Innovation, Openness & Platform Control

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Consider that a firm in charge of a business platform is a firm in charge of a microeconomy. To achieve the highest growth rate, how open should that economy be? To encourage third-party developers, how long should their intellectual property interests last? We address these questions through a sequential innovation model that balances two sets of tradeoffs. (i) Closing the platform increases the sponsor's ability to charge for access, while opening the platform increases developer ability to build upon it. (ii) The longer third-party developers retain property rights to their innovations, the higher the royalties they and the sponsor earn, but the sooner those developers rights expire, the sooner their innovations become a public good upon which other ecosystem developers can build. Our model allows us to characterize the optimal levels of openness and of IP duration in a platform ecosystem. We also model the relative profit potential of a sponsoring firm's decision to vertically integrate into downstream production as a closed hierarchy or to organize itself as a platform for open innovation. We use standard tools of Cobb-Douglas production and two-sided networks to derive our results. These findings can inform innovation strategy, choice of organizational form, intellectual property law, and 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, Standard Setting Organizations.

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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 – in the form of third-party developers – that can extend a core offering to create a vibrant and appealing ecosystem. The increase in platform business models raises important questions for firms that choose to participate. Despite considerable research on prices, quantities, and network effects, Yoo et al. (2010) note that little formal analysis has investigated ecosystem decisions of successful platform business models.

Our goal for this paper is to address this gap in the literature by modeling innovation decisions. Our thesis is that, in addition to correctly setting price, the firm must carefully open the platform so as to balance growth and profits. It must also carefully control appropriation of developer innovations in order to manage participation and ensure that third parties benefit from R&D spillovers. Finally, sponsor firms need criteria for choosing vertical integration over platforms and platforms over open standards. We build and explore a formal model to examine these choices.

We analyze platform openness as the degree to which sponsor firms share platform technologies with third-party developers. On the one hand, these developers can extend the platform's utility to end-users and can thus create revenue streams that the sponsor can tax. On the other hand, loss of control over open technology creates a loss of revenue through the threat of more intense competition. Thus, openly sharing technology affects not only the innovative capacity of developers, but also the pricing power available to platform sponsor.

In addition, we find the optimal duration of developer property rights. Analysis proceeds by considering when a sponsor should bundle developer innovations into the platform then push these features out to the entire market. There is strong precedent for sponsors to absorb developer innovations into the platform, which has the same effect as ending the duration of intellectual property protection. Whether through internal development or acquisition, and whether coercively or not, platform sponsors such as Apple, Cisco, Facebook, Google, Intel, Microsoft, and SAP have routinely absorbed valuable innovations developed by ecosystem partners. Cisco, for example, bundles into its networks innovation features that have appeared among multiple developer products. "Developers don't like it but realize it's good for the ecosystem."[1] Facebook has copied the key features from multiple developers including Snapchat, Foursquare, and Groupon (Manjoo, 2012). This parallels Microsoft's absorption of innovations such as disk defragmentation, encryption, streaming media, and web browsing (Jackson, 1999). SAP publishes an 18–24 month roadmap alerting developers that they will not face competition or appropriation during this period. After that, any strategic complements may be absorbed. On the one hand, a decision not to end developers' property rights increases their profits, which the sponsor can tax. On the other hand, this prolongs monopoly distortions and prevents valuable new features from becoming community standards. The sponsor thus faces a choice: by extending developers' interests, the sponsor might enjoy higher rents on existing innovations but by ending developer's interests, the sponsor might increase R&D spillovers on future innovations.

To motivate our analysis and verify our model constructs, we conducted an illustrative Delphi study that collected data from a diverse set experts who research platform economics and strategy. Table 1 reports study results with respect to platform attributes such as: (1) standalone platform value (utility out-of-the-box), (2) average third-party added value relative to total platform value (hypothetical for closed platforms), and (3) level of platform openness. Importantly, there is a range of variation across different platforms and across different stages in a platform's lifecycle. Given this variation, these data suggest that firms need guidelines for opening up their platforms in the presence of third-party innovation.

A sponsor's decisions about how much to open the platform and when to absorb developers' innovations are critical parts of an ecosystem strategy. These decisions drive adoption and harness developers as an extension of the sponsor's own production function. Though competitors play a role, ecosystem decisions focus on end-users and third-party developers, who might or might not be known to the sponsor, and who must find it beneficial to participate in the platform. Developers often have ideas the sponsor has not considered and resources that the sponsor does not control. To gain access to these resources, many platform sponsors have devised default contracts, enabling

[1] Interview with Guido Jouret CTO Emerging Markets Group, Cisco Systems Inc. 9-8-2006.

Table 1: Industry Platform Examples

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

* potential

The table was constructed using a Delphi method. In December 2012, data was collected using Survey Monkey from fourteen external experts who research platform economics and strategy.

what is often referred to as "permissionless innovation" Cerf (2012) with appropriate incentives such that even developers not known to the sponsor respond by producing for the sponsor's platform.

Different ecosystem strategies appear 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 importantly, surged again on opening to third-party developers (Piskorski et al., 2012). While Facebook focused on creating a robust platform that allowed third-party developers to build new applications, MySpace did everything itself. MySpace cofounder DeWolfe later acknowledged that its decision to keep all development in-house was ill-advised at best:

> "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)

In the analysis below, we explore how a sponsor's decisions about how much to open a platform and how long to extend developer property rights move with exogenous factors such as production technology and code reusability. To compare the firm's profit optimization with the public's welfare optimization, we analyze the same choices from the perspective of a social planner. We then extend the model to consider how technological uncertainty and the degree of developer competition affect platform choices. Continuing our analysis, we then examine whether profits are higher under open innovation, where developers remain independent, or under vertical integration, where the sponsor buys developer technology. Finally, we characterize the conditions under which developers prefer to join a platform that taxes and takes their innovations versus when they prefer to join an open standard that leaves their innovations unregulated. Regulating spillovers will turn out to alter developer preferences. We conclude by making connections to other literatures, reviewing the theoretical contributions of our model, and outlining the strategic and policy implications of our findings.

To the best of our knowledge, this is the first paper to add a production function to a model that includes a platform, end-users, and developers. The state-of-the-art contributions in the two-sided literature (Rochet and Tirole, 2003; Parker and Van Alstyne, 2005; Weyl, 2010) do not consider developer production functions. The most heavily cited papers in the sequential innovation literature – Green & Scotchmer (1995), Chang (1995), Bessen & Maskin (2009) – use only probabilistic innovation. The most heavily cited analytic models of optimal duration of intellectual property (IP) rights (e.g. Gilbert & Shapiro 1990, Klemperer 1990) do not treat sequential innovation or downstream reuse. Our model directly addresses sequential innovation and by doing so finds, in contrast, that IP duration is *not* arbitrarily long. This is also the first model we know of that formally shows when change in organizational form—from vertical integration to platform ecosystem or from platform ecosystem to open standard—is rational based on an increase in profit from downstream innovation. This connects our paper to the open innovation literature which has, for the most part, avoided formal models of analyzing tradeoffs, presumably because of the complexity of the problem. For example, see the edited volume *Open Innovation* by Chesbrough, Vanhaverbeke & West (2008).

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

2 Literature

Before reviewing the literature on sequential innovation, openness, and private ordering, we first make note of papers that offer definitions of platform economic systems. 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 sales channels (Ceccagnoli et al., 2012). Tee and Woodard (2013) describe the effect of cross-layer interactions on platform governance.

We define a platform business model as an open standard together with a default contract. The standard provides the technological real estate upon which developers build. The contract provides the mechanism that motivates and controls 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. Default contracts may, however, bind developer behavior as with Twitter's restrictions on in-app advertising or Apple's restrictions on off-platform purchases.

2.1 Sequential Innovation

Our formal analysis is rooted in the sequential innovation literature. Chang (1995) and Green and Scotchmer (1995) find that, to optimize rents, a lead innovator (the platform sponsor, in our context) should capture profits from follow-on innovators, and establish longer patents (the duration of intellectual property rights for third-party developers, in our context). Gilbert and Shapiro (1990) and Landes and Posner (2002) examine patent length and breadth as stimuli to innovation. They find that longer but narrower patents are superior to shorter but broader patents. We extend, and in some ways modify, the conclusions of this literature by finding that limited duration property rights are often better. This parallels findings by Partha and David (1994) and Benkler (2002) that property rights should have short or zero duration. However, we do not find zero duration patents to be optimal. To make our claims, we develop a three-period model of sequential innovation and then add a recursive downstream production function. This model allows a firm to control downstream innovation through its choices. The model then gives the firm control over two key constructs: the level of platform openness and the duration of developer property rights.

2.2 Openness

Our understanding of the openness construct is informed by the following literature. A platform is more "open" to the extent that it places fewer restrictions on participation, development, or use across its distinct roles, whether developer or end-user (Eisenmann et al., 2009). We conceive of complete openness?that is, the absence of control at the platform level, as a fully unrestricted open standard. Another factor distinguishing open from closed systems is the choice of governance model (Laffan, 2011), which we conceive of as the ability to bundle developer innovation (described below) and the decision to vertically integrate. 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 end user fears of lock-in, and stimulating downstream production. At the same time, opening a platform typically reduces user switching costs, increases forking and competition, and reduces the sponsor's 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 that firms can optimize their levels of openness. Our choice to model openness as a continuum follows Valloppillil et al. (1998), Parker and Van Alstyne (2009), and Laffan (2011).

2.3 Private ordering and bundling as limits to developer property rights

Our second choice construct is the platform contract that controls the duration of developer property rights. The mechanism for such a contract is articulated in the law and economics literature on "private ordering," which is 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 one-size-fits-all regulation, private ordering can yield better results than uniform law (Williamson, 2002). The central reason to limit developer property rights is to bundle key developer innovations into the core platform to make them available for all to build upon with the goal of fostering a higher rate of innovation. 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), our approach focuses on R&D spillovers. Prior literature characterizes R&D spillovers as 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.

3 The Model

Consider a model of sequential innovation that includes a platform sponsor, third-party application developers, and consumers as the end users. In this economy, developers build applications using resources – open code, APIs, and SDKs – provided by the platform sponsor. The end users consume both the platform and the developers' apps. The central questions are (i) what proportion of the platform should the sponsor open to developers, represented by sharing parameter $\sigma \in [0, 1]$, and (ii) how long should the sponsor allow developers to retain property rights to their innovations (typically, code) before the sponsor bundles them into the platform, represented as $t \in [0, \infty)$. Table 4 in the Appendix provides variable definitions. Developers may charge monopoly prices through the duration of their property rights (which is analogous to patent protection) then build freely on each others' code once this period expires. We represent sequential innovation as two such periods t_1 and t_2. If the platform sponsor chooses $t_1 = \infty$, and does not bundle first-round apps into the platform, then there is no output in the second round.

We start with a single developer and single end user, then add multiple developers and user-developer network effects in Sections 3.4 and 4. A user has a uniform value v for each unit of developer output and, as in (Chang, 1995), a uniform value V for the platform. The sponsor may sell the platform for V or share σV freely with developers, in which case platform sales fall to $(1 - \sigma)V$. Open innovation implies that the sponsor forgoes sales of the "free" resource (West, 2003). In the two-sided literature, σV is readily seen as a developer-side subsidy. For convenience, we define subsidy $S \equiv \sigma V$. A developer has Cobb-Douglas production technology to produce output $y = kx^\alpha$. As in standard IO models (Tirole, 1988), k represents real output per unit input and $\alpha \in (0, 1)$ represents diminishing returns technology. Initially, there are no costs of production. We introduce fixed F and variable $cy^{1/\alpha}$ costs in Section 3.2. In the first round, developers use the platform's open resource σV as input. Open code lasts only one round due to technological obsolescence. This prevents developers from reusing free code more than once, which would only increase the value of openness. If there is a second round, developer input becomes the new open code that becomes available at the end of round one.

Figure 1 illustrates model timing. The output of round one is $y_1 = kS^\alpha = k(\sigma V)^\alpha$ and that of round two is $y_2 = k(y_1)^\alpha = k^{1+\alpha}S^{\alpha^2} = k^{1+\alpha}(\sigma V)^{\alpha^2}$. Developer innovation is thus recursive. Although the production function stays constant, the effect of reuse rises from k to kk^α and the effect of technology strengthens from S^α to $(S^\alpha)^\alpha$. Depending on production function specifics –

the interplay of reuse and technology – an input subsidy to y_1 has the potential to provide an even larger input subsidy to y_2. By contrast, if the sponsor chooses a closed platform, then developers produce no output. We explore vertical integration of developer technology as an alternative to open innovation in Section 4.

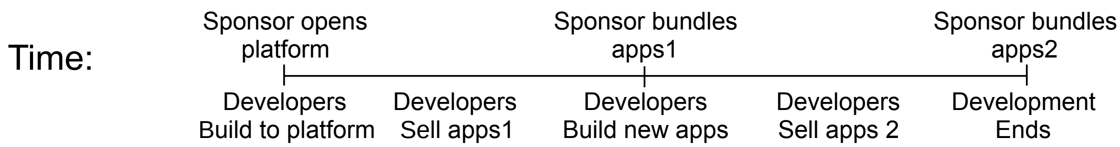

Figure 1: Platform Model Timing

Time 0: Platform sponsor opens the platform, choosing parameters σ and t for sharing and IP duration respectively. Developers gain access to open platform resources.

Time 1: Developers produce apps, sell apps, and split revenues. At period end, sponsor appropriates apps into the open platform. Developers gain access to *new* open resources.

Time 2: Developers produce *new* apps, sell apps, and split revenues. At period end, platform appropriates all apps and bundles them into the platform. Model ends.

The decision to expire developers' rights in their innovations limits their profits. Although consumers value each unit of output at v, they can also wait until code becomes open and widely available. Expiration then restricts price to $v - p \geq \delta v$, which implies developers may set a maximum price $p = v(1 - \delta)$. If the intellectual property rights period never expires, developers may charge the monopoly price $p = v(1 - 0) = v$ but if it expires immediately, developers may charge only the competitive price $p = v(1 - 1) = 0$. To connect discount δ to period t, note simply that $\delta = e^{-rt}$.

Platform sponsors share in the innovation profits of third-party developers by imposing a royalty. As in Green and Scotchmer (1995), we simplify this sharing by using the Nash bargaining solution, giving each party 50%.[2] Developer profit and platform sponsor profit can then be written as follows:

[2] As of this writing, Amazon, Apple, Facebook, Microsoft and SalesForce charge 30%. Silicon Valley venture capitalist Bill Gurley identifies platform fees ranging from 1.9% to 70%. This suggests a 50% split is a reasonable approximation (see `http://abovethecrowd.com/2013/04/18/a-rake-too-far-optimal-platformpricing-strategy/)`. Comparative statics are robust to choice of royalty.

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

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

Expressing platform sponsor profit in terms of model primitives yields

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

In contrast to prior literature, model innovations here include recursive production and resource spillovers. Section 4 goes further and adds user-developer network effects, applied to production, in order to explore the choice of organizational form.

3.1 Platform Sponsor Choice of σ and t

The platform sponsor faces two central tensions. First, closing the platform increases the sponsor's ability to charge for access while opening the platform increases developer ability to innovate. Second, the longer developers retain rights in their innovations, the higher the royalties they and the sponsor earn. In contrast, the sooner developers' rights expire, the sooner their innovations become a public good upon which other ecosystem developers can build. The optimal contract is thus a pair $\langle\sigma, t\rangle$ (isomorphic to $\langle\sigma, \delta\rangle$) where choice parameter σ represents the level of openness and choice parameter t represents the duration of exclusive control. As we shall see, production in each period, discount rate, code reuse, and value added by developers all govern a platform sponsor's choices.

Proposition 1 *The optimal length of exclusionary period δ^* has an interior solution and a corner solution, both governed by the ratio of first to second period output:*

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

This yields three results: (i) the interior solution occurs when second period output exceeds first period output, (ii) the condition for a finite developer property rights period is that first period output must exceed the developer subsidy, and (iii) 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 simplify by expressing profit in terms of output to simplify. Using equation 2, calculate first-order conditions on platform profit with respect to δ as follows:*

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

Note that, given parameter restrictions, $\frac{\partial^2 \pi_p}{\partial \delta^2} = -2vy_2 < 0$, which shows π_p is concave in δ and solving first order conditions provides a global maximum. To establish (i), rearrange terms in equation 5 to reveal equation 4. This has an interior solution if and only if $y_2 > y_1$. For $y_2 \leq y_1$, the optimal δ is 0 (i.e. t is ∞), meaning that it is best never to bundle new applications into the platform. This is the corner solution, occurring when later output does not increase in the subsidy. To establish (ii), substitute primitives in the inequality $y_2 > y_1$, giving $k^{1+\alpha}S^{\alpha^2} > kS^{\alpha}$. Raise both sides by $1/\alpha$ and reduce to see that equivalently $y_1 > S$. Finally, to establish (iii), observe that $\delta^* \leq \frac{1}{2}$ always therefore t^* is bounded above zero always. ■

If first period output is relatively more important, the sponsor is optimizing on $(1-\delta)y_1$, which binds at corner solution $\delta = 0$. If second period output is relatively more important, the sponsor is optimizing on $\delta(1-\delta)y_2$ which solves to an interior solution nearer $\delta = \frac{1}{2}$. Intuition follows from either the sponsor's profit equation 2 or from the optimal discount equation 4. If first period output matters more, the sponsor prefers near term royalties and lets developers raise prices so t increases, possibly infinitely. On the other hand, if second period output matters more, the sponsor wants to reach period two sooner yet still relies on developer contributions to get there, so t is finite.

This proposition provides what is, in effect, a choice of property rights 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.[3] 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.

Turning to the question of platform openness, we begin analysis by first establishing concavity, optimality, and uniqueness of σ.

Lemma 1 *Platform profits π_p are well behaved, and there exists a unique $\sigma^*(\alpha, k, v, V)$ that maximizes profit.*

Proof. *Please see Appendix* ■

It is interesting to note that σ^* can be greater than 1. This implies that the subsidy offered to developers can exceed the value of the platform, which can happen when the future value of the platform has the potential to exceed its current value (Noe and Parker, 2005) and the firm must finance investment through borrowing or venture capital. This can be observed in practice, especially for early stage platforms mobilizing their ecosystems. Twitter and Facebook, for example, both lost money the year before their IPOs, requiring millions of dollars to support platform investment (Hof, 2013) and heavy spending to create developer ecosystems.

We now provide the relationship between openness σ and elasticity of developer 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.*

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

[3]In practice, the 18–24 month window used by Cisco and SAP seem much more realistic for technology and software than the 20 year period granted under U.S. patent law.

Proof.

Take the first order condition of platform profit in 3 with respect to σ. Then, multiply all terms by σ to raise the production exponent by +1 and reproduce developer output in its primitive form.

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \frac{1}{2}\alpha pk(\sigma V)^{\alpha-1} + \frac{1}{2}\alpha^2 pk^{1+\alpha}(\sigma V)^{\alpha^2-1} = 0. \tag{7}$$

$$= -V\sigma + \frac{1}{2}\alpha py_1 + \frac{1}{2}\alpha^2 py_2 = 0. \tag{8}$$

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 third 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 level of platform openness, 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 $\delta = e^{-rt}$.

Corollary 1 *Comparative Statics – Table 2 summarizes effects of model primitives on platform sponsor choices of optimal contract.*

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

Table 2: Openness rises in v and k but falls in V. Duration t rises in v.

Proof. *Derivations appear in the Appendix.* ■

Rising platform value V implies reducing platform openness ($\frac{\partial \sigma^*}{\partial V} < 0$). 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 platform is unrelated to the duration of developer property rights until the sponsor absorbs innovations ($\frac{\partial t^*}{\partial V} = 0$), 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 property rights period t^*. Increased developer value in both periods has the effect of making the sponsor more patient, and more willing to postpone absorbing new features into the platform. The Atari 2600 provides an illustrative example of a platform that was 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 another example. 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." 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 that maintaining a longer intellectual property rights period before bundling will increase developer value add. We observe this in practice with 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.[4]

Reuse coefficient k has a different effect. As platform resources become more reusable, developer production increases. This dynamic implies opening the platform more but, surprisingly, does not alter the date at which the sponsor will enter the market. In terms of openness, higher reuse implies

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

higher value per unit of openness, leading the sponsor to open the platform more. For example, software tends to be more reusable than hardware, and tends to be given away more freely. In terms of developers? property rights period, however, 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 intellectual property rights protection.

3.2 Welfare

We extend the model to include developer fixed costs F in each period and increasing marginal costs, which we model as $c\,y^{1/\alpha}$. 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.[5] 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 from a social planner? point of view against those of a sponsor's maximum net profit. Adding fixed and marginal costs to Equation 2 provides the basis for comparison.

$$\pi_p^c = (1-\sigma)V + \frac{1}{2}\left(py_1 - cy_1^{1/\alpha} - F\right) + \frac{\delta}{2}\left(py_2 - cy_2^{1/\alpha} - F\right) \tag{9}$$

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

$$\arg\max_{\sigma,\delta} W = V + (vy_1 - cy_1^{1/\alpha} - F) + \delta(vy_2 - cy_2^{1/\alpha} - F) \tag{10}$$

Subject to a developer participation constraint:

[5] 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.

$$\pi_d^c = \frac{1}{2}\left(py_1 - cy_1^{1/\alpha} - F\right) + \frac{\delta}{2}\left(py_2 - cy_2^{1/\alpha} - F\right) \geq 0. \tag{11}$$

A positive price, $p = v(1-\delta) > 0$, represents a wealth transfer from consumers, while the extent of platform openness 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 $\langle \sigma_c^\dagger, t_c^\dagger \rangle = \langle 1, 0 \rangle$.

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 finding 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 a private firm.

3.3 Technological Uncertainty

Since innovation can involve risk, we analyze whether technological uncertainty influences the choice of level of platform openness and duration of the developer intellectual property rights period before bundling. 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

$$Y_1 = \begin{cases} \frac{k}{\omega}(\sigma V)^\alpha & \text{with probability } \omega, \\ 0 & \text{with probability } 1-\omega. \end{cases} \tag{12}$$

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:

$$Y_2 = \begin{cases} (\frac{k}{\omega})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } \omega^2 \\ 0 & \text{with probability } 1-\omega^2. \end{cases} \tag{13}$$

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:

$$\mathbf{E}(\pi_p) = V(1-\sigma) + \frac{1}{2}v(1-\delta)k(\sigma V)^{\alpha} + \delta\frac{1}{2}(1-\delta)k^{1+a}(\sigma V)^{\alpha^2}\omega^{1-\alpha} \tag{14}$$

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, a lower likelihood of technological success reduces platform openness and innovation, and increases the duration of time before platform sponsors bundle developer output. Decreasing ω implies that σ^* and Y_2 fall, while t^* rises.*

Comparative statics can be evaluated as follows. 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 a lower likelihood of technical success (i.e. decreased ω) 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, we have assumed that there is a single third-party developer whose prices are conditioned only by the duration of the property rights period. A natural question to ask is how increasing the number of developers N_d and introducing developer competition might affect platform sponsor choices for σ^* and t^*. In order to keep the analysis tractable, we adapt the reduced form methodology of Green and Scotchmer (1995). Increasing the number of developers N_d raises output in period one such that $\tilde{y_1} = N_d\, y_1$. Recursive production then yields $\tilde{y_2} = N_d^{1+\alpha} y_2$, where the additional N^α follows from production spillovers $y_2(N_d y_1)$ of period one developers. Competition among more developers, however, introduces price competition, which we model as $\tilde{p} = \frac{1}{N_d} p = \frac{1}{N_d} v(1-\delta)$ with $N_d \geq 1$.[6] More developers and more intense competition then have the following effects on platform sponsor choices.

Proposition 5 *Increasing the number of developers decreases the property rights period set by the platform sponsor, t^* (increases δ^*). The platform sponsor's choice of openness σ^* depends upon the level of technology α. For relatively good technology ($\alpha \to 1$), the sponsor increases platform openness as the number of developers increases. For relatively poor technology ($\alpha \to 0$), the sponsor*

[6]This formulation is similar to the standard Cournot quantity competition result (see, e.g., Tirole (1988), p. 220) where price is proportional to $\tilde{p} = \frac{1}{n+1} p$.

decreases platform openness as the number of developers increases. When the platform sponsor chooses $t \to \infty$, the number of developers has no impact on the sponsor's choice of σ.

Proof. *We begin with the platform's profit function, modified for price and output effects from N_d developers.*

$$\pi_p = V(1-\sigma) + \frac{v}{2N_d}(1-\delta)N_d\, y_1 + \delta\frac{v}{2N_d}(1-\delta)N_d^{1+\alpha}y_2 \tag{15}$$

Take the derivative with respect to δ and combine terms to get the following.

$$\frac{\partial\pi_p}{\partial\delta} = \frac{-y_1 v}{2} + \frac{N_d^{\alpha} v y_2}{2}(1-2\delta) = 0 \tag{16}$$

Divide through by v, and simplify to get the desired result δ^* increases with N_d.

$$\delta^* = \frac{1}{2}\left(1 - \frac{y_1}{N_d^{\alpha} y_2}\right) \tag{17}$$

Please see Appendix for proof of results for σ^*. ■

Increasing the number of developers makes second-period spillovers more valuable, which motivates the sponsor to reduce the duration of property rights such that second-period profits arrive sooner. To see this effect, note that in the first period, the benefit of additional developer output is offset by increased price competition. Having more output in the second period, however, more than offsets second-period price effects where production spillovers multiply profits.

The effect of number of developers on the platform sponsor's choice of level of openness is more complicated, being moderated by the level of technology. With low-level technology, rising developer competition hurts prices more than rising production helps app sales. Thus, the platform sponsor becomes less interested in sharing developer profits and more interested in direct platform sales; this decreases σ. With high-level technology, spillovers boost developer output enough to offset the effects of price competition and the platform sponsor prefers to stimulate additional app output; this increases σ.

3.4.1 Developer Number and Technical Risk

We can combine Proposition 5 with that of the previous section to see that as more developers help reduce technical risk, the optimal level of openness rises and the duration of developer property rights before bundling falls. 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 $1-\rho^{N_d}$. Equations, 12 and 13 then become

$$\tilde{Y_1} = \begin{cases} \frac{N_d k}{1-\rho}(\sigma V)^{\alpha} & \text{with probability } 1-\rho^{N_d} \\ 0 & \text{with probability } \rho^{N_d}, \end{cases} \tag{18}$$

$$\tilde{Y_2} = \begin{cases} (\frac{N_d k}{1-\rho})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } (1-\rho^{N_d})^2 \\ 0 & \text{with probability } (1-\rho^{N_d})\rho^{N_d}. \end{cases} \tag{19}$$

These imply that unconditional expected values become $\mathbf{E}(\tilde{Y_1}) = \frac{1-\rho^{N_d}}{1-\rho}\tilde{y}_1$ and $\mathbf{E}(\tilde{Y_2}) = \frac{(1-\rho^{N_d})^2}{(1-\rho)^{1+\alpha}}\tilde{y}_2$. Since both $\mathbf{E}(\tilde{Y_1})$ and $\mathbf{E}(\tilde{Y_2})$ rise in N_d, thus the platform has an incentive to increase σ^*.

To evaluate the impact on optimal duration of property rights before bundling, 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 $\delta = \frac{1}{2}\left(1 - \frac{(1-\rho)^{\alpha}}{1-\rho^{N_d}}\frac{\tilde{y}_1}{\tilde{y}_2}\right)$. Given $\frac{\tilde{y}_1}{\tilde{y}_2} = \frac{y_1}{N_d^{\alpha} y_2}$, as shown in Proposition 5, we can see that $\frac{(1-\rho)^{\alpha}}{1-\rho^{N_d}}$ decreases in N_d, implying that δ^* increases and t^* decreases even further in N_d when the risk of technological failure can be reduced.

The result that having more developers helps reduce risk 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 property rights period for technically successful applications.

3.5 Platform Competition

We now explore the effect of competition between platforms on the platform sponsor's optimal choice of $\sigma^*$and t^*. Continuing with the reduced form approach inspired by Green and Scotchmer

(1995), we moderate platform pricing power in the same way that competition reduces developer pricing power, by reducing platform price from $(1-\sigma)\,V$ to $(1-\sigma)\frac{V}{N_p}$ where $N_p \geq 1$ is the number of platform competitors.

Corollary 2 *Increasing the intensity of platform competition increases σ^* but has no effect on t^*.*

Proof. *The claims follow from Corollary 1 and can be seen by substituting $\frac{V}{N_p}$ for V.* ■

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 third-party developer innovation. In terms of competition policy, the regulatory implication is that to achieve higher innovation, the social planner should promote developer entry but not developer competition. Instead, the social planner should promote platform competition, which motivates sponsors to open up platforms and seek growth. This result directly parallels empirical findings. Based on case studies on IBM, Sun Microsystems, and Apple, West (2003) concluded that sponsors prefer the higher rents from closing their systems unless their platforms face pressure from rival platforms. We next examine how this dynamic interacts with developer intellectual property rights and the decision to buy developer technology.

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

Numerous mergers and acquisitions are predicated on the theory that a rational firm could improve profits by buying developers to acquire their technology. By vertically integrating, in our model, the sponsor might gain three advantages over open innovation. First, closing the platform saves the open innovation subsidy $S = \sigma V$, which increases direct profits. Second, the sponsor can build on the *entire* platform, not just the portion opened to developers; so output rises from $y(S) \mid_{S=\sigma V}$ to $y(S) \mid_{S=V}$. Third, application prices rise to monopoly levels $p = v$ because users cannot acquire apps by waiting for them to becomes a public good. Thus app profits rise. Allowing developers to keep half the value of their technology, based on Nash bargaining, the platform's profit under vertical integration becomes $\pi_{vi} = V(1-\sigma) \mid_{\sigma=0} + y_1 \mid_{\sigma=1} + y_2 \mid_{\sigma=1}$ which simplifies to

$$\pi_{vi} = V + \frac{1}{2} v k V^{\alpha} + \frac{1}{2} \delta v k^{1+\alpha} V^{\alpha^2}. \tag{20}$$

Vertical integration yields higher profit than Equation 3. It has higher output; it has no subsidy cost; and it has higher prices.[7] 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.

The second answer arises because, relative to closed systems, open systems invite more third

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

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)). For 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 $M_i, i \in (u, d)$ derived from two-sided market feedback in order to represent the sizes of spillover externalities from content creation and content consumption.

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. To keep market size finite, impose convergence constraint $e_{du}e_{ud} < 1$. Then these sequences converge to $N_dM_d = N_d\frac{1}{1-e_{ud}\, e_{du}}$ and $N_uM_u = N_u\frac{e_{du}}{1-e_{ud}\, e_{du}}$ respectively. Applying M_u to price terms and M_d to output terms, the resulting expression for platform profit given open innovation is:[8]

[8] $N_d = N_u = 1$ is simply a baseline. We analyze larger N in Proposition 5 and Corollary 2 and later in Proposition 7. Note also that M_u and M_d differ only by positive constants e_{ud} or e_{du} depending on which term starts the sequence.

$$\pi_{open} = M_u V(1-\sigma) + \frac{1}{2} M_u p M_d y_1 + \frac{1}{2} \delta M_u p M_d y_2 (M_d y_1). \tag{21}$$

While advantages of vertical integration include eliminating the subsidy, increasing prices, 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 conditional on the following terms.

Proposition 6 *In the absence of network effects, vertical integration strictly dominates open innovation. 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. Open innovation dominates vertical integration as network effects rise, content becomes more reusable, or developers add more value. Given open innovation, network effects from content creation M_d drive openness more than those from content consumption M_u.*

Proof. *Optimizing time in vertical integration equation 20 produces a corner solution $\delta^*_{vi} = 1$. Substituting into π_{vi} and simplifying yields*

$$\hat{\pi}_{vi} = V + \frac{1}{2} v k V^{\alpha} + \frac{1}{2} v k^{1+\alpha} V^{\alpha^2}.$$

Time optimization on open innovation equation 21 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

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

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 $f(0, M_u, M_d|\cdot) < 0$ 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 21 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, showing that price terms do not affect marginal openness while production terms do.* ■

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 monopoly platform from stealing the full value of the innovation. The importance of third party contributions also become clearer as we observe that price effects, which are one time gains, yield lower returns than production effects, which are recursive gains.

4.2 Open Standards & SSOs – Cooperation in the Absence of 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 places their code in the public domain after a time and no one pays royalties. After all, access to a richer pool of application resources fosters richer application development. Although the platform sponsor appropriates developer resources in order to make them available to other developers, is "confiscation" necessary?

To frame this problem, consider any open standard or BSD style license[9] that gives developers

[9] Berkeley Standard Distribution licenses are open source licenses accepted by both the Free Software Foundation and Open Source Initiative. They do not require royalties of any kind but instead require only that subsequent developers acknowledge earlier developers as the source. The original was devised by University of California, Berkeley on release of its version of the UNIX operating system.

Strategy		Period T_1		Period T_2
$\pi_{d_i}^{OO}$	=	$v(1-\delta)y_1$	,	$\delta v(1-\delta)N_d^{\alpha}y_2$
$\pi_{d_i}^{CO}$	=	vy_1	,	$\delta vN_d^{\alpha}y_2$
$\pi_{d_i}^{OC}$	=	$v(1-\delta)y_1$	,	$\delta v(1-\delta)y_2$
$\pi_{d_i}^{CC}$	=	vy_1	,	δvy_2

Table 3: Surplus from four strategies available to a developer in each time period.

access to a mass of shared code, like that of the platform sponsor, but does not require developers to give up their innovations in future periods. Three changes become salient. First, as in Sections 3.4 and 4.1, the number of other developers boosts ecosystem output in each period, bringing ecosystem totals to $N_d y_1$ and $N_d^{1+\alpha}y_2$, where recursive production contributes the extra N^{α}. From a single developer's perspective, individual profits are then proportional to y_1 and $N_d^{\alpha}y_2$. Second, because developers now have the option to not contribute, they no longer need to worry that consumers will simply wait for developer code to become public. This means developers may charge monopoly price $p = v$ instead of $p = (1-\delta)v$, earning an additional δv per unit of output if they keep their innovations private. Finally, if other developers keep their innovations private, then a given developer can only build on his own code and not that of others. If this occurs, individual output in T_2 falls from spillover output $N_d^{\alpha}y_2$ to solo output y_2.

Consider a full information game where developers choose simultaneously in a given period. They know each other's payoffs but building on the standard does not bind them in any way. They may voluntarily cooperate or defect with the former interpreted as opening their code at the end of the period and the latter interpreted as keeping code closed in order to charge for it. In response to the choice of others, a single developer has four strategies: (i) Open, Open (OO), (ii) Close, Open (CO), (iii) Open, Close (OC), or (iv) Close, Close (CC) where the first position denotes the strategy of an individual developer and the second position denotes the action of all other $N-1$ developers. Denote $\pi_{d_i}^{OO}$ as the profit that an individual developer makes when it opens and other developers open. Profits from the remaining three strategies are denoted similarly. Developer choices, summarized in Figure 4.2 and Table 3, then yield the two propositions below. Open code sacrifices δv in the current period, only benefiting *peers* via spillovers in the *next* period.

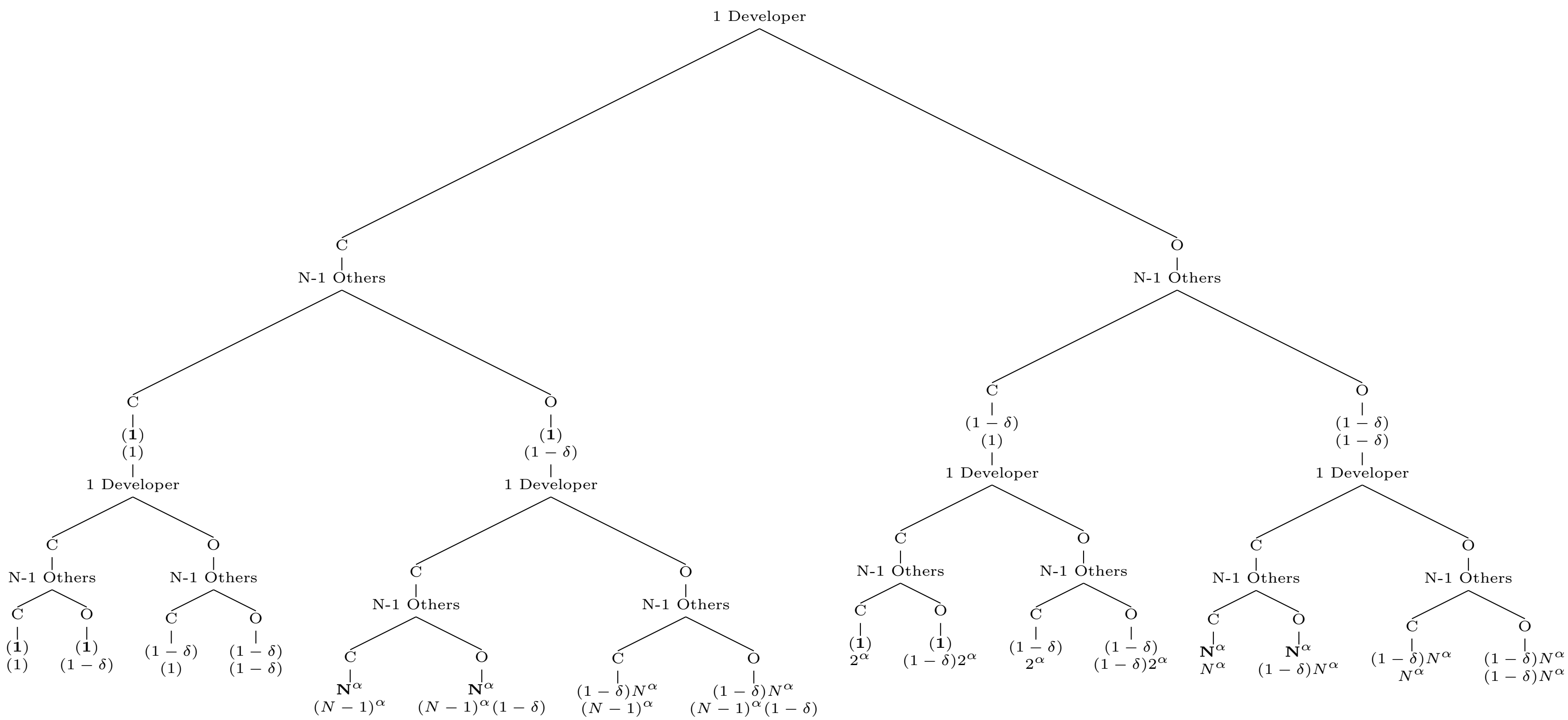

Figure 2: Relative Closed (C) and Open (O) strategy payoffs of a single developer relative to $(N-1)$ other developers. For exact payoffs, multiply all T_1 terms by vy_1, all T_2 terms by δvy_2, and all "other" payoffs by $(N-1)$. Individual dominant strategies, highlighted in bold, are summarized in Table 3. Open code sacrifices δv in the current period, only benefiting *peers* via spillovers in the *next* period. The strictly dominant and individually rational strategy is closed code, a sub-game perfect Nash equilibrium.

Proposition 7 *Among developers, [Close, Close] constitutes a subgame perfect Nash equilibrium.*

Proof. *Direct comparison of OO and CO payoffs reveals a prisoner's dilemma in each period. A profit-motivated developer prefers to defect when other developers cooperate. Starting at the end,* $\pi_{d_i}^{CO} = \pi_{d_i}^{OO} + \delta^2 v N_d^\alpha y_2$ *in* T_2 *and* $\pi_{d_i}^{CO} = \pi_{d_i}^{OO} + \delta v y_1$ *in* T_1*. Similarly,* $\pi_{d_i}^{CC} = \pi_{d_i}^{OC} + \delta^2 v y_2$ *in* T_2 *and* $\pi_{d_i}^{CC} = \pi_{d_i}^{OC} + \delta v y_1$ *in* T_1*, showing that an individual's dominant strategy is always to close.* ■

Having established that profit-motivated developers will not, in the absence of enforcement, freely choose to open their code, we ask when a developer would prefer to submit to a contract that would enforce the cooperative OO outcome.[10] That is, we compare the profits under OO to CC.

Proposition 8 *If second period innovation matters, i.e. the platform sponsor offers a finite protection period* $t^* < \infty$*, then there exists a contract committing developers to open their applications that makes them better off whenever* $N > 4^{\frac{1}{\alpha}}$*. If second period innovation does not matter, i.e.* $t^* = \infty$*, then developers prefer a non-coercive open standard.*

Proof. *Comparing* $\pi_{d_i}^{OO}$ *to* $\pi_{d_i}^{CC}$*, developer profits are higher when* $v(1-\delta)y_1 + \delta v(1-\delta)N_d^\alpha y_2 > vy_1 + \delta v y_2$*. Rearrange, then cancel* v *and* δ *terms, to produce* $(1-\delta)N_d^\alpha y_2 > y_1 + y_2$*. When* $t^* < \infty$*, Proposition 1 shows that* $y_2 > y_1$ *so a stronger bound is* $(1-\delta)N_d^\alpha y_2 > y_2 + y_2$*. Simplifying further yields* $N^\alpha > \frac{2}{1-\delta}$ *whose right hand side rises strictly in* δ*. As* δ *reaches its maximum at* $\frac{1}{2}$*, further manipulation produces* $N > 4^{\frac{1}{\alpha}}$*. In contrast, when* $t^* = \infty$*, there are no second period profits and* $v(1-\delta)y_1 \not> vy_1$ *so developers need not cooperate and prefer an open standard.* ■

When cumulative innovation matters more than one-shot innovation, Proposition 8 shows 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 by increasing

[10] Note that in any finitely repeated game, closing the final period would be optimal. We compare the fully open strategy to illustrate that, even here, openness becomes attractive with few developers. By the Folk Theorem, the cooperative (open) strategy also becomes optimal in the infinite game for any sufficiently patient agents.

spillovers. 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).

This analysis assumes that an open standard provides as much open code as a platform sponsor. A standard setting organization (SSO), however, might be able to increase this amount, in effect moving from $S = \sigma V$ to $S = V$ by requiring firms to give up everything initially. In that case, analysis could proceed along lines similar to vertical integration in the previous section without the Nash bargaining licensing fee. Propositions 6 and 8 show that if innovation is cumulative, developers benefit substantially from recursive R&D spillovers. These benefits accrue *only* if the SSO binds developers to give up their first period innovation in order that the ecosystem benefits from second period innovation.[11]

If this occurs, then the SSO behaves like a platform sponsor in that a strong sponsor helps resolve a classic "collective action" problem (Baldwin and Woodard, 2009). 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 sponsor (or SSO) can craft more specific timing than a regulator whose rules apply across industries. 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 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 8 shows that far from encouraging developers to avoid the platform, bundling their applications can

[11] We thank Jason Woodard for the insight that governing spillovers can apply also to SSOs.

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 Extensions and Managerial Implications

5.1 Extensions

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.

In keeping with other papers in the literature, we assume point mass consumer demand for tractability. Consumers as end users 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. Interestingly, if we allow Hi and Lo consumer types, such that only Hi types buy from developers during the intellectual property rights period, then the platform could sell to Lo types after bundling. This would require the platform to be "closed" but it might allow the sponsor to extract additional rents from developer innovations.[12] In the current framework, all consumers have all apps so this is not feasible.

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

[12]We thank a reviewer for this observation.

technology. Similar conclusions can be obtained with alternative 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. In fact, we know from the Folk Theorem that the cooperative – here open – strategies become optimal in the infinitely repeated game. Here, the necessary and sufficient ingredient is the recursive production function where output of one period is input in the next. In contrast, reducing the model to one period could change results as "reuse" could be lost. More periods preserve or amplify effects of reuse.

5.2 Managerial Implications

In contrast to traditional R&D, managers can capture open innovation by offering default contracts that grant ecosystem partners "permissionless innovation," that is a right to build without having to negotiate. This is the insight behind the default contract we model as $\langle \sigma, t \rangle$. As discussed in propositions 4-6, this reduces risk, increases profits as network effects grow, and reduces hold-up. Second, this means that managers in networked businesses must open their platforms and be willing to sacrifice current platform profits in order to subsidize unknown developers. If you know which ideas will succeed and who has them, then vertical integration is superior, but without this information open innovation is superior. Third, in order to achieve the highest growth, the platform must be willing to force openness on the developers. Sequential R&D spillovers then make the ecosystem, including developers themselves, better off. As in Propositions 1 and 8, if innovation is cumulative, then forcing openness better even for developers than an open standard.

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 the duration of third-party developer intellectual property rights to leverage downstream innovation. We analyze open innovation as a default contract in which a platform sponsor offers developers resources to innovate and a window of profitability in exchange for giving up property rights to 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 end user consumption and developer production through cycles of innovation. This insight yielded by our analysis 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 refine the subsidy models that are standard in the two-sided network literature by showing how openness fuels ecosystem production. We show how platform sponsors can optimize openness. Firms face a choice: they can innovate by acquiring downstream partners in order to avoid sharing technology, or they can open their technology platform in order to grow an ecosystem. Firms in our model find it privately rational to stimulate third-party innovation even at the cost of sacrificing rents from direct platform 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 end user pools, and rising resource reuse. Interestingly, the level of openness, and equivalently the size of subsidy in our model, can be so great as to exceed the current value of the platform.

Second, analogous to periods of patent protection, we identify conditions for a finite property rights or exclusionary period. In our model, this represents the time during which developers can charge for new applications before the sponsor folds these enhancements into the open platform. Platform absorption of first-period innovations should occur at 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. In our model, the optimal property rights period increases in response to an increase in developer value, yet 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 dynamic shows that developers can prefer sponsored platforms. For this to happen, sponsors need longer duration property rights, in keeping 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 sponsors 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 a platform sponsor as acting too aggressively when it folds applications into the core. On the other hand, if sponsors are too weak, then consumers as end users face monopoly distortion in the prices of applications, in hampered innovation, and in an increasingly complex task of integrating disparate applications.

Third, we show that a benevolent social planner chooses to open 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.

From the competition policy perspective, we analyze the size of the developer pool and the intensity of competition among developers and platforms. A larger developer pool leads to faster absorption of developer innovations into the platform. The effect of increased developer competition on platform openness depends upon developer technology. Platform openness increases for more productive developers because the platform can benefit more by taxing developer innovation than through direct platform sales. Increased competition among platforms also causes platforms to prefer a more open contract since direct platform revenues are lower.

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 compels them to share 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 greater 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. To maximize the innovation and thus profit potential of an ecosystem, a platform sponsor must have longer duration control rights than the intellectual property rights of the developers that build upon it.

7 Appendix

Table of Definitions

Var		*Paremeter Interpretation*
σ	–	Share of platform (%) opened to developers
t, δ	–	Time until exclusionary period expires (discount $\delta = e^{-rt}$)
α	–	Technology in Cobb Douglas production
F, c	–	Fixed and marginal costs
k	–	Coefficient of reuse
M_d, M_u	–	Market spillovers from developers & users, index sizes of network effects
N_d, N_u	–	Numbers of developers and users respectively
p	–	Price of individual developer applications $p = v(1-\delta)$
ρ	–	Technological uncertainty; equal to $1-\omega$
S	–	Subsidy platform sponsor provides developers ($S = \sigma V$); primarily, platform value that is open and freely given away
v	–	Value, per unit, of developer output
V	–	Standalone value of sponsor's platform
y_i	–	Output of developers in period i and input to developers in period $i+1$ with $y_i = ky_{i-1}^{\alpha}$ and $y_0 = S$
ω	–	Probability of success for a given innovation; equal to $1-\rho$

Table 4: Platform sponsor chooses σ and t (equivalently δ), thereby indirectly choosing p and y_i.

Proof of Lemma 1 - existence and uniqueness of σ^*

To be proven: there exists a unique σ^* that maximizes platform profit. From Proposition 1, we see that are two cases to analyze. In case 1, δ^* has an interior solution such that $\delta^* \in (0,1)$. In case 2, $\delta^* = 0$. We analyze each case in turn. Recall that platform profit is

$$\pi_p \quad = \quad V(1-\sigma) + \frac{1}{2}v(1-\delta)k(\sigma V)^{\alpha} + \delta\frac{1}{2}v(1-\delta)k^{1+\alpha}(\sigma V)^{\alpha^2}. \tag{22}$$

Case 1: interior $\delta^* \in (0,1)$

The first-order condition on platform profit with respect to σ is:

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \alpha\frac{1}{2}v(1-\delta)k\sigma^{\alpha-1}V^{\alpha} + \alpha^2\frac{1}{2}\delta v(1-\delta)k^{1+\alpha}\sigma^{\alpha^2-1}V^{\alpha^2} = 0. \tag{23}$$

Before proceeding, we check the second order condition for concavity of the platform profit function in σ. We substitute $\delta^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2}\right) = \frac{1}{2}\left(1 - \frac{k(\sigma V)^{\alpha}}{k^{1+\alpha}(\sigma V)^{\alpha^2}}\right)$ into the platform profit function and take the second derivative with respect to σ to get the following expression.[13]

[13]This requires a tedious bit of algebra that can be carried out mechanically using software such as mathematica.

$$\frac{\partial^2 \pi_p}{\partial \sigma^2} = \frac{1}{8}\alpha k v \sigma^{-\alpha^2-2} V^{-\alpha^2}\left((\alpha-2)(\alpha-1)^2\sigma^{2\alpha}k^{-\alpha}V^{2\alpha} + \alpha\left(\alpha^2-1\right)\sigma^{2\alpha^2}k^{\alpha}V^{2\alpha^2} + 2(\alpha-1)\sigma^{\alpha(\alpha+1)}V^{\alpha(\alpha+1)}\right) \quad (24)$$

Given positive values for primitives, $\sigma \geq 0$, and $\alpha \in (0,1)$, note that each additive term inside the parentheses is negative. We conclude that the second derivative is negative.

Returning to the first order condition, we multiply through by σ, let $S = \sigma V$, and rearrange terms to get the following expression

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

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

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

Let $L = kS^{\alpha-1}$.

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

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

$$\delta^* = \frac{1}{2}\left(1 - \frac{1}{L^{\alpha}}\right) \quad (25)$$

Thus

$$\begin{aligned} 1 &= \frac{\alpha v}{2}L(1-[\frac{1}{2}(1-\frac{1}{L^{\alpha}})])\left(1+\alpha[\frac{1}{2}(1-\frac{1}{L^{\alpha}})]L^{\alpha}\right) \\ 1 &= \frac{\alpha v}{4}\left(L+L^{1-\alpha}\right)\frac{1}{2}\left(2+\alpha L^{\alpha}-\alpha\right) \end{aligned}$$

Define

$$f(L) = 1 = \frac{\alpha v}{8}\left(L+L^{1-\alpha}\right)\left(2-\alpha+\alpha L^{\alpha}\right). \quad (26)$$

Given $\alpha \in (0,1)$ and $L > 0$, then $f(L)$ increases monotonically in L. Since $f(0) \to 0, f(\infty) \to \infty$ 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.)

Case 2: corner $\delta^* = 0$

Again, calculate the first-order condition on platform profit with respect to σ. However, in this case, $\delta^* = 0$ and $p = v(1-\delta)$ implies $p \to v$. The second period term goes to zero and the expression reduces to:

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \frac{1}{2}\alpha v k \sigma^{\alpha-1}V^{\alpha} = 0. \quad (27)$$

To ensure concavity, we check the second derivative with respect to σ.

$$\frac{\partial^2 \pi_p}{\partial \sigma^2} = \frac{1}{2}(\alpha - 1)\alpha v k \sigma^{\alpha-2} V^{\alpha} \tag{28}$$

The second derivative is clearly negative. Returning to the first order condition, note that the expression simplifies to

$$(\sigma V)^{1-\alpha} = \alpha v k/2. \tag{29}$$

Raise both sides to $1/(1-\alpha)$ and solve for σ to get the closed form solution

$$\sigma^* = \frac{(\alpha v k/2)^{1/(1-\alpha)}}{V}. \tag{30}$$

(Q.E.D.)

Derivation of Corollary 1 - Comparative Statics

Comparative statics for σ^*

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. Note that the comparative statics for σ^* are the same for both cases 1 and 2.

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

Case 1, $\delta^* \in (0,1)$: Given $L = kS^{\alpha-1} = k(\sigma V)^{\alpha-1}$, σ^* must fall in V in order to maintain the equality in equation 26.

Case 2, $\delta^* = 0$: By equation 30, σ falls in V.

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

Case 1, $\delta^* \in (0,1)$: The right-hand-side of equation 26 increases in v. Thus L^* falls in v in order to maintain the equality. Therefore σ^* increases in v.

Case 2, $\delta^* = 0$: By equation 30, σ increases in v.

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

Case 1, $\delta^* \in (0,1)$: Equation 26 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.

Case 2, $\delta^* = 0$: By equation 30, σ increases in k.

Comparative statics for δ^*

Note that comparative statics for δ^*only make sense in Case 1, $\delta^* \in (0,1)$. Therefore the derivations below refer only to this case.

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

Equation 25 expresses δ in terms of L. By equation 26, L^* is constant with respect to V.

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

By equation 25, δ^* increases in L^*. By equation 26, 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 25 expresses δ in terms of L. By equation 26, L^* is constant with respect to k.

Proof of 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

$$\delta_c^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{c y_2^{1/\alpha} + F}{v y_2}\right). \tag{31}$$

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

$$\delta_c^\dagger = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{c y_2^{1/\alpha} + F}{v y_2} + \Delta\right). \tag{32}$$

All terms except $\Delta = \frac{\sqrt{4 v y_2 (v y_1 - c y_1^{1/\alpha} - F) + ((v y_2 - c y_2^{1/\alpha} - F) - v y_1)^2}}{v y_2}$ 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.

$$\sigma_c^\dagger \quad : \quad \alpha(v y_1 - \frac{1}{\alpha} c y_1^{1/\alpha}) + \delta_c^\dagger \alpha^2 (v y_2 - \frac{1}{\alpha} c y_2^{1/\alpha}) = 0 \tag{33}$$

$$\sigma_c^* \quad : \quad \alpha(p y_1 - \frac{1}{\alpha} c y_1^{1/\alpha}) + \delta_c^* \alpha^2 (p y_2 - \frac{1}{\alpha} c y_2^{1/\alpha}) = 2\sigma V \tag{34}$$

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 can be sorted.

$$\sigma_c^\dagger \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^* \alpha^2 (vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = -\kappa_1 < 0 \tag{35}$$

$$\sigma_c^* \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^* \alpha^2 (vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = \kappa_2 > 0 \tag{36}$$

Where $\kappa_1 = \alpha\Delta(\alpha v y_2 - c y_2^{\frac{1}{\alpha}}) > 0$ and $\kappa_2 = 2\sigma V + \alpha\delta v y_1 + \alpha^2\delta^2 v y_2 > 0$. Under model assumptions, the first constraint binds always to the left of the second. In this case, producing $\sigma_c^\dagger > \sigma_c^*$.

■

Proof of Proposition 5 - Developer Competition

Effect of Developer number on σ^*

To prove: σ^*increases in the number of developers N_d.

Our proof will parallel that of Lemma 1 above. We begin with the platform's profit function, modified for price and output effects from N_d developers.

Case 1: Interior δ^*

$$\pi_p \quad = \quad V(1-\sigma) + \frac{1}{2N_d} v(1-\delta) N_d\, k(\sigma V)^\alpha + \delta \frac{1}{2N_d} v(1-\delta)(N_d\, k)^{1+\alpha}(\sigma V)^{\alpha^2} \tag{37}$$

Take the derivative with respect to σ and combine terms to get the following.

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \alpha\frac{1}{2}v(1-\delta)k\sigma^{\alpha-1}V^\alpha + \alpha^2\frac{1}{2}\delta v(1-\delta)N_d^\alpha k^{1+\alpha}\sigma^{\alpha^2-1}V^{\alpha^2} = 0. \tag{38}$$

We multiply through by σ, let $S = \sigma V$, and rearrange terms to get the following expression

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

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

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

Substitute L for $k\,S^{\alpha-1}$. Rearrange terms to get the following.

$$1 = \frac{1}{2}\alpha(1-\delta)Lv\left(\alpha\delta L^\alpha N_d^\alpha + 1\right)$$

Now substitute $\frac{1}{2}\left(1 - L^{-\alpha}N_d^{-\alpha}\right)$ for δ. After simplification, the first order condition can be expressed as follows.

$$1 = \frac{1}{8}\alpha v\left((2-\alpha)L^{1-\alpha}N_d^{-\alpha} + \alpha L^{\alpha+1}N_d^\alpha + 2L\right)$$

Let us focus on the two terms that contain N_d: $(2-\alpha)\frac{L^{1-\alpha}}{N_d^\alpha} + \alpha L^{\alpha+1}N_d^\alpha$

Good developer production technology

When α is large ($\alpha \to 1$), the first term goes to $2/N_d$ and the second term dominates. In the second term, when N_d increases, L must decrease to maintain the equality demanded by the first order condition. Thus, for good developer production technology, an increase in the number of developers implies a more open platform.

Poor developer production technology

Conversely, when α is small ($\alpha \to 0$), we see offsetting $2L/N_d^\alpha$ versus $\alpha L N_d^\alpha$. However, the second term disappears because of the α multiplier. Thus, for sufficiently small α, the first term dominates. For poor developer production technology, an increase in the number of developers implies a less open platform.

Case 2: Corner δ^*=0

In the second case, when $t \to \infty$, the number of developers has no impact on the platform's choice of σ. This is because the price impact and output impact of increasing N_d offset one another in the first period and the second period never arrives.

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