and distribute copies. Ecosystem participation grows but competitors promptly absorb all valuable innovations. In the 1980s, IBM's fast-to-market PC strategy opened enough that it lost ecosystem control to Microsoft. Loss of control was so complete that industry nomenclature shifted from "IBM PC" to "Wintel platform" (West, 2003). Even within firms, views on proprietary control evolve. In the 1980s and 1990s, Apple neared bankruptcy after a series of failures including its Newton handheld computer, precursor to the iPhone, and after decades of keeping its architecture too closed (Gawer and Cusumano, 2008). When asked how to fix Apple, Dell Computer's CEO opined that he would "shut it down and give the money back to the shareholders" (Singh, 1997).

Microsoft's contrasting PC strategy licensed technology broadly, opened but controlled APIs on its desktop operating system, and priced its system developer toolkit (SDK) at less than one-third that of Apple to foster development. Controlled openness and agressive bundling appears to have worked. By the time of Microsoft's 1998 antitrust trial, it enjoyed more than 80% market share; more than 70,000 applications ran on Microsoft Windows, compared to roughly 12,000 on Apple's Mac OS and 2,500 on IBM's OS/2, and developers contributed far more applications to Microsoft Windows than to UNIX (Jackson, 1999). Apple learned from past mistakes. After revising its ecosystem strategy, Apple surpassed Dell in market capitalization on Jan 13, 2006; it then passed Microsoft on May 26, 2010. And, on August 9, 2011, Apple passed Exxon Mobile to become, at least briefly, the most valuable company in the world.

Table 1 illustrates different platform approaches considering: (1) standalone platform value (utility out-of-the-box), (2) average 3^{rd} party added value relative to total platform value (hypothetical for closed platforms), (3) degree of platform openness, and (4) whether the platform got this decision right. We use these constructs in the model below to motive our analysis by the widely disparate strategies we see firms pursuing in practice, the varying successes of platform companies across a spectrum of products and services, and the need for tools to analyze their decisions.

A platform's decisions on degree of openness and bundling are critical parts of an ecosystem strategy, which we define as one that drives adoption and harnesses developers as an extension of the sponsor's own production function. Though competitors play a role, ecosystem decisions focus on users and developers, who might or might not be known to the sponsor, and who must be coaxed into platform participation. Developers often have ideas the sponsor has not considered and resources that the sponsor does not control. In order to gain access to these resources, many successful platforms have devised default contracts, with appropriate developer incentives such that even developers not known to the sponsor respond by producing on the sponsor's behalf. Such a strategy is necessarily open in the sense that source codes and access details are published (Eisenmann et al., 2009; West, 2003) and are two-sided in the sense that it is priced attractively to one group–developers–so as to profit from another group–end users (Parker and Van Alstyne, 2000a,b, 2005; Rochet and Tirole, 2003).

Table 1: Industry Platform Examples

Platform & Sponsor	*Standalone Value*	*Avg 3rd Party Value Add*	*Openness Level*	*Right Level Openness?*
Apple OS 1990s	high	med	low	too closed
Apple iOS 2000s	high	med	med	yes
Atari 1980s	high	low	med	too open
Facebook 2000s	high	med	med	yes
Google Android 2010s	med	med	high	yes
Microsoft Windows OS 1990s	med	high	high	yes
Microsoft Windows Mobile 2010s	med	med	med	yes
Microsoft XBox 2000s	low	high	med	too closed
Motorola Cable Set Top Box	med	low*	no	too closed
MySpace 2000s	med	low	low	too closed
RedHat Linux 1990s	med	high	high	too open
General Dynamics F16 1970s	high	med	low	yes
Lockheed Martin F16 2000s	med	high	med	too closed
IBM PC 1980s	high	high	med	too open
SalesForce 2000s	high	high	high	yes
SAP-ERP 2000s	high	high	med	yes
SAP-Cloud-2010s	med	med	med	yes
TiVo 2000s	high	low*	no	too closed

* potential

The table was constructed using data collected from from fourteen external experts who research platform economics and strategy. Each author independently coded parameter values and then consensus estimates were created from external expert and author input.

The focus on users and developers can yield competitive advantage by causing alternate platforms to starve from lack of participation. For example, an open ecosystem strategy appears to have played a role in the rise of Facebook and the demise of MySpace. Not only did Facebook membership surge once it opened from the exclusive '.edu' to the '.com' domain, but it surged with the addition of a digital store, and, most important, surged again on opening to outside developers (Piskorski et al., 2012). This effectively pushed MySpace out of competition. Indeed, MySpace co-founder DeWolfe noted that the decision to keep all development in-house was ill-advised at best; while Facebook focused on creating a robust platform that allowed outside developers to build new applications, Myspace did everything itself.

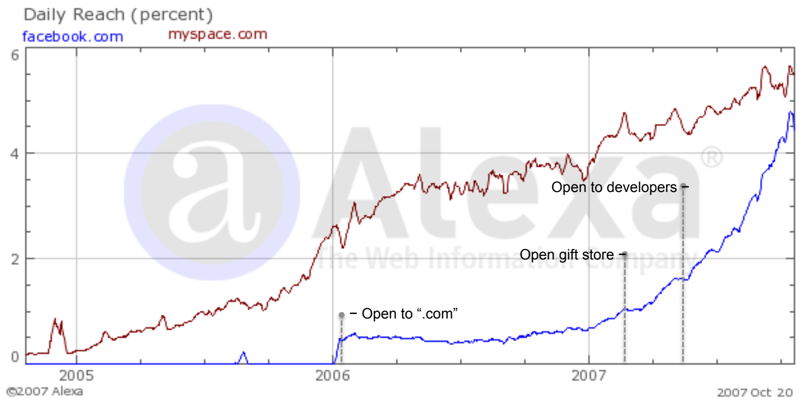

Figure 1: Accesses to the social networking platform MySpace appear above while those to Facebook appear below. Starting from the ".edu" domain, Facebook opened to the ".com" domain in early 2006, then opened a digital store, later opening to developers in 2007. This appears to have increased usage among consumers and developers. A Chow test of log slope differences at each break point is significant at the 5% level.

> "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?' " says (MySpace cofounder) DeWolfe. "We should have picked 5 to 10 key features that we totally focused on and let other people innovate on everything else." (Gillette, 2011, p. 57)

The phenomenon of platform ecosystems extends beyond the well-known information systems examples described above to encompass more traditional industries such as military capital equipment. For example, military aircraft are platform systems whose capabilities can be increased through the addition of third party systems such as avionics packages, engine upgrades, and external peripherals such as cruise missiles and reconnaissance cameras. The F-16 is a successful platform with a robust community of developers that has extended the useful service life long after the basic airframe became obsolete (Tirpak, 2007). Conversely, older aircraft platforms that do not support a robust supplier base face increasing cost and reduced performance (Jones and Zsidisin, 2008). This observation is consistent with Srinivasan et al. (2004) who predict and find that pioneer firms of technologically intense new products face obsolescence, but nonetheless can fight off competition through a platform ecosystem strategy.

The remainder of the paper proceeds as follows. Section 2 reviews literature and provides definitions. Section 3 develops the model and main results, including social welfare, competition, and technological uncertainty. Section 4 considers alternate organizational forms. We consider extensions in 5 and conclude in Section 6.

2 Literature

Boudreau (2010) defines platforms as the components used in common across a product family. Their functionality can be extended by third parties and are subject to network effects (Eisenmann et al., 2011; Evans et al., 2006; Parker and Van Alstyne, 2000a,b, 2005). Platforms are building blocks serving as a foundation for constructing complementary products and services (Gawer and Cusumano, 2002, 2008; Gawer and Henderson, 2007) or systems for matching buyers and suppliers who transact with each other using system resources (Hagiu and Wright, 2012) or as sales channels (Ceccagnoli et al., 2012). Our use is similar but distinct.

For purposes of this paper, we define a platform business model as an open standard together with an open contract. The standard provides the technological real estate upon which developers build. The contract provides the mechanism that motivates and circumscribes developer behavior. Both are published in the sense that ex ante negotiation is unnecessary and developers need not disclose their identities or ideas before choosing to invest.

A platform is "open" to the extent that it places no restrictions on participation, development, or use across its distinct roles, whether developer or end-user (Eisenmann et al., 2009). Openness is easily modeled as a continuum (Parker and Van Alstyne, 2009). Opening completely, i.e. the absence of control at the platform level, we analyze as a fully unrestricted open standard. Choosing the optimal level of openness is critical for firms that create and maintain platforms (Boudreau, 2010; Chesbrough, 2003; Eisenmann et al., 2009; Gawer and Cusumano, 2002; Gawer and Henderson, 2007; West, 2003). This decision entails a tradeoff between growth and appropriation (West, 2003). Opening a platform can spur growth by harnessing network effects, reducing users' fears of lock-in, and stimulating downstream production. At the same time, opening a platform typically reduces users' switching costs, increases forking and competition, and reduces sponsors' ability to capture rents. Empirical estimates of innovation based on level of openness exhibit an inverted-U shape (Boudreau, 2010; Laursen and Salter, 2005), suggesting firms can optimize innovation and openness.

To build the ecosystem, platform sponsors often embrace modular technologies and encourage partners to supply downstream complements (Baldwin and Clark, 2000; Fine, 1999; Boudreau, 2010). Loose integration promotes layered industries. In the personal computer industry, for example, these layers consist of semiconductor manufacture, PC assembly, operating system, and application software, among others (Baldwin and Clark, 2000; Grove, 1996; Shapiro and Varian, 1999). The credit card and telecommunications industries are similarly layered (Evans et al., 2006).

As a result of the increasing economic importance of platforms, a growing literature has focused on leadership (Gawer and Cusumano, 2008), economics (Bresnahan and Greenstein, 1999; Farrell et al., 1998), launch (Bhargava et al., 2012), and strategies for managing them (Boudreau, 2010; Cusumano, 2010). Markovich and Moenius (2009) analyze competitive platform dynamics and show that weak developers can benefit from value added by strong developers. Huang et al. (2012) show that developers with stronger property rights can more successfully resist expropriation by the platform. Scholten and Scholten (2011) identifies control points that allow the platform sponsor to charge for access. The two-sided literature conceives of platforms as mediating markets with network externalities that cross distinct user groups and shows how subsidies to one group become optimal (Parker and Van Alstyne, 2000a,b; Caillaud and Jullien, 2003; Rochet and Tirole, 2003; Parker and Van Alstyne, 2005; Eisenmann et al., 2006; Rysman, 2009). Giveaways and subsidies to developers are common in technology markets.[1] Two-sided models, however, do not account for control over downstream production; most simply assume network attraction. Our model extends this work to describe how firms control downstream innovation, including the decision of when to enter markets of downstream partners.

Entry into downstream production also represents vertical integration, a decision that turns on transactional economies and market imperfections (Perry, 1989). Similar to prior literature, our model shows sponsor coordination improves over an open standard. But, unlike prior literature,

[1] To launch Windows mobile, Microsoft spent thousands on developer subsidies (http://www.youtube.com/watch?v=OCvpypcUJI8. Accessed Dec. 31, 2012). To launch Android mobile, Google offered $5.5 million in prizes for new applications (google.com/android/adc. Accessed Aug. 30, 2011).

information asymmetry and externalities do not necessarily lead to vertical integration, which can be infeasible here. Platform sponsors can lack awareness of prospective developers and so must promote participation not knowing whom to motivate. Moreover, vertically integrating into one side of a two-sided network can limit the very network effects the sponsor must promote. We also show when innovation can increase by organizing as a platform rather than as a hierarchy.

Absorbing innovations resembles product bundling yet with a different purpose. Whereas others analyze bundling for its ability to capture rents (Salinger, 1995; Bakos and Brynjolfsson, 1998; McAfee et al., 1989) or provide competitive advantage (Nalebuff, 2004; Eisenmann et al., 2011), we connect it to R&D spillovers. Prior literature characterizes R&D spillovers as spatially-mediated knowledge externalities that increase the productive capacity of a region (Audretsch and Feldman, 1996) or increase the growth of whole economies (Edwards, 2001). In contrast, a platform-mediated spillover increases the productive capacity of ecosystem partners via a continuous process of innovation absorption and redistribution. Developers can then build on each other as well as on the platform. The mechanism for such a contract is articulated in the law and economics literature on "private ordering," governance via private contract that seeks to achieve welfare gains higher than that provided by a system of public laws (Eisenberg, 1976). Due to information asymmetry and generic defaults, private ordering can do better than social planning (Williamson, 2002).

Making analysis dynamic then brings in work on sequential innovation. When follow-on innovation is uncertain, Chang (1995); Green and Scotchmer (1995) find that a lead innovator should capture profits from follow-on innovators to invest optimally. Related intellectual property models examine patent length and breadth as stimuli to innovation (Gilbert and Shapiro, 1990; Klemperer, 1990; Landes and Posner, 2002). We start from a two period model of sequential innovation, then add a recursive downstream production function. This allows a firm to control downstream innovation. From the firm's perspective, we can then analyze optimal openness and duration of developer property rights, and provide comparative statics for the variables in Table 1. From a regulator's perspective, we demonstrate a prisoners' dilemma among developers such that, absent platform control, the ecosystem grows more slowly without the sponsor's coordination. Thus sponsors need longer term property rights than developers in order to effectively manage downstream innovation.

Reference literature includes network economics, modular systems theory, IP contracting, R&D spillover, and vertical integration. To date, however little formal modeling has addressed the question of how a platform sponsor should design a contract in order to capture profits and promote growth in the platform ecosystem (Boudreau and Hagiu, 2009). Indeed, how a firm should strategically control its platform over time is a key area of unanswered research (Yoo et al., 2010).

In extending the literature referenced above, our model allows us to characterize (i) the optimal level of openness for a platform (ii) the optimal exclusionary period (i.e. when a sponsor should bundle innovation and when downstream apps should face rent destroying competition), (iii) when a platform sponsor should choose vertical integration over platforms and platforms over open standards, (iv) how competition affects openness, and (v) why the presence of a platform sponsor that forces openness on downstream developers can make even developers themselves, as well as users, better off. While the model provides numerous analytic results, intuitions provided below are also shaped by dozens of interviews with executives at platform firms.

3 The Model

Consider a model of ecosystem innovation that includes platform sponsors, developers, and consumers. The platform, controlled by the sponsor, has value V independent of developer applications. To allow for sequential innovation, time spans two periods of equal length t with discount rate r. Developers can add value in both periods, with output denoted y_1 and y_2. Consistent with the sequential innovation literature, we consider output in each period to measure the innovation in each period. At time zero, a platform sponsor makes fraction σ of its platform's value openly available to developers, representing free access to libraries, APIs and SDKs. This free code from the sponsor represents input σV that developers use to produce applications for the platform. In a parallel to the two-sided market literature, an alternate interpretation of σV is that it represents a subsidy to developers. Thus we define $S = \sigma V$.

Developers must cover fixed and variable costs, F and $cy^{1/\alpha}$, to produce output y that has a per-unit value of v to consumers. Developers produce according to a standard Cobb-Douglas production function where k is a reuse coefficient determining the level of conversion from code stock into new applications, and technology parameter α determines production efficiency.[2] Thus $y_1 = k(\sigma V)^\alpha$. We discuss robustness of these assumptions in section 5.

As in Chang (1995), consumers share common values for V, the platform's value, and for v each unit of application value. We assume that leakage to consumers results in a net loss of platform value in the amount of platform opened, σV. Loss of control implies competitive supply and loss of profit from this resource (West, 2003). The open code lasts only one period due to technological obsolescence. This prevents developers from reusing free material more than once, which would only increase the value of openness. Developer output in period one, however, can be reused in period two, meaning downstream production is potentially recursive. Thus, the sponsor can choose to stimulate period 1 output, which can then stimulate period 2 output. If period one output is also opened, then developer output in periods 1 and 2 can be expressed as $y_1 = k(\sigma V)^\alpha$ and $y_2 = k(y_1)^\alpha = k^{1+\alpha}(\sigma V)^{\alpha^2}$. Section 4 considers vertical integration to avoid opening and losing platform value. To make revenue streams comparable, second period revenue is discounted to the end of period one at rate r.

Let t be the length of the exclusionary period offered to developers during which they can sell their applications at positive profits. That is, analogous to a period of patent protection, t represents the time before which a sponsor agrees not to compete with the developer, but after which the sponsor will fold new developer add-ons into the open platform. Newly open features from one developer then become available to all. To facilitate analysis, we combine parameters r and t into discount coefficient $\delta = e^{-rt}$. Time is bounded by $0 \leq t < \infty$ which restricts δ to the range $0 < \delta \leq 1$. Price is then determined by the length of time before an application is forced into the open domain. Consumers know that applications will be freely available after the exclusionary period t. Therefore, developers can charge consumers only for the difference between the full value of the product today and the discounted value of the product when it becomes open and free. Thus, by the Coase conjecture on inter temporal discounting of a monopoly product (Coase, 1972),

[2] In standard IO models, k is simply real output per unit input. We assume $\alpha \in (0, 1)$ in order to represent diminishing returns technology.

$p = v - \delta v = v(1-\delta)$.[3] If the sponsor never bundled new applications into the platform ($t \to \infty$) then $\delta \to 0$ and $p = v$. Likewise, if the exclusionary period ends immediately ($t = 0$), then $\delta = 1$ and $p = 0$.

As in Green and Scotchmer (1995), we assume that Nash bargaining governs the revenue split on downstream innovation, giving each party $\frac{1}{2}$ the downstream developer-produced surplus.[4] For now, we assume zero marginal production costs and a sufficiently large value added, v, that developers cover their fixed costs. For many information goods, and even physical goods such as semiconductors, zero marginal cost is a reasonable approximation. Regardless, we consider costs in section 3.2. Developer profit and platform sponsor profits can then be written as

$$\pi_d = \frac{1}{2}py_1 + \delta\frac{1}{2}py_2 \tag{1}$$

$$\pi_p = V(1-\sigma) + \frac{1}{2}py_1 + \delta\frac{1}{2}py_2 \tag{2}$$

Expressing platform sponsor profit in terms of model primitives yields

$$\pi_p = V(1-\sigma) + \frac{1}{2}v(1-\delta)k(\sigma V)^{\alpha} + \delta\frac{1}{2}v(1-\delta)k^{1+\alpha}(\sigma V)^{\alpha^2}. \tag{3}$$

Platform sponsors choose σ and t; remaining terms are exogenous. For reader convenience, Table 3 provides definitions.

3.1 Platform Sponsor Choice of σ and t

Next, we explore the central tension facing the platform sponsor: the degree to which it should sacrifice direct platform profits in order to stimulate downstream innovation, and its commitment to avoid competing directly with developers before expiration of the proprietary period. The optimal contract is a pair $\langle\sigma, t\rangle$ (isomorphic to $\langle\sigma, \delta\rangle$) where choice parameters σ and t represent the share

[3] Equivalently, reduce v in Eq. 1 by ex ante developer belief that the sponsor will enter its market.

[4] In practice, licensing encourages growth through openness but "indexes the sponsor's share of profits to platform expansion in a low friction way." (Interview Source: Guido Jouret, CTO Emerging Markets Group, Cisco Systems Inc. 9-8-2006). At this time, royalties at Apple, Amazon, and Salesforce are .3, thus a .5 Nash bargain is a reasonable approximation.

Var		*Definition*
σ	–	Share of platform (%) opened to developers
t, δ	–	Time until exclusionary period expires (discount $\delta = e^{-rt}$)
V	–	Standalone value of sponsor's platform
v	–	Value, per unit, of developer output
S	–	Subsidy platform sponsor provides developers ($S = \sigma V$); primarily, platform value that is open and freely given away
k	–	Coefficient of reuse
M	–	Market multiplier, indexes size of network effects
α	–	Technology in Cobb Douglas production
y_i	–	Output of developers in period i and input to developers in period $i+1$ with $y_i = ky_{i-1}^{\alpha}$ and $y_0 = S$
p	–	Price of individual developer applications $p = v(1-\delta)$
F, c	–	Fixed and marginal costs

Table 2: Parameter interpretations.

of value (level of openness) used as input by developers, and the period of proprietary developer protection. The production technology in each period, the discount rate, and the value added by developers will govern a platform sponsor's choices. We assume a convex region of interest, defined by a negative semidefinite matrix with respect to openness and time. Thus it must satisfy the standard Hessian conditions for a two dimensional optimum. We first explore the platform sponsor's choice of time during which developers enjoy proprietary protection for their innovations.

Proposition 1 *The optimal length of exclusionary period δ^* is governed by the following ratio of developer output:*

$$\delta^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2}\right) \tag{4}$$

This implies three rules (i) that the condition for a finite exclusionary period is first period output must exceed the amount of code opened to developers, (ii) that second period output must exceed the first, and (iii) that it is never profit maximizing to force immediate openness on developer applications.

Proof. *Since δ terms do not appear in y_1 or y_2 , we express profit in terms of output to simplify. To establish the required result, calculate first-order conditions on platform profit with respect to δ.*

$$\frac{\partial \pi_p}{\partial \delta} = -y_1 v + y_2 v(1-\delta) - \delta y_2 v = 0, \quad (5)$$

Rearranging terms provides equation 4. Since $y_2 \leq y_1$ would imply $\delta \leq 0$ (equivalently $t \geq \infty$), which is infeasible, it must be that $y_2 > y_1$ and second period output must exceed the first. Raise both sides of this inequality by $1/\alpha$ and reduce to see that equivalently $y_1 > S$. Finally, observe that $\delta^* \leq \frac{1}{2}$ always therefore t^* is bounded above zero always. ■

This proposition provides what is, in effect, a choice of exclusionary period analogous to an industry specific patent, after which a sponsor can absorb innovations into the corpus of open innovation resources. In exchange for access to the platform and royalties on sales, the platform sponsor grants to developers a short term monopoly on their innovations.[5] Independent of the duration of protection that patent or copyright law might provide, a platform firm could then choose terms that adapt to the productivity conditions of its ecosystem.

To facilitate our analysis of the platform sponsor's choice of σ, we introduce the following lemma.

Lemma 1 *There exists a unique $\sigma^*(\alpha, k, v, V)$ that maximizes platform profit.*

Proof. *Please see Appendix* ■

It is interesting to note that σ need not be bounded above by 1. A σ above 1 is feasible and implies that the code opened to developers is greater than the value of the platform. In this case, a market capitalization above zero implies that investors are valuing growth of a network and not the core platform (Noe and Parker, 2005). We believe this can be observed in practice, especially for early stage platforms mobilizing their ecosystems. Amazon and Groupon both went public with positive valuations despite negative net incomes.[6]

[5] In practice, this is easily enforced via contract, conditional on the developer paying royalties. Even though the sponsor has market power in the platform, any quid pro quo makes a contract enforceable.

[6] "[Groupon's] IPO valuation that now sits at just \$12.65 billion... Groupon lost \$414 million last year, on revenue of \$313 million." http://blogs.wsj.com/venturecapital/2011/11/03/where-groupons-12-65-billion-ipo-valuation-ranks/

We now show the relationship between openness σ and the elasticity of output in each period where $\eta_i = \frac{\partial y_i}{\partial \sigma}\frac{\sigma}{y_i}$, $i = 1, 2$.

Proposition 2 *The platform sponsor's optimal choice of openness σ^*yields open code proportional to the elasticity of developer output across both periods.*

$$\sigma V = S = \eta_1 \pi_{d1} + \delta \eta_2 \pi_{d2} \tag{6}$$

Proof.

Take the first order condition of platform profit with respect to σ.

$$\frac{\partial \pi_p}{\partial \sigma} = -V\sigma + \frac{1}{2}\alpha p y_1 + \frac{1}{2}\alpha^2 p y_2 = 0. \tag{7}$$

Add $S = \sigma V$ to both sides and substitute developer profit $\pi_{d1} = \frac{1}{2}py_1$ and $\pi_{d2} = \frac{1}{2}py_2$ in periods 1 and 2. Cobb-Douglas production yields, $\eta_1 = \alpha$ and $\eta_2 = \alpha^2$. Substituting η terms for α terms completes the derivation. ■

Intuitively, when the platform sponsor opens its core platform resources to outside parties, the gain from sharing in developer profits must offset platform losses (forgone revenue σV). The elasticity term governs how sensitive developer output is to the amount of the platform opened so that the optimal level of σ properly balances revenues lost and gained.

In Corollary 1 below, we explore the effect of model primitives on the platform sponsor's choice variables. Time t moves in the opposite direction from discount coefficient $\delta = e^{-rt}$.

and "Amazon issued its [IPO] on May 15, 1997, ... at a price of US$18.00 per share. When the dot-com bubble burst, and many e-companies went out of business, Amazon persevered, and finally turned its first profit in the fourth quarter of 2001." http://en.wikipedia.org/wiki/Amazon.com. Accessed July 13, 2012.

Corollary 1 *Comparative Statics – The following table summarizes effects of model primitives on platform sponsor choices of optimal contract.*

	σ^*	t^*
Platform value: V	-	*0*
Developer value: v	$+$	$+$
Reuse coefficient: k	$+$	*0*

Proof. *Derivations appear in the Appendix.* ■

Rising platform value V implies closing the platform more ($\frac{\partial \sigma^*}{\partial V} < 0$). Equation 6 shows this directly for σ^* since V only appears as part of σV. A more valuable initial platform means that less of its value needs to be sacrificed to stimulate developer production. The initial value of the upstream platform is unrelated to the length of time until the sponsor absorbs downstream complements ($\frac{\partial t^*}{\partial V} = 0$), a reasonable assertion as V and v are not otherwise related.

In contrast, increasing the developer value, v, per unit produced has the effect of increasing the sponsor's willingness to open the platform. The sponsor rationally sacrifices direct platform profits in order to share in rising developer value. Likewise, an increase in the value of developer output leads a platform sponsor to offer developers a longer proprietary period t^*. Increased developer value in both periods has the effect of making the sponsor more patient, and more willing to fold new features into the platform later. The Atari 2600 provides an illustrative example of a platform that is too open. Atari lost control of the ability to conduct quality control and a large number of poorly executed titles from advertisers such as Fox, CBS, Quaker Oats, and Chuck Wagon dog food drove users from the platform and sparked the industry "crash of 1983" Kent (2001).

The successful F-16 military aircraft platform, now in its 40th year with over 4500 aircraft produced, provides an example of a platform that had a reasonable level of openness at first, but is now probably too closed. Teece (1988) observed that "The trend in fighter plane subsystem costs has been away from air vehicle and propulsion and toward avionics, and this trend is likely to continue." One implication of this observation is that even though the core airframe/propulsion value of the F-16 platform is stable or falling (relative to new platforms such as the F-35), the overall value of the system can remain high enough to be viable given the availability of advanced avionics and weapons systems. As analyzed above, platforms with falling core value V and/or a rising developer value add v should choose a higher degree of openness. Thus, General Dynamics decision to pursue a relatively closed platform in the 1980s made sense and all system upgrades were conducted by the prime contractor. Surprisingly, only the first major system upgrade for a large user, the Korean Air Force, is now being led by BAE systems instead of Lockheed Martin (Sweetman and Perrett, 2012). Given the relatively larger fraction of value in add-ons to the airframe/propulsion platform, we conjecture that the current sponsor, Lockheed Martin, might profit from inviting more firms to take larger roles in upgrading and extending the F-16 while maintaining rights to critical complements to maintain platform control and the ability to share in external innovator profits.

Our model also predicts a longer time before bundling for larger developer value add. We observe this in practice at SAP which agreed to longer exclusivity for ADP, a major payroll processing player, in order to attract ADP to the SAP platform as it transitions from on-premise installations to a cloud-based solution.[7]

Reuse coefficient k has a different effect. As platform resources become more reusable, developer production increases. This implies opening the platform more but, surprisingly, does not alter the date at which the sponsor will later enter the market. In terms of openness, higher reuse implies higher value per unit of openness, leading the sponsor to open more. As illustration, software tends to be more reusable than hardware and tends to be given away more freely. Yet, in terms of proprietary period, the effect of rising reusability is negligible. Given the same production technology, reusability increases developer output at the same rate in both periods such that, after discounting, the sponsor has no reason to favor first or second period output. If technology *changed* between periods, better technology might correspond with shorter protection.

[7] Interview with Thomas Spandl, SAP Vice President of Ecosystems, July 18 2011.

3.2 Welfare

We extend the model to include developer fixed costs F in each period and increasing marginal costs which we model as $c\,y^{1/\alpha}$. In order to avoid introducing an additional parameter, this formulation uses the same technology parameter α as in the production function. In the cost function $c\,y^{1/\alpha}$, $\alpha \in (0,1)$ serves to model convex increasing costs.[8] For simplicity, marginal cost remains small enough that $vy_2 \geq \frac{c}{\alpha} y_2^{1/\alpha}$. We continue to assume a convex region of interest, defined by a negative semidefinite matrix with respect to openness and time. These additions allow us to compare the choices for a welfare optimum against those of a sponsor's maximum net profit. Adding fixed and marginal costs to Equation 2 provides the basis for comparison.

$$\pi_p^c = (1-\sigma)V + \frac{1}{2}\left(py_1 - cy_1^{1/\alpha} - F\right) + \frac{\delta}{2}\left(py_2 - cy_2^{1/\alpha} - F\right) \tag{8}$$

Including consumer surplus, the following welfare equation then determines the social planner's optimization.

$$\arg\max_{\sigma,\delta} W = V + (vy_1 - cy_1^{1/\alpha} - F) + \delta(vy_2 - cy_2^{1/\alpha} - F) \tag{9}$$

Subject to a developer participation constraint:

$$\pi_d^c = \frac{1}{2}\left(py_1 - cy_1^{1/\alpha} - F\right) + \frac{\delta}{2}\left(py_2 - cy_2^{1/\alpha} - F\right) \geq 0. \tag{10}$$

A positive price, $p = v(1-\delta) > 0$, represents a wealth transfer from consumers, while the amount of platform opened σV represents a wealth transfer from the platform sponsor. Both are irrelevant to a social planner except to the degree that developers must cover development costs. Note that in the absence of costs, a social planner simply allocates all existing resources for innovation without delay and chooses $\langle \sigma_c^\dagger, t_c^\dagger \rangle = \langle 1, 0 \rangle$.

[8] This formulation includes the standard quadratic form cy^2 as a special case (i.e. $\alpha = \frac{1}{2}$) but allows cost to fall with improved technology. In this way, increasing (decreasing) α serves both to increase (decrease) output and reduce (increase) costs.

Proposition 3 *The social optimum is a contract $\langle \sigma_c^\dagger, t_c^\dagger \rangle$ with $\sigma_c^\dagger > \sigma_c^*$ and $t_c^\dagger < t_c^*$. The social planner prefers a more open platform and a shorter proprietary period ($\delta_c^\dagger > \delta_c^*$) for applications than do platform sponsors.*

Proof. *See Appendix.* ■

We observe that the greater the share of downstream innovation captured by the platform sponsor, the greater is the incentive to open. This parallels results elsewhere in the literature: internalizing downstream innovation causes the owner of an upstream innovation to behave more like a social planner. Interestingly, the proof shows that the converse is also true: higher costs cause the social planner to behave more like the proprietary sponsor. Rising costs cause each to resemble the other.

3.3 Technological Uncertainty

Since innovation can involve risk, we ask whether technological uncertainty influences the choice of openness and time to bundle. Let the probability of technical success be given by ω (thus "technological uncertainty" is $\rho = 1 - \omega$). Further, to balance risk and reward, allow output from riskier innovations to rise conditional on their success. Then, first period production is given by the random variable

$$Y_1 = \begin{cases} \frac{k}{\omega}(\sigma V)^\alpha & \text{with probability } \omega, \\ 0 & \text{with probability } 1 - \omega. \end{cases} \tag{11}$$

This formulation assumes that in industries where technical success is difficult, i.e. ω is low, such success is highly rewarded.

Expected first round innovation is given by $\mathbf{E}(Y_1) = k(\sigma V)^\alpha$ and variance is given by $Var(Y_1) = \left(\frac{1-\omega}{\omega}\right) k^2 (\sigma V)^{2\alpha}$. Although the expected value of production is independent of technical risk, the variance of production increases with decreasing probability of technical success (Singh and Fleming, 2010). In the limit, as $\omega \to 1$, we retrieve the original model with zero variance.

Similarly, provided that first period innovation was technically successful, second period production is given by the random variable

$$Y_2 \,|\, \text{success in period 1} = \begin{cases} \frac{k}{\omega}(y_1)^\alpha & \text{with probability } \omega, \\ 0 & \text{with probability } 1-\omega. \end{cases}$$

The unconditional, time zero, production in the second period is given by:

$$Y_2 = \begin{cases} (\frac{k}{\omega})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } \omega^2 \\ 0 & \text{with probability } 1-\omega^2. \end{cases} \tag{12}$$

The unconditional expected value of second stage production at time zero is $\mathbf{E}(Y_2) = \omega^{1-\alpha}k^{1+\alpha}(\sigma V)^{\alpha^2}$ with variance $Var(Y_2) = \left(\frac{1-\omega^2}{\omega^{2\alpha}}\right)k^{2+2\alpha}(\sigma V)^{2\alpha^2}$. Again, as $\omega \to 1$, we retrieve the original model with zero variance. Since $0 \leq \alpha \leq 1$, the value of the second stage production is increasing in the likelihood of technical success ω and therefore decreasing in variance. Low likelihood of technical success (i.e. low ω, high ρ) does not negatively affect the value of first stage innovation because innovation is more valuable if it is difficult to achieve, but it does negatively affect the value of second stage innovation because, for a second stage to exist, the first stage must be successful.

With these definitions, the platform sponsor profit function becomes:

$$\mathbf{E}(\pi_p) = V(1-\sigma) + \frac{1}{2}v(1-\delta)k(\sigma V)^\alpha + \delta\frac{1}{2}(1-\delta)k^{1+a}(\sigma V)^{\alpha^2}\omega^{1-\alpha} \tag{13}$$

Propositions 2 and 1 continue to hold but with y_1 and y_2 replaced by $\mathbf{E}(Y_1)$ and $\mathbf{E}(Y_2)$. We summarize these implications in the following result.

Proposition 4 *Holding all else constant, greater technological uncertainty reduces platform openness and innovation, and increases the amount of time sponsors delay bundling and collect royalties. Increasing ρ implies that σ^* and Y_2 fall, while t^* rises.*

Comparative statics are easy to evaluate. The effect of increasing technical success ω goes in the same direction as increasing output Y_2. Increasing Y_2 increases both σ^* and δ^*. Therefore we can conclude that greater technical uncertainty (i.e. increased ρ) decreases the optimal choice of how much to open the platform. Also, because subsequent innovation entails more risk, the sponsor prefers to collect royalties t^* longer rather than gamble on innovation from bundling sooner.

3.4 Developer Number and Competition

To this point, the model has effectively assumed a single developer. How does increasing the number (or size) of developers and introducing developer competition affect platform sponsor choices for $\sigma^*$and t^*? Increasing the number of developers $N > 1$ raises output in each period such that $\tilde{y_1} = Ny_1$ and $\tilde{y_2} = N^{1+\alpha}y_2$. Increasing the intensity of developer competition softens prices such that $\tilde{p} = \gamma v(1-\delta)$ with $0 \leq \gamma < 1$. More developers and more intense competition then have the following effects.

Corollary 2 *Increasing the size of the developer pool increases σ^*but does not affect t^*. Increasing competitive intensity decreases both $\sigma^*$and t^*.*

Proof. *The comparative statics results from Corollary 1 provide a straightforward demonstration. Let $\tilde{k} = Nk$ and $\tilde{v} = \gamma v$ being careful to interpret rising competition as reducing γ.* ∎

Intuitively, increasing the number of independent developers increases platform openness because downstream innovation increases at a higher rate. On margin, openness becomes more profitable. Yet increasing the number of developers, absent competition, has no effect on developer profits and so by Corollary 1, the sensitivity on k shows no effect on the proprietary period. Note that competition among developers who share a platform can be less intense than among standalone firms. Developer success on platform 1 can steal market share from platform 2, indirectly raising demand for developers who share platform 1. Standalone firms have no such indirect effect (Markovich and Moenius, 2009).

We can combine Corollary 2 with that of the previous section to see that as more developers help reduce technical risk, optimal openness rises further. Consider that if each developer represents an additional chance at technical success (with probability $\omega = 1 - \rho$), then the risk of technical failure declines as $1 - \rho^N$. Equations, 11 and 12 then become

$$\tilde{Y}_1 = \begin{cases} \frac{Nk}{1-\rho}(\sigma V)^{\alpha} & \text{with probability } 1-\rho^N \\ 0 & \text{with probability } \rho^N, \end{cases} \tag{14}$$

$$\tilde{Y}_2 = \begin{cases} (\frac{Nk}{1-\rho})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } (1-\rho^N)^2 \\ 0 & \text{with probability } (1-\rho^N)\rho^N. \end{cases} \tag{15}$$

These imply that unconditional expected values become $\mathbf{E}(\tilde{Y}_1) = \frac{1-\rho^N}{1-\rho}\tilde{y}_1$ and $\mathbf{E}(\tilde{Y}_2) = \frac{(1-\rho^N)^2}{(1-\rho)^{1+\alpha}}\tilde{y}_2$. The comparative statics are straightforward to evaluate. Both $\mathbf{E}(\tilde{Y}_1)$ and $\mathbf{E}(\tilde{Y}_2)$ rise in N, thus increasing σ^*. To evaluate the impact on time-to-bundle, replace $\frac{y_1}{y_2}$ with $\frac{\mathbf{E}(\tilde{Y}_1)}{\mathbf{E}(\tilde{Y}_2)}$ in Equation 4. The resulting expression is $\delta = \frac{1}{2}\left(1 - \frac{(1-\rho)^{\alpha}}{1-\rho^N}\frac{\tilde{y}_1}{\tilde{y}_2}\right)$. Since $\frac{\tilde{y}_1}{\tilde{y}_2} = \frac{N}{N^{1+\alpha}}\frac{y_1}{y_2}$, we see that $\frac{(1-\rho)^{\alpha}}{1-\rho^N}$ and $\frac{\tilde{y}_1}{\tilde{y}_2}$ both decrease in N, implying, respectively, that δ^*increases and t^*decreases in N.

This result is consistent with empirical research that finds handheld device platforms opened to more developers precisely to reduce the risk of technological innovation (Boudreau, 2010). For the same reason, social network platforms encourage developers to experiment with applications because "much remains unknown concerning preferences and technical approaches to social applications" (Boudreau and Hagiu, 2009, p. 11). Further, our model shows that, conditional on developer success, the platform sponsor profits by extending the royalty period for technically successful applications.

Competition among developers, however, has a different implication. Holding other factors constant, more intense developer competition reduces the Nash bargaining surplus available to the platform sponsor. This surplus goes instead to platform users, reducing the sponsor's incentive to open the platform. Developer competition reduces openness.

That sponsors dislike developer competition stands in contrast to the standard result that platforms prefer to "commoditize complements" (Gawer and Cusumano, 2002; Shapiro and Varian, 1999; Farrell and Katz, 2000). The standard argument holds that the upstream platform prefers downstream competition to curb vertical pricing power and quantity distortion. But this assumes complements exist. In a dynamic analysis, before downstream innovation has occurred, the sponsor needs developers to *create* follow-on products. Thus the sponsor prefers to give developers pricing power, lest they curb their downstream development. This explains why platforms limit competitive intensity among developers of new products via certification, royalty terms, and favorable directory placement (Boudreau and Hagiu, 2009). When downstream complements must be created, there can still exist incentives for the platform to "squeeze" the complements (Farrell and Katz, 2000). We show this effect weakens when the platform participates in sales via royalties. Alternatively, the platform sponsor might vertically integrate but must identify ex ante which developer innovations will succeed ex post. If the sponsor could identify successful developers, then it might buy their technology, a situation we analyze in Section 4. We note simply that sponsor interest in downstream innovation also provides reason to prefer (initially) less downstream competition.

3.5 Platform Competition

We now examine the effect of competition between platforms on the platform sponsor's optimal choice of $\sigma^*$and t^*. In the same way that competition reduces developer pricing power, platform competition reduces direct platform price from $(1-\sigma)\,V$ to $(1-\sigma)\,\lambda\,V$ with $0 \leq \lambda < 1$. By varying λ, we see that increasing the intensity of platform competition has the opposite effect of increasing the intensity of developer competition.

Corollary 3 *Increasing the intensity of platform competition increases both σ^* and t^*.*

Proof. *To establish the first claim, substitute model primitives for output terms into equation 6 from Proposition 2 and hold all else constant to show that the following equality holds.*

$$\frac{b_1}{\sigma^{1-\alpha}\lambda} + \frac{b_2}{\sigma^{1-\alpha^2}\lambda} \quad = \quad 1 \tag{16}$$

Increasing competitive intensity by decreasing lambda implies increasing σ in order to maintain the equality. To establish the second claim substitute constants for model parameters other than σ into equation 4 from Proposition 1. The optimal choice of δ^* is governed by the following ratio.

$$\delta^* \quad = \quad \frac{1}{2}\left(1 - b\frac{\sigma^{\alpha}}{\sigma^{\alpha^2}}\right) \tag{17}$$

Given $0 < \alpha < 1$*, we conclude that a larger* σ^* *corresponds to a lower* δ^* *which implies a higher* t^**.*

■

Holding all else constant, greater platform competition reduces the direct platform surplus available to the platform sponsor. The sponsor's incentive is therefore to open the platform in order to increase indirect profits from downstream innovation. Because the platform sponsor must take more of its profits from developer revenues, the platform sponsor also has a greater interest in maintaining developer price, which leads the sponsor to increase the proprietary period. The effect of platform competition is therefore to increase both openness and subsequent developer output. In terms of competition policy, the regulatory implication is that to achieve higher innovation, promote developer entry but not developer competition. Instead, promote platform competition which motivates sponsors to open and seek growth. This directly parallels empirical findings. Based on case studies of IBM, Sun Microsystems, and Apple, West (2003) concluded that sponsors generally prefer the higher rents from proprietary governance unless their platforms face significant pressure from rival platforms. We examine how this interacts with private subcontracting and property rights next.

4 Alternate Organizational Forms: Platforms vs. Hierarchies vs. Standards

Is an open platform the best way to organize for innovation? Might not vertical integration or simply publishing an open standard do better? So far, our analysis has assumed an open platform. This section examines alternate organizational forms, including the sponsor's decision to integrate and the developer's decision to cooperate with other developers rather than bargain with the platform sponsor.

4.1 Open Innovation vs. Vertical Integration

Up to this point, we have assumed that firms rationally open their platforms to seek innovation, precluding the possibility that a rational sponsor might do better by negotiating directly with known developers to acquire their technology. By vertically integrating, the sponsor could save the subsidy cost $S = \sigma V$. The sponsor could also build on the entire platform, not just the open portion, thereby increasing output from $y\mid_{\sigma V}$ to $y\mid_{V}$. As before, developers keep half the value of their technology based on Nash bargaining. We can express the platform's profit under vertical integration as $\pi_{vi} = V(1-\sigma)\mid_{\sigma=0} + y_1\mid_{\sigma=1} + y_2\mid_{\sigma=1}$ which simplifies to

$$\pi_{vi} = V + \frac{1}{2}pkV^{\alpha} + \frac{1}{2}\delta pk^{1+\alpha}V^{\alpha^2}. \tag{18}$$

Vertical integration yields higher profit than Equation 3 as it has both higher output and no subsidy cost.[9] We then ask how might profits from open innovation ever dominate those from vertical integration?

We posit two distinct answers. One is that there exist developers the sponsor does not know and therefore cannot acquire before they complete their innovations. The other is that network effects can increase disproportionately under openness. The former might arise if there are numerous small developers who might step forward if they see an opportunity. This reason is especially salient among developers who risk disclosing their novel ideas by identifying themselves or their applications to the platform sponsor. Owning the indispensable asset, the sponsor has bargaining power and needs only the ideas to steal them (Bessen and Maskin, 2009; Parker and Van Alstyne, 2000a, 2012). Commitment to stay out of the developer's market during the exclusionary period provides the incentive such developers need to step forward. The law literature (Eisenberg, 1976) notes that setting such rules, and committing to honor them, affects the downstream conduct of other parties in cases where the mere act of negotiating reveals sensitive information. This is clearly in evidence in the SAP ecosystem, for example, where the platform sponsor commits to stay out of "whitespaces," functionality that anyone is free to develop, for minimum periods of 18–24 months.

[9] Model analysis can easily extend to subcontracting, an organizational form between vertical integration and open innovation, by choosing different levels of σ.

The second answer arises because, relative to closed systems, open systems invite more third party participation. Mechanisms by which openness might increase participation include transparency, bug reporting and feedback that can reduce R&D costs and increase platform quality, and user ability to modify open systems (Chesbrough, 2003; West, 2003). Openness can reduce negotiation costs, facilitate free redistribution (Raymond, 1999), and serve as a low price commitment analogous to second sourcing (Farrell and Gallini, 1988). It can aid horizontal integration (Farrell et al., 1998). The "two-sided" network literature (Parker and Van Alstyne, 2000a, 2005; Rochet and Tirole, 2003) specifically demonstrates how openly subsidizing one community, i.e. developers, can increase value to and participation of another community i.e. end-users. For a variety of reasons, openness can increase both value and participation.

As both answers rely on growing the platform ecosystem, we modify the earlier open platform model to include classic two-sided network effects across consumers and developers who value one another's participation on the platform (e.g., Parker and Van Alstyne (2005)). To maintain tractability, we develop a novel yet simplified version of two-sided network effects to understand how their strength affects a sponsor's choice to provide access to all developers versus working with a select few. Thus we introduce market multiplier $M_i, i \in (u, d)$, which we derive using two-sided market feedback.

To derive M_i, allow a larger user base to attract a larger developer pool and a larger developer pool to attract a larger user base. Based on externality spillover e_{ud}, augment baseline developers N_d proportional to the number of users N_u, thus increasing developers by $e_{ud}N_u$. Likewise, based on externality spillover e_{du}, augment baseline users N_u proportional to the number of developers N_d, thus increasing users by $e_{du}N_d$. New users attract additional new developers, and vice versa, in amounts $e_{du}e_{ud}N_u$ and $e_{ud}e_{ud}N_d$, a recursion process that defines Cauchy sequences for both groups. Developer size increases according to $N_d(1 + e_{ud}\, e_{du} + (e_{ud}\, e_{du})^2 + (e_{ud}\, e_{du})^3 + ...)$ and similarly for users. Given the constraint that $e_{du}e_{ud} < 1$, these sequences converge to $N_d M_d = N_d \frac{1}{1-e_{ud}\, e_{du}}$ and $N_u M_u = N_u \frac{e_{du}}{1-e_{ud}\, e_{du}}$ respectively. Applying M_u to priced terms and M_d to output terms, the resulting expression for platform profit given open innovation is:[10]

[10] In this derivation $N_d = N_u = 1$ is simply a baseline. We analyze larger N in Corollaries 1 and 3 and later in Proposition 6. Note also that M_u and M_d differ only by positive constants e_{ud} or e_{du} depending on which term starts

$$\pi_{open} \quad = \quad M_u V(1-\sigma) + \frac{1}{2} M_u p M_d y_1 + \frac{1}{2}\delta M_u p M_d y_2(M_d y_1). \tag{19}$$

While advantages of vertical integration include eliminating the subsidy and increasing output, the advantage of open innovation is growing the market. Higher adoption and network effects can then justify open innovation relative to vertical integration based on the following:

Proposition 5 *In the absence of network effects, vertical integration is preferred. But, for any set of exogenous parameters V, k, and v_d, there exist M_u and M_d such that the platform sponsor prefers open innovation to vertical integration. Further, openness σ^* falls in V but rises in M_d, k and v. Thus open innovation dominates vertical integration as network effects increase, content becomes more reusable, or developers add more value.*

Proof. *Optimizing time in vertical integration equation 18 produces $\delta^*_{vi} = \frac{1}{2}\left(1 - \frac{V^\alpha}{k^\alpha V^{\alpha^2}}\right)$. Substituting into π_{vi} and simplifying yields*

$$\hat{\pi}_{vi} \quad = \quad \frac{1}{8}\left(8V + vk^{1-\alpha}V^{-\alpha^2}\left(V^\alpha + k^\alpha V^{\alpha^2}\right)^2\right)$$

Similar time optimization on open innovation equation 19 produces $\delta^*_{open} = \frac{1}{2}\left(1 - \frac{(\sigma V)^\alpha}{(kM_d)^\alpha(\sigma V)^{\alpha^2}}\right)$. Substituting into π_{open} and simplifying yields

$$\hat{\pi}_{open} \quad = \quad \frac{M_u}{8}\left(8V(1-\sigma) + v(kM_d)^{1-\alpha}(\sigma V)^{-\alpha^2}\left((\sigma V)^\alpha + (kM_d)^\alpha(\sigma V)^{\alpha^2}\right)^2\right)$$

The platform sponsor prefers openness when $\hat{\pi}_{open} > \hat{\pi}_{vi}$. Define $f(\sigma, M_u, M_d|k, v, V) = \hat{\pi}_{open} - \hat{\pi}_{vi}$ and observe that $f(\cdot)$ is monotone increasing in M_u and M_d. Absent network effects, vertical integration is preferred as $f(\sigma, 0, 0|\cdot) < 0$. Open innovation with $\sigma = 0$ cannot be rational as

the sequence.

$f(0, M_u, M_d|\cdot) < 0$ so choose any $\sigma = \epsilon > 0$. Then, since $f(\epsilon, 0, 0|\cdot) < 0$ and $f(\epsilon, 0, \infty|\cdot) \to \infty$ by the single crossing property there exists an M_d such that open innovation is always preferred (and similarly for M_u). To establish comparative statics, observe that M_d in equation 19 serves the same role as k in equation 3 implying that Corollary 1 also applies to M_d. As M_u multiplies all terms linearly, it falls from comparative statics. ■

In the absence of network effects, the platform sponsor should own all means of production. Opening the platform to outside developers, however, becomes more attractive (i) as network effects rise (or the sizes of user or developer pools grow) (ii) as developer output rises, and (iii) content becomes more reusable. Vertical integration becomes more attractive as (i) platform value itself grows. Note that the decentralized innovation is achieved without bargaining costs. A default contract with $\langle \sigma > 0, t > 0 \rangle$ gives developers an option to enter the market without disclosure to the platform sponsor. Open innovation, with a guarantee of lead time, preserves the information asymmetry that protects the innovator and prevents a powerful monopsony platform from stealing the full value of the innovation.

4.2 Open Standards – Cooperation in the Absence of Platform Control

Another possibility is that innovation might be higher under an open standard. Perhaps developers are better off without a platform sponsor under conditions where everyone may place their code into the public resource pool. After all, access to a richer pool of application resources fosters richer application development. Although the platform sponsor appropriates developer resources at time t^* in order to make them available to other developers, is "confiscation" necessary?

To analyze this problem, we consider the outcomes from cooperation versus defection with the former interpreted as contributing to the common resource pool and the latter means withholding resources in order to charge for them. This affords developers four broad strategies rather than just participate or not. Developers can (i) cooperate, cooperate (CC), (ii) defect, cooperate (DC), (iii) cooperate, defect (CD), and (iv) defect, defect (DD) where the first position denotes the strategy of an individual developer and the second position denotes the action of the remaining developers. Denote $\pi_{d_i}^{CC}$ as the profit that an individual developer makes when it cooperates and all other

Strategy		T_1 Own		T_2 Other		T_2 Own		T_1 Tail		T_2 Tail
$\pi_{d_i}^{CC}$	$=$	$v(1-\delta)y_1$	$+$	$v\delta^2 N_d^\alpha y_2$	$+$	$\delta v(1-\delta)y_2$	$+$	0	$+$	0
$\pi_{d_i}^{DC}$	$=$	$v(1-\delta)y_1$	$+$	$v\delta^2 N_d^\alpha y_2$	$+$	$\delta v(1-\delta)y_2$	$+$	$v\delta y_1$	$+$	$v\delta^2 y_2$
$\pi_{d_i}^{CD}$	$=$	$v(1-\delta)y_1$	$+$	0	$+$	$\delta v(1-\delta)y_2$	$+$	0	$+$	0
$\pi_{d_i}^{DD}$	$=$	$v(1-\delta)y_1$	$+$	0	$+$	$\delta v(1-\delta)y_2$	$+$	$v\delta y_1$	$+$	$v\delta^2 y_2$

Table 3: Surplus from four strategies available to developers under an open standard.

developers cooperate. The profits from the remaining three strategies are denoted similarly.

Individual developer profits differ in two ways. First, individual developers explicitly consider the number N_d of other applications apart from their own. Second, defecting developers can benefit from revenues beyond the time of bundling $t > t^*$. These changes yield the four strategies with surpluses as given in Table 3 and the proposition below.

Proposition 6 *Among developers, [Defect, Defect] constitutes a dominant pure strategy Nash equilibrium.*

Proof. *We show a prisoners' dilemma as follows. Direct comparison of CC and DC profits reveals that a profit-motivated developer prefers to defect when the other developers cooperate. That is* $\pi_{d_i}^{DC} = \pi_{d_i}^{CC} + v\delta y_1 + v\delta^2 y_2$. *The comparison of* $\pi_{d_i}^{DD}$ *to* $\pi_{d_i}^{CD}$ *is similar, showing that profit-motivated developers defect.* ■

Having established that profit-motivated developers will not, in the absence of enforcement, cooperate by freely releasing their enhancements, we ask when a developer would prefer to submit to a contract that would enforce the cooperative CC outcome. That is, we compare the profits under DD to CC. First, note that in the case of DD, there is no open stock release, so the user base and first and second period resource pools remain constant, but the developer retains access to his own privately reusable stock.

Proposition 7 *If the platform sponsor would offer a finite protection period* $t^* < \infty$, *then there exists a contract committing developers to give up their applications that makes them better off whenever* $N > 2^{\frac{1}{\alpha}}$.

Proof. *Comparing differential gains from* $\pi_{d_i}^{CC}$ *to those in* $\pi_{d_i}^{CC}$*, developer profits are higher when* $v\delta^2 k^{1+\alpha} N_d^\alpha (\sigma V)^{\alpha^2} > v\delta k(\sigma V)^\alpha + v\delta^2 k^{1+\alpha}(\sigma V)^{\alpha^2}$*. Since* $t^* < \infty$ *it follows that* $y_2 > y_1$ *so* $v\delta^2 k^{1+\alpha} N_d^\alpha (\sigma V)^{\alpha^2} > 2v\delta^2 k^{1+\alpha}(\sigma V)^{\alpha^2}$*. Rearranging produces an expression* $N^\alpha > \frac{2\delta}{1-\delta}$ *whose right hand side rises strictly in* δ*. As* δ *reaches its maximum at* $\frac{1}{2}$*, further manipulation produces the required result.* ■

This proposition establishes that the total number of developers only needs to exceed a small constant in order for the cooperative solution to produce greater surplus than the uncooperative solution. This has strong implications for the role of the platform sponsor. Essentially, the sponsor enforces a set of $O(N)$ bilateral contracts binding developers to give up their applications after a reasonable profit period in order that all developers may reuse each others' valuable resources. This not only economizes on $O(N^2)$ transaction costs, it increases the total surplus available to each individual developer. The contract offered to developers thus represents a "private ordering," a governance model whose purpose is to infuse order, relieve conflict, and realize mutual gain (Williamson, 2002).

A consequence of Proposition 7 is that developers can prefer governance by a platform sponsor to that of an uncoordinated open standard. Ceccagnoli et al. (2012) provide empirical support as Independent Service Providers (ISVs) who join a major proprietary platform have higher sales and increased probability of going public. A strong sponsor can help resolve a classic "collective action" problem (Baldwin and Woodard, 2008). In the absence of orchestrated governance, individual incentives to profit maximize lead to Pareto inferior welfare in terms of innovation and profits. As the comparative statics of Corollary 1 show, the optimal timing of property rights can also depend on industry specific factors such as v. If this is true, then an industry platform sponsor can craft more specific timing than a regulator whose rules apply across platforms. Relative to open standards and regulation, efficiency gains from platform sponsorship might therefore occur in coordination and in technology specificity. This allows innovation to adjust to the different "clockspeeds" of different industries.

The platform sponsor's interest in efficient innovation has interesting real world application as a resolution to the problem of the "anticommons," identified as the hold-up that occurs when too many different parties each can block downstream innovation because each has a conflicting yet interlocking property right (Heller and Eisenberg, 1998). Under a platform model, the platform sponsor unblocks later innovation by making earlier innovation available to all developers on a non-discriminatory basis. The sponsor uses its property right in the platform to grant access to developers conditional on securing the ability to bundle enhancements into future versions of the platform. Proposition 7 shows that far from encouraging developers to avoid the platform, bundling their applications can make them better off over multiple cycles of innovation. From the introduction, expanded opportunity in the 1990s is one reason why developers might have preferred Windows over UNIX despite Microsoft's aggressive bundling. Platform ownership adds value. The sponsor's self-interest in platform innovation motivates it to shepherd the platform much as if it were a social planner. R&D spillovers are not simply an accident of proximity (Audretsch and Feldman, 1996; Edwards, 2001) but a controlled optimization of appropriation and dissemination that benefits the community.

5 Robustness Checks

It is worth examining the robustness of analysis to changes our assumptions. Major assumptions include (1) a point estimate of consumer value, (2) a Cobb-Douglas production model, (3) a one period useful lifetime for open platform stock and developer applications, and (4) dynamics limited to two periods.

Clearly, and consistent with other papers in the literature, we assume point mass consumer demand for tractability. Consumers enjoy positive surplus in our model as a result of platform openness and finite property rights for developer output. Also, many information goods are sold in bundles, making a point mass estimate of average value a reasonable approximation. Bakos and Brynjolfsson (1998) show that the standard deviation of the item values in a bundle can be made arbitrarily small by aggregating additional goods into the bundle. Adding multiple features to a platform is easily interpreted using such an average value v.

The common assumption of Cobb-Douglas production is, again, made for tractability and allows for simple results expressed in terms of constant elasticity of output with respect to changes in technology. Similar conclusions can be obtained with alternate formulations but results are particularly elegant with the current specification. Our model also introduces a novel choice parameter, contractual openness, which plays a central role.

Relaxing the assumption of a one period lifetime for developer output would complicate analysis but also strengthen results as increased longevity would increase R&D spillovers. If open platform stock stimulates production beyond one period, increasing developer output also increases willingness to open the platform. Similarly, extending the two period model to multiple periods or to continuous time would not undermine the main results. The necessary and sufficient ingredient is the recursive production function i.e. output of one period becomes input in the next. In contrast, reducing the model to one period would be difficult as 'reuse' could be lost. More periods should preserve or amplify effects of reuse.

6 Discussion & Conclusions

Firms have disagreed over how to manage innovation, openness and platform control. Our contribution is to show how a platform sponsor can optimize openness and bundling to leverage downstream innovation. We analyze open innovation as a contract in which a platform sponsor offers developers resources to innovate and a window of profitability in exchange for giving up their innovations in the future. A successful platform sponsor achieves a 'private ordering' with R&D spillovers. It acts as a self-interested social planner for its ecosystem, making choices that account for user consumption and developer production through cycles of innovation. This expands the law, sequential innovation, and bundling literature as well as explaining empirical phenomena in mobile devices, enterprise systems, web search, social networks, and other platforms. Several intuitions follow.

First, we show how platform sponsors can optimize openness. Firms face a choice: they can innovate by acquiring dowstream partners so as to avoid sharing technology or they can open their technolgy so as to grow an ecosystem. Firms in our model find it privately rational to stimulate 3^{rd} party innovation even at the cost of sacrificing sales. The rule for optimal openness is to give away enough free access that its value in the current period is proportional to developer elasticity of output in later periods. Optimal openness declines in response to a rise in intrinsic platform value but rises in response to rising developer value, the sizes of developer and user pools, and rising resource reuse. Further, the level of openness, equivalently the size of subsidy in our model, can be so great as to exceed the value of the platform.

Theoretically, this refines subsidy models, endemic in two-sided network literature, by showing how the subsidy seeds ecosystem production. It can function not just as a negative price to attract participation but also as input for developer output. This also refines theories of vertical integration. While a platform does economize on coordination costs, which is more hierarchical than an open standard, it does not necessarily integrate based on reducing information asymmetry or internalizing externalities. Its information asymmetry is not that of effort but rather who has an idea. Its network effects are not enhanced by internalizing technology but rather by giving it away. Thus platform contracts should not require negotiation or even prior knowledge of the develpers with whom the sponsor might negotiate.

Second, analogous to periods of patent protection, we identify conditions for a finite exclusionary period. In our model, this represents the time during which downstream developers can charge for new applications before the sponsor folds these enhancements into the open platform. Platform envelopment of first period innovations should occur at a time determined by the point at which second period developer output exceeds first period output. If second period output is smaller, then it is never optimal to bundle developer enhancements into the platform as this reduces first period surplus. The optimal exclusionary period increases in response to an increase in developer value yet, ironically in our model, remains unaffected by changes in reuse.

We contribute to theory by providing a boundary condition for the earlier finding that optimal duration for intellectual property protection can be arbitrarily long (Gilbert and Shapiro, 1990; Landes and Posner, 2002). Earlier models do not account for reuse which can have a significant impact on the optimal outcome. Our analysis of the developer participation game shows that developers can prefer sponsored platforms. For this to happen, sponsors need longer duration rights which agrees with earlier findings that the period of protection should favor the upstream innovator relative to that downstream (Green and Scotchmer, 1995). As a contribution to practice, we find that platform managers should execute contracts that reserve authority to bundle developers' innovations and they should share these innovations with the ecosystem to spur additional production. This practice must be carefully managed. Applications developers can view platforms as acting too aggressively when sponsors fold applications into the core. On the other hand, if sponsors are too weak, then consumers face monopoly distortion in applications prices and in retarded innovation, not to mention an increasingly complex task of integrating disparate applications.

Third, we show that a benevolent social planner chooses to release a greater portion of the platform and to bundle earlier than does a self-interested platform sponsor. However, increasing costs lead the choices of platform sponsors and social planners toward convergence. For competition policy, we also analyze the size of the developer pool and the intensity of competition among developers and platforms. A larger developer pool leads to a more open platform and also decreases the time until new features become part of the platform. In contrast, increased developer competition reduces openness because it reduces surplus available to the sponsor. Competition among developers also shortens the proprietary period because new value comes relatively more from new production than from existing sales. Increasing competition among platforms has the opposite effect. Platform sponsors have less direct profit and therefore prefer to increase developer revenues through a more open contract with a longer proprietary period.

Finally, we demonstrate a prisoners' dilemma where developers individually refuse to open their applications even though they would prefer that every other developer open theirs. As a result, given a sufficiently large developer pool, all developers are better off if a strong platform sponsor forces them to open their contributions. As in the case of regional R&D spillovers, the reason is that subsequent output can build on top of a larger base, leading to higher total innovation. The platform sponsor must enforce such contracts not only for benefit of the platform itself, but also for the developers themselves. This result matters both for industry regulators and platform contract designers. In order to maximize innovation potential of an ecosystem, a platform must have longer duration control rights than the developers who build upon it.

7 Appendix

Proposition 3 - Welfare

Proof. To establish the claim with respect to δ, solve the platform sponsor's maximization problem inclusive of cost. Taking the first order condition of platform profit π_p^c w.r.t. δ leads the platform sponsor to choose

$$\delta_c^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{cy_2^{1/\alpha} + F}{vy_2}\right). \tag{20}$$

The social planner chooses δ subject to the participation constraint $\pi_d^c \geq 0$ for cost recovery. Solving for δ produces two roots. Eliminate the negative root by choosing $c = F = 0$. In the absence of cost, the positive root reduces to $\delta = 1$. Hence, absent the need to recover cost, a social planner prefers to release developer additions immediately. Otherwise, the social planner chooses

$$\delta_c^\dagger = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{cy_2^{1/\alpha} + F}{vy_2} + \Delta\right). \tag{21}$$

All terms except $\Delta = \frac{\sqrt{4vy_2(vy_1 - cy_1^{1/\alpha} - F) + ((vy_2 - cy_2^{1/\alpha} - F) - vy_1)^2}}{vy_2}$ are the same as those chosen by the platform sponsor. Observing that Δ is the positive root completes the claim. Also note that $\delta_c^\dagger > \delta_c^*$ implies that the developer constraint is always satisfied by the platform sponsor's choice.

To establish the claim with respect to σ, apply the steps used in Proposition 2 to the system of equations including costs to produce the following pair of implicit functions.

$$\sigma_c^\dagger \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^\dagger\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = 0 \tag{22}$$

$$\sigma_c^* \quad : \quad \alpha(py_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(py_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = 2\sigma V \tag{23}$$

Transform the first by mapping $\delta_c^\dagger$ to δ_c^* and the second by mapping p to v. As second period surplus is always non-negative, the welfare and profit constraints are easily sorted.

$$\sigma_c^\dagger \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = -\kappa_1 < 0 \tag{24}$$

$$\sigma_c^* \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = \kappa_2 > 0 \tag{25}$$

Where $\kappa_1 = \alpha\Delta(\alpha vy_2 - cy_2^{\frac{1}{\alpha}}) > 0$ and $\kappa_2 = 2\sigma V + \alpha\delta vy_1 + \alpha^2\delta^2 vy_2 > 0$. Under model assumptions, the first constraint binds always to the left of the second. In this case, producing $\sigma_c^\dagger > \sigma_c^*$.

■

Lemma 1 - existence and uniqueness of σ^*

To be proven: there exists a unique $\sigma^*(\alpha, v)$ that maximizes platform profit.

First calculate the first-order condition on platform profit with respect to σ:

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \alpha \frac{1}{2} pk\sigma^{\alpha-1}V^{\alpha} + \alpha^2 \frac{1}{2} \delta pk^{1+\alpha}\sigma^{\alpha^2-1}V^{\alpha^2} = 0. \tag{26}$$

Multiply through by σ, substitute $v(1-\delta)$, let $S = \sigma V$, and rearrange terms to get the following expression.

$$S = \frac{1}{2}\alpha kv(1-\delta)\left(S^{\alpha} + \alpha k^{\alpha}\delta S^{\alpha^2}\right).$$

Divide through by S and pull $S^{\alpha-1}$ out front to get

$$1 = \frac{1}{2}S^{\alpha-1}\alpha kv(1-\delta)\left(1 + k^{\alpha}\alpha\delta S^{\alpha^2-\alpha}\right).$$

Let $L = kS^{\alpha-1}$. Since $y_1 = k(\sigma V)^{\alpha}$ and $\delta^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2}\right)$, we have the following expression

$$\delta^* = \frac{1}{2}\left(1 - \frac{1}{L^{\alpha}}\right). \tag{27}$$

Thus

$$1 = \frac{\alpha v}{4}\left(L + L^{1-\alpha}\right)\left(\frac{1}{2}\alpha L^{\alpha} + \left(1 - \frac{1}{2}\alpha\right)\right).$$

Define

$$f(L) = 1 = \frac{\alpha v}{4}\left(L + L^{1-\alpha}\right)\left(\frac{1}{2}\alpha L^{\alpha} + \left(1 - \frac{1}{2}\alpha\right)\right). \tag{28}$$

Given $\alpha \in (0,1)$, then $(1-\alpha) > 0; \alpha > 0; \left(1 - \frac{\alpha}{2}\right) > 0$. Therefore, $f(L)$ increases in L. Since $f(0) \to 0, f(\infty) \to \infty$ and $f(L)$ monotonically increases in L, there exists a unique $L^*(\alpha, v)$ that solves $f(L^*) = 1$. Given $L = k(\sigma V)^{\alpha-1}$, $\alpha < 1$ implies that L monotonically decreases in σ. Thus $f(L)$ can be expressed as $f(L(\sigma))$ and a unique L implies a unique σ. (Q.E.D.)

Comparative statics for σ^* and δ^*

Using the derivations developed in Lemma 1, we explore the behavior of the platform choice variables of openness and time to bundle developer innovations as a function of exogenous parameters.

$\frac{\partial \sigma^*}{\partial V} < 0$

Given $L = kS^{\alpha-1} = k(\sigma V)^{\alpha-1}$, σ^* must fall in V in order to maintain the equality in equation 28.

$\frac{\partial \sigma^*}{\partial v} > 0$

The right-hand-side of equation 28 increases in v. Thus L^* falls in v in order to maintain the equality. Therefore σ^* increases in v.

$\frac{\partial \sigma^*}{\partial k} > 0$

Equation 28 establishes that a unique solution exists in L that optimizes platform profit. Given $0 < \alpha < 1$ and $L = kS^{\alpha-1} = k(\sigma V)^{\alpha-1}$, we conclude that σ^* increases in k.

$\frac{\partial \delta^*}{\partial V} = 0$

Equation 27 expresses δ in terms of L. By equation 28, L^* is constant with respect to V.

$\frac{\partial \delta^*}{\partial v} < 0$

By equation 27, δ^* increases in L^*. By equation 28, L^* falls in v. Therefore δ^* falls in v. This is consistent with the derivation above. By equation 4 (with primitives substituted for y terms), δ^* falls in σ and we showed earlier that σ increases in v; thus δ^* falls in v.

$\frac{\partial \delta^*}{\partial k} = 0$

Equation 27 expresses δ in terms of L. By equation 28, L^* is constant with respect to k.

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