Innovation, Openness & Platform Control

Geoffrey Parker
Tulane University
gparker@tulane.edu

Marshall Van Alstyne
Boston University/MIT
mva@bu.edu

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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 drives developer profits down but bundling late delays platform growth. Interestingly, developers can prefer sponsored platforms to unmanaged open standards despite giving up rights to their applications. Results can inform innovation strategy, antitrust and intellectual property law, and the management of competition.

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1 Introduction

What choices improve platform profits and innovation? In particular, can openness feed downstream development; when does open beat closed technology; and if ecosystem partners develop ideas, does it make sense to take those ideas and bundle them into the platform? While platform business models have become mainstream, little formal analysis yet tells us how to run them Yoo et al. (2010). This paper seeks to analyze platform decisions regarding openness, developer subsidies, and appropriation – via bundling – of ideas platform sponsors themselves might not have anticipated. These choices affect many common products such as personal computers, mobile devices, gaming systems, and telecommunications infrastructure as well as services such as social networking, hosted in-memory computing, and streaming media (cf. Table 1). We build a model of sequential innovation and consider how platform firms can expand their capabilities, and their markets, by opening their technology and encouraging third party developers. Analysis focuses on three major questions.

Table 1: Example Industry Platforms

Platform	*Companies or Products*
Desktop OS	Mac, Windows, Unix
PDAs	Palm, Psion, Newton
Game Consoles	Wii, Xbox, Playstation
Network Switches	Cisco, IBM, HP
Multimedia	Flash, Silverlight, HTML5
Payment Systems	Paypal, Google Checkout, Visa, Apple, Mobile Felica
Mobile Devices	iPhone, Android, Symbian, Blackberry
Enterprise Systems	Salesforce, Oracle, i2, IBM, SAP
Social Networks	Facebook, MySpace, LinkedIn, Monster, Twitter
Health Care	WebMD, MedHelp
Web Search	Google, Bing, Baidu
Ebooks	Kindle, iPad, Nook, Sony

If openness affects profits and innovation, how much should platform components open? Over the past three decades, firms have chosen different and competing strategies. At one extreme, manufacturers of television set top boxes, such as TiVo circa 2005 have used provisions of the Digital

Millennium Copyright Act to lock out industry players who sought to attach to their systems (Slater and Schoen, 2006). At the other extreme, open source software firms such as RedHat have chosen to use licensing terms, standard under the GNU Public License, that give anyone who receives their code the right to modify and distribute copies.[1] Ecosystem users benefit, yet competitors promptly absorb all valuable innovations.

Platform strategies have evolved and executives have disagreed on their viability. At the turn of the century, Apple neared bankruptcy after a series of failures including its Newton handheld computer, precursor to the iPhone. When asked how to fix Apple, the CEO of Dell Computer opined that it was unrecoverable: "I'd shut it down and give the money back to the shareholders" (Singh, 1997). Yet, on Jan. 13, 2006, Apple went on to pass Dell in market capitalization; on May 26, 2010 it passed Microsoft; and on Aug. 9, 2011 it passed Exxon Mobile to become, at least briefly, the most valuable company in the world.[2]

Arguably, Microsoft executed a more open and more successful platform ecosystem strategy in the 1980s and 90s than did Apple. Microsoft licensed its technology broadly, opened Application Programming Interfaces (APIs) on its desktop operating system to third party developers, and priced its system developer toolkit at less than one third that of Apple. It also aggressively absorbed innovations of ecosystem partners. By the time of the 1998 antitrust trial, more than 70,000 applications ran on Microsoft Windows compared to roughly 12,000 on Apple's Mac OS (Jackson, 1999). As of 2011, however, Apple had successfully executed an ecosystem strategy that harnessed hundreds of thousands of developers outstripping Microsoft and others in mobile devices.

If a platform opens, a second question is whether and how much to subsidize downstream developers. Salesforce has, at different times, viewed its system developer toolkit (SDK) and API as profit centers and free giveaways (Babcock, 2011). Similarly, Apple, charged thousands of dollars for SDKs in the 1980s but charged $0 in the 2010s.[3] Selective free access to its APIs was one of the complaints lodged against Microsoft during its antitrust trial. To foster the growth of its

[1] See www.redhat.com/licenses/gpl.html. Accessed Aug. 30. 2011.

[2] Gamet, J., "Apple Passes Dell's Market Cap," *Mac Observer* Jan 15, 2006. Helft, M. & Vance, A. "Apple Passes Microsoft as No. 1 in Tech" *New York Times* May 26, 2010. Satasiano, A. "Apple Overtakes Exxon Becoming World's Most Valuable Company," *Bloomberg News* Aug. 10, 2011.

[3] See developer.apple.com/devcenter/mac/index.action. Accessed Jan. 18. 2012.

mobile platform, Google offered \$5.5 million in prizes for the best new mobile applications.[4] This is consistent with the two-sided network literature showing that platforms often price at or below zero to one class of consumers to account for a cross-price elasticity resulting from one group attracting another, as with women attracting men on dating sites or sellers attracting buyers on auction sites (Parker and Van Alstyne, 2000, 2005; Rochet and Tirole, 2003). However, these models do not account for control over downstream production. In fact, most simply assume network attraction. Is there a another principle by which one might choose such a subsidy?

A third concern is whether to bundle downstream innovation into the platform or, interpreted differently, when to compete with developers by entering their markets. On one hand, failure to bundle developer innovations into the platform prevents valuable new features from becoming standard and it prolongs downstream monopoly distortion. Whether through internal development or acquisition, coercive or not, platform firms such as Apple, Facebook, Google, Intel, Microsoft, and SAP have routinely absorbed features developed by their ecosystem partners. On the other hand, the threat of bundling reduces developer effort while actual bundling causes developer exit and can lead to government intervention. Google and Intel have both faced antitrust scrutiny while Microsoft has been convicted of antitrust violation (Jackson, 1999). Is there a time when platforms should bundle downstream innovation and does this benefit the ecosystem or just the platform sponsor?

These decisions on openness, subsidies, and bundling constitute an *ecosystem* strategy, which we define as one that focuses on users and developers, who might or might not be known to the sponsor, and who must be coaxed into platform participation. Competitors do play a role yet the initial focus is to drive adoption and harness developers as an extension of the sponsor's own production function. Developers often have ideas the sponsor has not considered and resources the sponsor does not control. The first step is therefore to devise a default contract, with appropriate developer incentives – taxes, reverse taxes, and opportunities – 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 of publishing source code and access details (Eisenmann et al., 2009; West, 2003) and

[4] See code.google.com/android/adc. Accessed Aug. 30, 2011.

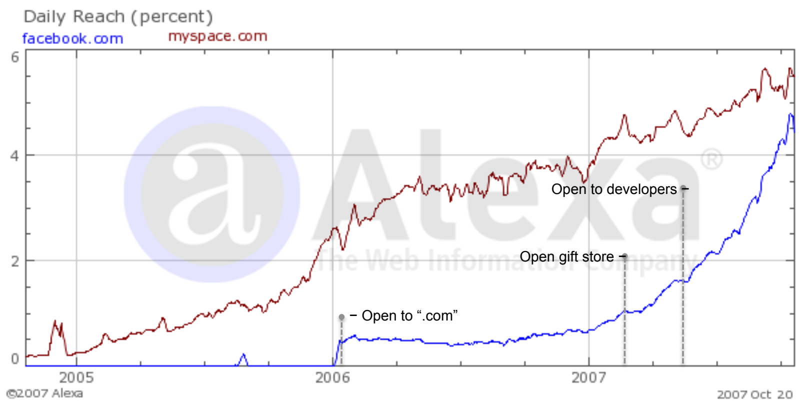

Figure 1: Accesses to the social networking platform MySpace appear above while those to Facebook appear below. Starting from the ".edu" domain, Facebook opened to the ".com" domain in early 2006, then opened a digital store, later opening to developers in 2007. Anecdotally, this appears to have increased usage among consumers and developers.

also *two-sided* in the sense of pricing attractively to one group i.e. developers, in order to profit from another group i.e. end-users (Parker and Van Alstyne, 2000, 2005; Rochet and Tirole, 2003).

This focus on users and developers can yield competitive advantage by causing alternate platforms to starve from lack of participation. An open innovation ecosystem strategy appears to have played a role in the rise of Facebook and the demise of MySpace (see Figure 1).

> While Facebook focused on creating a robust platform that allowed outside developers to build new applications, Myspace did everything itself. "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)

For a complete analysis of strategies to pull users and developers from competing platforms, see Eisenmann et al. (2011). Here, the ecosystem issue is how the presence of competitors affects the choice of optimal contract offered to developers, measured in terms of openness, subsidies, and bundling.

1.1 Literature

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 provision, and application software, among others (Baldwin and Clark, 2000; Grove, 1996). The credit card and telecommunications industries are similarly layered (Evans et al., 2006).

As a result of the increasing economic importance of platform ecosystems, a growing literature has focused on platform design (Cusumano and Gawer, 2002), platform economics, and the associated business strategies for managing them (Boudreau, 2010; Bresnahan and Greenstein, 1999; Cusumano, 2010; Farrell et al., 1998). Recent literature conceives of platforms as mediating markets with two-sided network externalities and analyzes pricing across potentially distinct user groups (Caillaud and Jullien, 2003; Parker and Van Alstyne, 2000, 2005; Rochet and Tirole, 2003; Rysman, 2009). Choosing the optimal level of openness is also 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 appropriability (West, 2003). Opening a platform can spur growth by harnessing network effects, reducing users' fear of lock-in, and stimulating downstream production. At the same time, opening a platform typically reduces users' switching costs and increases competition, reducing sponsors' ability to capture rents.

To date, however, there has been little formal modeling to address 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 product platform over time is a key area of unanswered research (Yoo et al., 2010). Earlier non-price work has focused at the regulatory level to explore the question of how to promote initial innovation by allowing an innovator to capture profits from follow-on innovations. This literature has looked primarily at patent length and breadth for government regulation, leaving open the question of how firms themselves could use these results (Chang, 1995; Gilbert and Shapiro, 1990; Green and

Scotchmer, 1995; Klemperer, 1990; Landes and Posner, 2002).

We build on the sequential innovation literature and broaden the analysis to the following set of questions: When should a platform sponsor open a resource to outside development? How does competition affect openness? How does the ability to reuse platform assets affect the level of openness? Does the number of downstream developers or their added value affect openness? If downstream developers do add value, should the firm privately subcontract with a subset or should the firm open the platform to the entire developer pool? When should a platform fold new developer applications into the platform?

To address these questions, we develop a tractable model of downstream production by developers who add value to a platform by producing applications. We define a *platform* as the components used in common across a product family (Boudreau, 2010) whose functionality can be extended by third parties and is subject to network effects (Eisenmann et al., 2011; Evans et al., 2006; Parker and Van Alstyne, 2000, 2005). 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., 2011). Opening completely, i.e. the absence of control at the platform sponsor level, we analyze as a fully unrestricted open standard. We focus on the set of platforms that grow primarily through sequential innovation. Our model incorporates the ability to reuse output from one period as production input in the next period. Developers can then incorporate platform assets into their applications development. Further, the development of second generation applications can depend on the value and quantity of applications developed in the first. The tradeoff is that converting assets from closed to open sacrifices sales, thus creating a tension between profits now and innovation later. The model allows us to characterize (i) the optimal level of openness for a platform (ii) the optimal exclusionary period (i.e. when downstream apps should also face rent destroying competition), (iii) when a platform sponsor should use closed subcontracts instead of decentralized open innovation, (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. One regulatory implication is that sponsors need longer term property rights than developers in order to effectively manage downstream innovation. Section 2 develops the model and main results, including social welfare, competition, and technological uncertainty. Section 3 considers alternate organizational forms. We consider extensions in 4 and conclude in Section 5.

2 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. At time zero, a platform sponsor makes fraction σ of its platform's value openly available to developers, representing free access to APIs and SDKs. This free code from the sponsor represents an input subsidy $S = \sigma V$ that developers use to produce applications for the platform. Developers must cover fixed and variable costs, F and cy^2, 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. Thus $y_1 = kS^{\alpha}$. We discuss potential relaxations to these assumptions in section 4.

To build intuition and develop necessary building blocks, we first analyze the model without competition, developer choice, or costs. After determining platform choices in isolation, we consider social planner choices. We then explore the effects of technological change and the number of developers. We analyze competition at both the platform and developer levels. We conclude by analyzing the participation game that developers face in the absence of strong contract enforcement. Current U.S. copyright laws provide exclusive protection for 95 years for corporate authorship. European laws provide similarly long protection. A key finding of our model is that one-size-fits-all copyright duration at both the platform and application level is neither socially optimal, nor profit-maximizing in the context of sequential innovation. Hence we focus on directly analyzing the duration of protection for follow-on innovation.

We follow Chang (1995) in assuming that consumers share a common value V for the platform and v for each unit y of application produced. We assume that leakage to consumers results in a net loss of platform profit in the amount of the first period giveaway, $S = \sigma V$. Technological obsolescence prevents developers from reusing open resources more than once (further reuse would increase the value of openness). Thus, second period open stock, which developers use as a production input, is the period 1 production. 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 2.2 considers a direct licensing contract to avoid the loss of 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, $p = v - \delta v = v(1 - \delta)$.[5] 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.[6] For now, we assume zero marginal production costs and a sufficiently large value added, v, that de-

[5] An equivalent profit, reducing v in Eq. 1, could depend on ex ante developer beliefs on whether the sponsor will enter its market.

[6] 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). A Nash bargain is thus a reasonable approximation.

velopers 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 2.2. 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, we provide the following table of definitions.

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 ($S = \sigma V$) equivalently, platform value that is open and freely given away
k	–	Coefficient of reuse
α	–	Technology in Cobb Douglas production
y_i	–	Output of developers in period $i \in \{1, 2\}$ and input to developers in period $i \in \{0, 1\}$ 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.

2.1 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 of value (level of openness) used to subsidize 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 developer subsidy, (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.*

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

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.[7] 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 subsidy 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. We believe this can be observed in practice, especially for early stage platforms working to mobilize their ecosystems. Many platform firms and hopeful startups have had positive valuations despite pouring money into customer *and* developer acquisition at levels exceeding platform specific revenues. When launching its online search platform, for example, Microsoft incurred \$2 billion in losses Siegler (2010).

Proposition 2 *The platform sponsor's optimal choice of openness σ^*yields a subsidy 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.

[7] 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.

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

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. Since elasticity of output in each period with respect to σ is $\eta_i = \frac{\partial y_i}{\partial \sigma}\frac{\sigma}{y_i}$, $i = 1, 2$, 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 platform subsidy 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 – 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 can be sacrificed to stimulate developer production. As illustration, the market for small to medium enterprise resource planning (ERP) deployments was smaller than that for large enterprise systems, and the former was correspondingly more open. 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. This is consistent with how platform sponsors treat "marquee" developers for their platforms, giving them more favorable terms on both σ and t. Microsoft gave more favorable terms to Electronic Arts for its XBox than standard developers. SAP also agreed to longer exclusivity for ADP, a major payroll processing player. This works in reverse as well. In ecosystems where developers add less value, they face absorption and competition sooner. At SAP, the clockspeeds of ERP systems in on-premises, on-demand, and mobile are respectively years, months, and weeks.[8]

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 subsidy, leading the sponsor to subsidize 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.

2.2 Welfare

We extend the model to include developer fixed costs F in each period and increasing marginal costs $c\,y^{1/\alpha}$ where,[9] for simplicity, marginal cost remains small enough that $vy_2 \geq \frac{c}{\alpha} y_2^{1/\alpha}$. We continue

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

[9] 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.

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 platform subsidy 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. *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*

$$\delta_c^* = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{cy_2^{1/\alpha} + F}{vy_2}\right). \tag{11}$$

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.

$$\delta_c^\dagger = \frac{1}{2}\left(1 - \frac{y_1}{y_2} - \frac{cy_2^{1/\alpha} + F}{vy_2} + \Delta\right). \tag{12}$$

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.

$$\sigma_c^\dagger \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^\dagger\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = 0 \tag{13}$$

$$\sigma_c^* \quad : \quad \alpha(py_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(py_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = 2\sigma V \tag{14}$$

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.

$$\sigma_c^\dagger \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = -\kappa_1 < 0 \tag{15}$$

$$\sigma_c^* \quad : \quad \alpha(vy_1 - \frac{1}{\alpha}cy_1^{1/\alpha}) + \delta_c^*\alpha^2(vy_2 - \frac{1}{\alpha}cy_2^{1/\alpha}) = \kappa_2 > 0 \tag{16}$$

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 $\sigma_c^\dagger > \sigma_c^*$.

■

We observe that the greater the share of downstream innovation captured by the platform sponsor, the greater is the incentive to open. The Nash share is $s = \frac{1}{2}$ but, more generally, for $s \in [0,1]$, the platform sponsor's constraint moves with $\frac{1}{s}\sigma V$, which falls weakly toward the constraint of the social planner as s rises. 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, this also shows that higher costs cause the social planner to behave more like the proprietary sponsor. As total costs rise, Δ falls (as profit terms tend toward 0) such that the choice of the social planner increasingly resembles that of the platform sponsor.

2.2.1 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

$$Y_1 = \begin{cases} \frac{k}{\omega}(\sigma V)^{\alpha} & \text{with probability } \omega, \\ 0 & \text{with probability } 1 - \omega. \end{cases} \tag{17}$$

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:

$$Y_2 = \begin{cases} (\frac{k}{\omega})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } \omega^2 \\ 0 & \text{with probability } 1-\omega^2. \end{cases} \tag{18}$$

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:

$$\mathbf{E}(\pi_p) = V(1-\sigma) + \frac{1}{2}v(1-\delta)k(\sigma V)^{\alpha} + \delta\frac{1}{2}(1-\delta)k^{1+a}(\sigma V)^{\alpha^2}\omega^{1-\alpha} \tag{19}$$

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.

2.2.2 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 profits and so by Corollary 1, the sensitivity on k shows no effect on the proprietary period.

We can combine this result 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, 17 and 18 then become

$$\tilde{Y_1} = \begin{cases} \frac{Nk}{1-\rho}(\sigma V)^\alpha & \text{with probability } 1-\rho^N \\ 0 & \text{with probability } \rho^N, \end{cases} \tag{20}$$

$$\tilde{Y_2} = \begin{cases} (\frac{Nk}{1-\rho})^{\alpha+1}(\sigma V)^{\alpha^2} & \text{with probability } (1-\rho^N)^2 \\ 0 & \text{with probability } (1-\rho^N)\rho^N. \end{cases} \tag{21}$$

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). 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). 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 subcontract, a situation we analyze in Section 3.1. We note simply that sponsor interest in downstream innovation also provides reason to prefer (initially) less downstream competition.

2.2.3 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 $\sigma^*$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.*

$$\frac{b_1}{\sigma^{1-\alpha}\lambda} + \frac{b_2}{\sigma^{1-\alpha^2}\lambda} \quad = \quad 1 \tag{22}$$

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.

$$\delta^* \quad = \quad \frac{1}{2}\left(1 - b\frac{\sigma^{\alpha}}{\sigma^{\alpha^2}}\right) \tag{23}$$

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.

3 Alternate Organizational Forms

In this section, we examine alternate ways to organize for innovation including the decision to subcontract instead of license openly and the decision of developers to cooperate rather than bargain with the platform sponsor.

3.1 Open Innovation vs. Private Subcontracts

Up to this point, we have assumed that firms rationally open their platforms to seek innovation. This overlooks the possibility that a rational sponsor might do better by negotiating directly with developers that it already knows. Under a closed subcontract, the sponsor could save the subsidy cost $S = \sigma V$. The sponsor could also grant subcontractors full access to all technology embedded within its platform. These subcontractors could then increase their output based on the full platform value V rather than fractional open value σV. This parallels Apple's strategy of sharing with a small developer pool and producing a tightly integrated system for its original Macintosh computer (Boudreau, 2010). An equation to represent closed subcontracts is given by:

$$\begin{aligned}
\pi_{sub} &= V(1-\sigma)\mid_{\sigma=0} + y_1 \mid_{\sigma=1} + y_2 \mid_{\sigma=1} \\
\pi_{sub} &= V + \frac{1}{2}pkV^{\alpha} + \frac{1}{2}\delta pk^{1+\alpha}V^{\alpha^2}.
\end{aligned}$$

With higher output and lower subsidy cost in a closed platform, how might profits from open innovation ever dominate those from subcontracts?

There are two possible answers. One is that there exist developers the sponsor does not know. The other is that network effects can increase due to 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 take them (Bessen and Maskin, 2009; Parker and Van Alstyne, 2000). Commitment to stay out of the developer's market during the exclusionary period provides the incentive such developers need to step forward.

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, 2000, 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.

We analyze these cases by considering network effects. Let there exist a market multiplier M, which we derive below based on two-sided market feedback.[10] While advantages of a closed subcontract include keeping the cost of the subsidy and increasing subcontractor output, the advantage of open innovation lies in growing the market. This equation is given by:

$$\pi_{open} \quad = \quad V(1-\sigma) + \frac{1}{2}pMy_1 + \frac{1}{2}\delta pMy_2(My_1)$$

Broader participation and network effects compound over two periods of production. The result is that higher adoption and network effects can justify open innovation relative to closed subcontracting. More formally, we provide a strong bound.

Proposition 5 *If the platform sponsor offers a finite exclusionary period, open innovation is more profitable than closed subcontracts whenever the market multiplier is large enough that* $M^{1+\alpha} > (\frac{1}{\sigma^{\alpha^2}} + \frac{S}{\delta p y_2})$.

Proof. *The platform sponsor prefers openness when* $\pi_{value} > \pi_{sub}$ *or, after subtracting and grouping terms, when* $\sigma V < \frac{1}{2}pkV^{\alpha}(1-M\sigma^{\alpha}) + \frac{1}{2}\delta pk^{1+\alpha}V^{\alpha^2}(1-M\sigma^{\alpha^2})$. *When the sponsor values second period production, the second righthand term exceeds the first. Thus a stronger bound on the inequality is* $\sigma V < 2\frac{1}{2}\delta pk^{1+\alpha}V^{\alpha^2}(1-M\sigma^{\alpha^2})$. *Algebraic simplification yields* $\frac{\sigma V}{\delta pk^{1+\alpha}V^{\alpha^2}} < M\sigma^{\alpha^2}$. *Division, then substituting for the definition of* y_2 *provides the necessary expression.* ■

Opening the platform becomes more attractive (i) as the subsidy $S = \sigma V$ falls (ii) second round output y_2 grows, and (iii) technology α improves. This proposition argues for decentralized innovation when user-developer network effects rise far enough. Note that the decentralized innovation

[10] We need not assume M but can derive it based on a two-sided market model. 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 Q_d proportional to the number of users Q_u, thus increasing developers by $e_{ud}Q_u$. Likewise, based on externality spillover e_{du}, augment baseline users Q_u proportional to the number of developers Q_d, thus increasing users by $e_{du}Q_d$. New users attract yet new developers, and vice versa, in amounts $e_{du}e_{ud}Q_u$ and $e_{ud}e_{ud}Q_d$, a recursion process that defines Cauchy sequences for both groups. Developer size increases according to $Q_d(1 + e_{ud}\,e_{du} + (e_{ud}\,e_{du})^2 + (e_{ud}\,e_{du})^3 + ...)$ and similarly for users. These converge to $Q_dM_d = Q_d\frac{1}{1-e_{ud}\,e_{du}}$ and $Q_uM_u = Q_u\frac{e_{du}}{1-e_{ud}\,e_{du}}$ respectively. Since these differ by a trivial constant, we simplify to M. Note that while we implicitly set $Q_d = Q_u = 1$, changing them to N simply scales v and V, conditions handled in Corollaries 1 and 2.

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

Table 3: Surplus from the four strategies available to developers.

is achieved without bargaining costs. A default open contract with $\sigma > 0$ gives developers an option to enter the market for any fixed costs up to the amount they can recover, and without current period disclosure to the platform author. They need not risk disclosing their idea to the monopsonistic platform author who could potentially appropriate its value.

3.2 Cooperation in the Absence of Platform Control

The ability to reuse material from one application in the development of another raises the prospect that developers can reciprocally contribute to one another's forward development. After all, access to a richer pool of application resources fosters richer application development. In effect, the platform sponsor appropriates developer resources at time t^*in order to make them available to other developers via the platform. 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. The four strategies we consider are (i) cooperate, cooperate (CC) where the first position denotes the strategy of an individual developer and the second position denotes the action of the remaining developers, (ii) defect, cooperate (DC), (iii) cooperate, defect (CD), and (iv) defect, defect (DD). Denote $\pi_{d_i}^{CC}$ as the profit that an individual developer makes when it cooperates and all other 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 of other applications apart from their own. Second, uncooperative developers can recover the revenues in the tail of the distribution $t > t^*$. 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* $\pi_{d_i}^{DC} = \pi_{d_i}^{CC} + \frac{1}{2}\delta v y_1 + \frac{1}{2}\delta^2 v y_2$. *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. The only difference is that the developer has access to his own private stock as well as Ω_1.

Proposition 7 *If the platform sponsor chooses* $t^* < \infty$ *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* $\frac{1}{2}v\delta^2 k^{1+\alpha} N^{\alpha} (\sigma V)^{\alpha^2} > \frac{1}{2}v\delta k(\sigma V)^{\alpha} + \frac{1}{2}v\delta^2 k^{1+\alpha}(\sigma V)^{\alpha^2}$. *Since* $t^* < \infty$ *it follows that* $y_2 > y_1$ *so* $\frac{1}{2}v\delta^2 k^{1+\alpha} N^{\alpha}(\sigma V)^{\alpha^2} > 2\frac{1}{2}v\delta^2 k^{1+\alpha}(\sigma V)^{\alpha^2}$. *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.

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 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 - this illustrates "openness" by our earlier definition. 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. The sponsor's self-interest in platform innovation motivates it to shepherd the platform much as if it were a social planner. Sponsor interest in downstream royalties, in fact, encourages it to delay bundling longer than would a social planner as the sponsor does not directly participate in consumer surplus.

4 Extensions

It is worth examining the robustness of our analysis to changes in 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 are captured using a two-period model.

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 (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. This model also introduces a novel choice parameter, contractual openness, which plays a central role.

Relaxing the assumption of a one period lifetime for platform and developer stock would complicate analysis but also strengthen results. If open platform stock stimulates production for additional periods, the increase in developer output also increases willingness to share the platform in order to share developer surplus. On margin, openness and decentralized innovation then become more valuable. A continuous time endogenous growth model will be developed in future research.

5 Summary & Conclusions

Our main contribution is to show how a platform sponsor, who optimizes openness, subsidies, and bundling, can increase platform profits and innovation. Open innovation can be analyzed as a contract in which a platform sponsor offers developers resources to innovate and a window of opportunity in exchange for giving up those innovations at a future date. The platform sponsor 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 builds on both the sequential innovation and two-sided network literature as well as explaining empirical phenomena in mobile devices, enterprise systems, web search, social networks, and other platforms. Several sharp intuitions follow from this model.

First, we show that platform sponsors can increase profits through an optimal choice of openness, which can be interpreted as a proxy for shared value. They find it privately rational to stimulate 3^{rd} party production even at the cost of sacrificing 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 and rising 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. Empirically, this is consistent with business models of Internet startups that have positive valuations despite massive giveaways (Noe and Parker, 2005). 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.

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, remains unaffected by changes in reuse.

As a contribution to theory, our results condition an earlier finding that optimal duration for intellectual property protection can be arbitrarily long Gilbert and Shapiro (1990); Landes and

Posner (2002). In sequential innovation literature, we confirm 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 managers of proprietary platforms face a challenge as they try to steer their platforms between current and future profit. Applications developers can view them as acting too aggressively when managers fold applications into the core. On the other hand, if managers are too slow, 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 forces earlier disclosure of developer production than does a self-interested platform sponsor. However, increasing costs lead platform sponsor and social planner behaviors 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.

Fourth, the model provides conditions for choosing between competing contract types. To promote sequential innovation, a sponsor can choose closed developer contracts that do not sacrifice platform profits or open contracts that stimulate greater developer participation. Open contracts that lead to decentralized innovation are increasingly preferred when the subsidy cost is smaller, developer output larger, or technology superior. These results are achieved without appeal to transaction costs, which should intrinsically favor open contracts that are simply default offers requiring no negotiation. Results also do not depend on prior awareness of any developer's skills.

Fifth, we demonstrate a prisoners' dilemma where developers individually refuse to open their applications even as they prefer every other developer open theirs. Given a sufficiently large developer pool, however, all developers are better off submitting to a contract forcing them to open their applications. The reason is that subsequent output can build from a larger pool of initial input, leading to higher total surplus. The platform sponsor must enforce such contracts not only for benefit of the platform but of the developers themselves, a role not unlike that of a social planner. This result is of particular importance for regulators and platform systems designers. In order to maximize the value creation potential of a platform ecosystem, the platform sponsor must have a longer tenure than the developers who build upon it.

6 Appendix

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:

$$\frac{\partial \pi_p}{\partial \sigma} = -V + \alpha \frac{1}{2} pk\sigma^{\alpha-1} V^{\alpha} + \alpha^2 \frac{1}{2} \delta pk^{1+\alpha} \sigma^{\alpha^2-1} V^{\alpha^2} = 0. \tag{24}$$

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

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

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

$$f(L) = 1 = \frac{\alpha v}{4} \left(L + L^{1-\alpha} \right) \left(\frac{1}{2} \alpha L^{\alpha} + \left(1 - \frac{1}{2} \alpha \right) \right). \tag{26}$$

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 26.

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

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.

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

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.

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

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.

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