Open Platform Strategies and Innovation:

Granting Access versus Devolving Control

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This paper distinguishes two fundamentally distinct approaches to opening a technology platform, and their different impacts on innovation. One approach is to grant access to a platform and thereby open-up markets for complementary components around the platform. Another approach is to go further and give up control over the platform itself. Using data on 21 systems from handheld computing systems (1990-2004), I find that granting greater levels of access to independent hardware developer firms related to up to a fivefold acceleration in new handheld device development, depending on the precise degree of access and how this was implemented. Where operating system platform owners went further to give up control (beyond just granting access to their platforms) the incremental effect on new device development was still positive but an order of magnitude smaller. The evidence from the industry and theoretical arguments both suggest that distinct economic mechanisms were set in motion by these two approaches to opening.

Key words: technical change; systems; open strategies; platforms; complementors; distributed innovation; information technology

1. Introduction

Within the broader question of how best to organize the development and commercialization of a technology, an innovator may choose to "open" its technology by allowing outsiders to participate in its development and commercialization (Shapiro and Varian 1998). Such strategies are particularly amenable to systems (Katz and Shapiro 1994, Marschak 1962) made up of multiple components, which can be opened one component at a time.[1] Whether or not to open a new technology is understood to be one of the most crucial decisions an innovator will face. Opening has the potential to build momentum behind a technology, but could leave its creator with little control or ability to appropriate value (Katz and Shapiro 1986, Kende 1998, Morris and Ferguson 1993, Schilling 2009, Shapiro and Varian 1998, West 2003). Case study evidence suggests that an important element of this tradeoff relates to the impact of opening on various aspects of innovation and technical progress: the improvement of individual components; the creation of extensions,

[1] I focus here on multi-component systems. See Chesbrough et al. (2006) for a broader discussion.

add-ons and upgrades; the elimination of bugs and errors; and quality and cost improvements (e.g., Baldwin and Clark 2000, Kuan 2002, Langlois 1992, von Burg 2001, von Hippel 2005).

In this paper I present empirical evidence on how different approaches to opening a system influence the rate of innovation.[2] I consider two broad and fundamentally different approaches to opening: granting outsiders *access* the platform, and thus open up markets for complementary innovation around the platform, and giving up some control over the platform itself. Part of the difficulty in distinguishing these approaches is that they often coincide in theory and practice. If the platform owner devolves all control over the platform, there is no longer a party within the system who can restrict access to outsiders wishing to develop the platform or other components; consequently, widespread entry may follow (cf. Katz and Shapiro 1986, 1994). For example, much of the development of public telecommunications and inter-computer communications networks over the last century has occurred around key platform technologies whose definitions were managed by public standards authorities. Thus, firms around the world could develop not just the core communications network equipment but also testing and installation equipment, specialized billing and messaging equipment, and other sorts of complementary components and services (e.g., consulting). Analogously, open source versions of the UNIX operating system platform, such as Linux, have enabled firms to freely enter the markets for complementary applications software, hardware, and services.

However, platform owners can and do open up the system of interoperating complementary components without having to give up all control. It is enough that independent developers of complementary components be granted access to the platform, in the sense of ensuring that these components are (legally and technically) interoperable with the platform and each other (cf. Boudreau and Hagiu 2009, Farrell 2007, Merges 2008, Parker and Van Alstyne 2008). For example, Apple tightly controls development of its iPhone operating systems (and the closely-linked iPhone, iPod and iPad hardware), but allows thousands of outsiders to develop software applications, commercial media, and user-generated content. This example illustrates the important distinction between giving up control over the platform and simply granting access to the platform in order to open up complementary development.

Indeed, it is possible to discern strands of research focused more or less on the distinct notions of devolving control and granting access. For example, a number of theoretical papers have considered how granting wide access to independent developers of interoperating, mix-and-matchable components can foster

[2] See Laursen and Salter (2006) for evidence on open innovation and knowledge-sharing in a wide sample of industrial firms. See Murray et al. (2009) for a recent working paper on open intellectual property within academic "open science" institutions.

vibrant markets with diverse ideas and active experimentation (e.g., Baldwin and Clark 2000, Farrell et al. 1998, Farrell and Weiser 2003, von Hippel 2005). A quite distinct strand considers the ability of platform owners to stimulate innovation by relinquishing control over foundational platform technologies (e.g., Katz and Shapiro 1986, Farrell 2007, Farrell and Katz 2000, Shapiro and Varian 1998).[3]

In this paper, I am able to empirically distinguish the independent effects of granting access and devolving control by studying a dataset on the development history of handheld computing systems (1990-2004). These were relatively simple systems, where the hardware played the role of complementary components and operating systems played the role of platforms. Operating system platform owners at times varied the degree of access granted to outsiders (by changing their licensing policies, and sometimes by also lowering entry barriers bysharing hardware "reference designs"). Platform owners also varied the level of control over their platforms by sharing equity ownership, narrowing their vertical scope, and allowing outsiders to contribute to isolated parts of the operating system (such as the graphical user interface).

The econometric analysis relates the rate at which new handheld devices were released to alternative modes and degrees of openness, within a robust count data panel framework (Wooldridge 1999). (A number of special considerations in this context motivate this particular approach to modeling and measurement. These considerations are detailed at length within the article.) I find that granting access to independent hardware developers was associated with a dramatic increase in the rate at which new devices were developed—up to a fivefold acceleration. The liberalness of the licensing approach explains most of this acceleration, with intermediate policies (i.e., somewhat restrictive licensing) resulting in the highest development rates. Lowering entry barriers by sharing hardware designs also had a positive impact on development, but this effect was considerably smaller. Among platform owners who went a step farther by giving up varying degrees of control over their operating systems, to total effect was an order of magnitude smaller than those of granting access. Together, the various measures of giving up platform control account for a roughly 20% increase in development rates. (The precise estimate depends on the model specification, and the effect is not statistically significant in all models.) These results are robust to system fixed effects and covariates, various specifications of time controls, alternative functional specifications of the mean and error, and regressions on subsamples. I also confirm that the pre-switch trends of switchers and non-switchers are similar, to provide assurance that meaningful econometric comparisons were made.

Both the empirical results and qualitative arguments based on the history of the industry at the time

[3] Farrell (2007) and Rysman (2009) discuss analogous distinctions related to opening.

suggest that fundamentally different economic mechanisms were set in motion by the two approaches to opening. By granting access to independent developers of complementary components, platform owners drew on a diverse set of capabilities and concepts while intensifying competition among these outsiders. Where platform owners went further to lessen their control, the results are consistent with changing vertical "power" between the bottleneck platform owner and outside developers and the contribution of outside ideas to the platform itself. However, the small magnitude of the effect calls into question whether small, incremental variation in platform control (as seen in these data) can do much to activate these mechansisms. Further research is required to more precisely determine the nature and workings of these mechanisms.

The paper is organized as follows. Section 2 reviews the literature on open strategies in systems and innovation. Section 3 focuses on the distinction between opening the platform and opening complementary development. Section 4 describes the empirical context, and Section 5 presents the data. Section 6 describes the empirical approach. Section 7 presents the model results and robustness tests. Section 8 discusses the patterns that were found in the analysis. Section 9 concludes.

2. Literature and Background

This section reviews the literature on open and closed systems with links to innovation. I begin by defining terms of reference.

2.1 Systems, Platforms and Complementary Components

Systems are products made up of multiple components (Katz and Shapiro 1994, Marschak 1962), such as computers, automobiles, telecommunications services and video games. The platform consists of those elements that are used in common or reused across implementations. A platform may include physical components, tools and rules to facilitate development, a collection of technical standards to support interoperability, or any combination of these things.[4] Serving as a stable nexus or foundation, a platform can organize the technical development of interchangeable, complementary components[5] and permit them to interact with one another. These same characteristics imply that platforms are also technological bottlenecks (Jacobides et al. 2006, Rochet and Tirole 2004). (In contrast, different varieties of a complementary component may be substituted for one another.) The entity holding property rights over a platform therefore

[4]See, for example: Baldwin and Woodard (2009), Cusumano and Selby (1995), Gawer and Cusumano (2002), Franke and von Hippel (2003), Kim and Kogut 1996, Meyer and Lehnerd (1997), Meyer and Utterback 1993, Robertson and Ulrich 1998, Simpson et al. (2006), Spulber (2008), and Wheelwright and Clark (1992).

[5]Some alternative terms are "complements", "subsystems", "modules", "peripherals" and "edge technologies".

also possesses "bouncer's rights" (Strahilovetz 2006) to exclude outsiders from the entire system (Boudreau and Hagiu 2009). Just as it is the platform owner's prerogative to place restrictions on the use, development and commercialization of the platform and system, it is also their prerogative to "open" or *remove* any restrictions on the use, development and commercialization of a system or any individual components within it.[6] Traditionally, the decision to open has been viewed as a trade-off between encouraging diffusion of the technology and maintaining appropriability (Katz and Shapiro 1986, Kende 1998, Morris and Ferguson 1993, Schilling 2009, Shapiro and Varian 1998, West 2003). However, case study evidence now reveals that opening can also shape technical progress: the improvement of individual components; the creation of extensions, add-ons and upgrades; the elimination of bugs and errors; and quality and cost improvements (e.g., Baldwin and Clark 2000, Kuan 2002, Langlois 1992, von Burg 2001, von Hippel 2005).

2.2 Open versus Closed Systems

Broadly speaking, openness relates to the easing of restrictions on the use, development and commercialization of a technology. The polar extremes of openness can be understood in relation to property rights (Katz and Shapiro 1986, 1994). Closed technologies are wholly owned, proprietary, vertically integrated, and controlled by a single party. By default, the owner of a closed technology fully restricts development, excluding outsiders through patents and copyrights, secrecy, or other means (cf. Cohen et al. 2000).

In contrast, a purely open technology is placed in the public domain, neither owned nor controlled by any party, thus accessible to all. This policy might be implemented through public standards bodies, disclosure and publication in the public domain, or by explicitly transferring ownership to a public authority. Opening key enabling assets thus allows free entry into the supply of the technology (cf. Katz and Shapiro 1986). Open policies sometimes go even further by guaranteeing rights to modify, transform and build upon previous developments in an unfettered and non-discriminatory fashion—insofar as practical and institutional considerations allow.

2.3 Key Trade-offs

A firm considering whether to open its technology faces a trade-off that has come to be known as "adoption versus appropriability" (West 2003). Pursuing an open strategy reduces the innovator's share of profits by lowering entry barriers and introducing intra-system competition. On the other hand, all else being equal, opening might encourage wider adoption of the system by reducing consumers' fears of being

[6] In this paper I focus on multi-component systems. See Chesbrough et al. (2006) for a broader discussion.

locked into a single vendor (Farrell and Gallini 1988; Katz and Shapiro 1994). For example, Cusumano et al. (1992) argue that by sharing the standard (and the market) for VHS videocassette recorders, JVC effectively created a larger business for the VHS system and thus guaranteed its victory over Sony's Betamax system.

But when a technology system requires ongoing innovation after being opened (for example, when interfaces and protocols need to be extended to accommodate higher system performance) other economic mechanisms come into play. These considerations result in a new trade-off, which might be referred to as "diversity versus control".[7] On the diversity side, an open system may benefit from the input, ideas and knowledge of a broader pool of contributors. Indeed, drawing on external knowledge has been one of the more persuasive arguments for opening innovation (cf. Chesbrough 2003; von Hippel 2005).

However, external knowledge must also be actively *applied*, requiring deliberate effort and investment. For this reason, opening may pose a problem in situations where diffuse property rights reduce all parties' incentives to invest and sponsor innovation in the system (Katz and Shapiro 1986, 1994; Shapiro and Varian 1998).[8] Furthermore, when multiple parties try to innovate simultaneously, coherence may be lost across the system (Almirall and Casadesus-Masanell 2010, Gawer and Cusumano 2002). The resulting "co-ordination by committee" may further complicate matters (Greenstein 1996). For this reason, numerous scholars have pointed out the advantages of closed, vertically integrated systems when innovation requires cross-component coordination or knowledge sharing.[9]

2.4 Partially Open Systems

Recent research has clarified that many technology systems once considered "open" are in fact neither purely open nor purely closed (West 2003). The governance of a "partially open" regime should be inherently more complex than that of a purely open or purely closed regime, because the assignment of property rights does not wholly clarify freedoms of use, development and commercialization. Partial openness retains the concept of *owners*, parties with the ability to modify rights, freedoms and obligations via contracts or other rule-setting instruments (Boudreau and Hagiu 2009).[10]

[7] The diversity/control trade-off is not necessarily independent of the adoption/appropriability trade-off. I simply wish to lay out the issues in simple terms.

[8] Research on "internalizing complementary efficiencies" (cf. Davis and Murphy 2000; Farrell and Weiser 2003) suggests that even if specialized component suppliers are able to capture rents, they still will not maximize *overall* value creation in a system.

[9] See, for example, Christensen et al. (2002), Evans et al. (2005 p. 194), Fixson and Park (2008), Langlois (2007), Macher (2006), Novak and Eppinger (2001), Teece (1996), Wolter and Veloso (2008).

[10] See Eisenmann et al. (2010) for a survey of the uses of numerous instruments.

At least as a rough approximation, we might think of implementing a certain "degree" of openness as a means of reconciling the adoption/appropriability and diversity/control trade-offs (Boudreau 2006, West 2003, 2007). However, to move beyond this rough approximation, characterizing a partially open regime with greater precision requires detailed answers to many more questions. Which parts of the system are opened? Which freedoms and restrictions are in effect? Are fees charged? Which IPs are implicated? (For example, opening architectural IP may ensure interoperability and allow the owner to guide the high-level design attributes of third-party components; opening the detailed designs of working component implementations leads to a far more explicit form of sharing.)

Adding further complication, the degree of openness can impact the procedural and institutional character of the innovation process. Whereas baseline economic models predict that diffuse property rights will lead to markets composed of undifferentiated competitors, in some cases open approaches result in highly socialized, cooperative "communities" of contributing innovators (rather than competing firms). Thus, in addition to rivalry and profit-seeking, open community processes can be shaped by norms, pro-social behavior, signaling and non-pecuniary interests (Boudreau and Lakhani 2009, Feller et al. 2005, Lerner and Tirole 2002, Roberts et al. 2006). Open communities can also subject innovative activity to informal governance rules, processes and rituals (O'Mahony and Ferraro 2007, von Krogh et al. 2003).

Thus, partially open regimes may vary widely in their treatment of property rights, contracts and rules, as well as their procedural characters. Any comparative analysis of such regimes requires careful inspection and interpretation of institutional differences (cf. Gawer and Henderson 2007, Greenstein 2009, Valloppillil 1998).[11]

3. Granting Access to Complementary Development versus Giving Up Platform Control

This section considers the differences between opening a core platform technology and granting access to independent developers of complementary components around the platform. In particular, I discuss rea-

[11]For example, the Berkeley Software Distribution (BSD) license places all designs in the public domain and allows anyone to use, modify, and commercialize the technology. While the GNU General Public License (GPL) is widely considered to be more open than either the BSD or Apache open source licenses, the GPL *restricts* charging for derivative works and *requires* that all derivative works be returned to the core code base. The Sun Community Source License makes its source code transparent and allows outsiders to modify the code, but imposes fees for commercial redistribution and also imposes testing requirements. Microsoft's Windows operating system for personal computers has been described as open, in the sense of disclosing sufficient architectural IP to allow outsiders to draw on functions of the operating system. Microsoft's share source license goes even further, disclosing some source code to large partners and universities for educational purposes.

sons that the two policies should affect innovation in qualitatively different ways (referring to the trade-offs described in Section 2.3). Given the wide scope of this theme, the primary goal of this section is simply to demarcate key issues—not to make narrow predictions.

3.1 Granting Access and Opening Complementary Development

At a minimum, granting access to independent developers of complementary components requires that architectural IP be shared. Outsiders must have a basic set of design rules to ensure the technical interoperability of their contributions. Whether framed within a licensing contract or freely disclosed, this IP effectively *grants access* to the market for complementary components. Any number of factors and conditions might then further shape the openness of the component (cf. Section 2.4).

As described in Section 2.3, opening a system to complementary development plausibly affects innovation by drawing on diversity. This might be particularly true of mix-and-matchable components, insofar as they can benefit from economies of specialization (Arora and Bokhari 2007, Farrell 2007, Farrell and Weiser 2003, Langlois 1992), distributed heterogeneous knowledge (Chesbrough 2003, von Hippel 2005), the independent experimentation of complementors, and the closely-related processes of variation and selection (Baldwin and Clark 2000, Farrell et al. 1998, Garud and Kumaraswamy 1995).

The usefulness of diversity depends on the choices and behaviors of complementors. They must be motivated and willing participants, contributing significant investment and effort. However, the incentive to innovate should also be affected by the degree of openness. For example, Parker and Van Alstyne (2008) theorize that simply granting wider access can reduce incentives by strengthening direct competition; on the other hand, opening the platform to diverse and differentiated complementors might encourage spillovers that buoy innovation. Rey and Salant (2008) similarly argue that the owner of critical upstream IP (i.e., a platform) should carefully weigh the benefits of variety against the risk of diminished incentives when changing the barriers to downstream entry. Research on network effects in systems suggests analogous patterns. Opening could intensify the agglomeration economies around a technology, but at the same time lead to intensified rivalry and competition (e.g., Augereau et al. 2006, Economides 1996, Tucker *forthcoming*). Indeed, these mechanisms could interact with one another and with the heterogeneity, experimentation, variation and selection processes in ways we have yet to fully comprehend.[12] Each of these points warrants considerable research attention in its own right; here, I simply wish to emphasize the nature and mix of

[12]If opening were to occur in an especially intense standards battle to capture the market, each of these mechanisms might also operate in a context of high strategic uncertainty (cf. Besen and Farrell 1994).

potential mechanisms set in motion when opening in this manner.

The other trade-offs mentioned in Section 2.3 might be expected to play a lesser role when opening a platform to complementary development. For example, a platform owner's bargaining power (conferred by control over a bottleneck platform) might be sufficiently strong to lock in consumers and complementors without necessarily controlling the entire system. In this case, granting access to complementors would not necessarily affect the adoption/appropriability trade-off. (Jacobides et al. (2006) provide a description of this general bargaining principle, as applied to a bottleneck supplier.) The trade-off between coordination and control might also be mitigated to the extent that technical interfaces have been fully specified, facilitating "arm's-length" coordination in the system.

3.2 Opening the Platform and Giving up Control

Concentrating control in the hands of the platform owner should bear directly upon the adoption/appropriability trade-off (Section 2.3). A number of models imply that platform owners with extensive control over their system will be tempted to "squeeze" the complementors for profits once the latter have innovated. As a result, independent complementors may be reluctant to invest in innovation in the first place (Becchetti and Paganetto 2001, Choi et al. 2003, Farrell and Katz 2000, Farrell 2007 p. 378, Heeb 2003, Niedermayer 2007, Nocke et al. 2007; see also Martin and Orlando, *forthcoming*). (Many comparable types of abuse and neglect by platform owners are imaginable.[13]) By giving up some measure of control over the platform, a platform owner might credibly commit to not abusing its partners—thereby restoring an incentive to invest in complementary innovation. Whether this strategy works in practice is unclear; Gawer and Henderson's (2007) case study of Intel reveals that giving up a degree of formal control (by not integrating into the production of complementary technologies) was not enough on its own; Intel also had to engage in a range of organizational practices to establish its commitment. Perrons (2009) similarly argues that establishing trust and a good reputation was at least as important in influencing complementors' behaviors as Intel's formal power over its system (and perhaps despite this power). Therefore, it is not clear whether small differences in the platform owner's power or control have an appreciable effect. At the same time, cutting deeply into control could diminish a platform owner's architectural advantage, jeopardizing its ability to sponsor and orchestrate activity across its system.

In cases where opening goes so far as to allow outsiders to contribute to the platform itself, the diver-

[13] For example, Pierce (2009) shows that focal firms in the auto industry can create turbulence and failure in complementary markets.

sity/control trade-off may become particularly relevant. This is because opening the platform to outside contributions creates a new challenge: accumulating and consolidating diverse contributions *to a single object*. Given that the platform must be supplied in just one variety, it is not straightforward for contributors to work in parallel; there is a greater need for collaboration. All else being equal, opening a platform might therefore jeopardize innovative performance. It should not then be surprising that open platform technologies with multiple contributors tend to be supported by extraordinary institutional arrangements to promote successful coordination, accumulation and consolidation of their contributions. Open-source software projects (particularly those related to large and complex platforms such as Linux and Apache), the World Wide Web Consortium (W3C), and open standards organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunication Union (ITU) are institutions that might be interpreted in this light.

3.3 Research Questions

Given their implications, the differences between giving up control over the core platform and granting access to the platform and thus opening markets for complementary innovation to independent developers might be shorthanded as "opening the platform" and "opening the complement". The literature suggests that either form of opening should evoke a range of countervailing effects. The precise relationship between openness and innovation outcomes should therefore be considered an empirical matter, subject to the characteristics of the context.[14] We have ample reason to expect that fundamentally different mechanisms will be set in motion by the two approaches. Therefore, I hypothesize that the observed relationship between openness and innovation is qualitatively different depending on whether the platform itself was opened or just the complementary components. The remainder of this paper is devoted to empirically exploring these differences. I later relate the empirical findings to the mechanisms previously discussed.

4. Openness and Device Innovation in Handheld Computing

Technical and commercial experimentation in handheld computers largely began in the 1980s. The earliest versions of these pocket-sized devices could be likened to advanced calculators. More sophisticated, 16-bit programmable systems were developed by the late 1980s, and included features analogous to those of desktop computers. From the early 1990s until the early 2000s, global sales of handheld computers (often

[14]Note that neither open nor closed systems can be regarded as generally more efficient than the other (e.g. Hagiu 2009).

referred to as personal digital assistants or PDAs) grew from several hundred thousand to over ten million units per year. This industry remained a distinct niche of the broader computer industry until its boundaries were blurred by the appearance of smartphones and digital music players in the mid-2000s. The present analysis focuses on the period prior to this convergence.

Boudreau (2006) and Casadesus-Masanell et al. (2008) have documented the technical and managerial challenges surrounding the initial creation of working designs and architectures. After successfully establishing a platform, commercial success largely depended on sustaining a stream of new devices with more features and increasing quality and appeal (Chwelos et al. 2004; Nair et al. 2004; Yoffie et al. 2004). Figure 1 plots the flux of devices released by various players in the industry.

Figure 1

Although handheld computers comprised several different elements (software applications, peripheral hardware, etc.), the most technically and economically important parts were the operating system and the hardware. Often, multiple independent suppliers designed similar devices on top of a common operating system. The operating system and hardware therefore meet our definitions for a platform and its complementary development respectively (Section 2).

Complementary hardware innovations related to board-level electronics designs, industrial design (a device's look and feel), and improved integration and testing to refine how design elements worked together. Ongoing development led to regular releases of new devices with advanced processor speeds and memory, new ports and input-output functionality, new shapes ("form factors"), reduced size, novel features, and other improvements. Declining production costs and the availability of superior subcomponent technologies (memory, processors, etc.) led to relatively stable nominal prices while performance steadily improved (Chwelos et al. 2004). Periodic upgrades to the operating system platforms also supported progress.

4.1 The Key Construct: Open Strategies

The openness of handheld systems varied across systems and time. Figure 2 displays the number of systems present in the industry during each year of the study, subdivided into whether access was granted to independent complementary hardware developer firms ("Open Complementary Hardware") and whether—

in addition— some degree of control had been given up over the operating system platform ("Open Hardware and Operating System Platform").

Figure 2

The development of complementary hardware always fell short of a purely open regime (West 2003). Independent hardware developers were granted access, but competed with one another to develop proprietary designs. Granting access involved licensing the right to use the operating system, disclosing interfaces, and providing documentation and technical support. The prices paid for this access generally remained fixed at roughly $10 per unit, with a slight downward trend. Notably, these fees did not appear to fluctuate in response to market conditions.

Variations in openness were mainly related to the number of outsiders to whom the platform owners granted licenses. The extent of access varied from outright exclusion to licensing all comers. For example, despite the interest expressed by outside manufacturers, Palm turned away would-be partners at several points in its history, even in its early days.[15] Microsoft began by licensing large OEMs (existing partners from its personal computing business), and later granted licenses more liberally. In 2009, Microsoft retreated to a more restrictive licensing approach.

However, the industry went beyond just granting access. Some platform owners transferred IP, sharing "reference designs" or blueprints for fully-working devices. Devices built on a reference design could be differentiated by altering and customizing the design. The availability of a reference design lowered entry barriers, as modifying a fully-working design was much more straightforward than developing a new design to meet the platform owner's specifications. For example, Asian companies that had traditionally manufactured devices but not designed their own were now able to enter the market.

For the most part, operating system platforms remained under the control of their original developers, the platform owners. However, a few platform owners (e.g., Geoworks, Montavista, Psion and Palm) sold some of their equity to independent hardware developers. The vertical scope of the platform owners also varied. For example, Palm, Apple (Newton) and Psion (EPOC) conducted their own hardware development alongside independent hardware developers at certain points in their history.

Apart from this shifting concentration of control, outsiders sometimes directly contributed to platforms.

[15] Personal interviews with the CEO, David Nagel, and the Palmsource executive team (2005).

For example, Montavista, EPOC, Palm and Royal all incorporated open source components into their otherwise proprietary platforms. EPOC and Montavista allowed certain key elements of their platforms (notably the graphical user interface and hardware drivers) to be produced by external firms.

Figure 3 summarizes some of the broad categorical distinctions between modes and degrees of openness that could be readily observed in the industry, with examples. Note that within each category of openness, there were also variations of degree. These distinctions are discussed in more detail below.

Figure 3

5. Sample and Data

I hand-collected information on all handheld computer devices released from 1990 to 2004.[16] This period corresponds to the years during which handhelds occupied a distinct niche in the computing industry, as discussed earlier. For each product I recorded the month and year of release, the hardware developer, and the operating system platform. The dependent variable *NEW_DEVICES*, which represents the number of new devices released in a system and month, was constructed from these data. Table 2 provides descriptive statistics and correlations for this and all other variables. (Later I will discuss the distribution of the dependent variable in relation to the econometric approach.)

These data were also used to define the sample. I included only those systems that were active for at least two years during the sample period.[17] There are 21 such systems: Atari ST, Cruise, Cybiko, DOS, EPOC, GEOS, Hewlett Packard, MagicCap, Microsoft Mobile, Montavista Linux, Newton, Norand, Palm, Pen DOS, Pen Windows, PenPoint, PenRight!, REX, RIM, Royal Consumer and Windows. Their data form an unbalanced panel with 1706 system-month observations (an average of 6.8 years per system). Seven of these systems changed their open policy at least once during the sample period. These "switchers" are

[16] The data collection process involved the author and multiple research assistants, and lasted more than 24 months. Product lists, hardware suppliers, and platform suppliers were identified through Internet searches and trade publications. For each product, firm and platform identified, we initiated a more focused effort to collect data on the full range of associated devices (using the same platform, supplied by the same firm, etc.). This process continued until no new platforms, devices or firms could be discovered. The extensive product lists maintained by industry enthusiasts and company officials were particularly helpful in this exercise.

[17] This criterion rejects a number of small, proprietary and clearly unsuccessful systems. Including these systems in the analysis has no perceptible effect on results (not reported), because a time period of less than two years adds no meaningful variation to a regression with fixed effects. Product development cycles in this industry are generally one to two years.

EPOC, Microsoft Mobile, Montavista Linux, Newton, Palm, RIM and Royal Consumer. Switchers account for 541 of the panel data points (6.4 years per system). Table 1 lists and defines all variables used in the following analysis.

Table 1

Table 2

5.1 Measuring Open Policies

The product release data described above were merged with a data set quantifying the openness of company policies over time.

Devolving Platform Control. To measure the extent to which the platform owner gave up control, I collected the equity shares s_k held by independent hardware developers in platform owners, as well as that held by the platform owner itself.[18] These data were collected by reading through the entire history of platform owner press releases. The shares are combined into a single Hirschman-Herfindahl-style measure as follows:[19]

$$PLATFORM\_CONTROL\_HHI = 1 - \sum_k s_k^2$$

This formula results in a measure that increases with openness. When no equity is held by outsiders, *PLATFORM_CONTROL_HHI* is zero; for very diffuse ownership the measure approaches one. To provide a cruder, categorical measure, the indicator variable *PLATFORM_CONTROL* is set to one when *any* equity was shared.

To supplement the two measures of control, *PLATFORM_DISINTEGRATION* is an indicator variable set to one when the platform owner was disintegrated from hardware development and hardware was opened to outsiders (i.e., the platform owner did not continue developing hardware alongside outsiders). Shifts in vertical integration policy were widely publicized in the industry, so could easily be identified through press releases and secondary sources.

[18]For, example, in a case where 10% equity is devolved to one hardware developer and 5% to another, the shares would be 10%, 5% and 85%.

[19]I thank a referee for this helpful suggestion.

PLATFORM_CONTRIBUTIONS captures instances in which outsiders were involved in developing the platform itself. This indicator variable was set to one when outsiders contributed to the graphical user interface, the operating system kernel, or the platform's "drivers" (software used to control analog components in a device) (Section 4.1). Within the sample period, Montavista Linux, Royal and EPOC opened their platforms in this manner, but only the latter two switched policies. Constructing this variable involved reading annual reports and 10-k filings, and reviewing monthly articles citing relevant companies in Factiva (a database carrying hundreds of periodicals). This process did not uncover any policy changes that were not already widely known in the industry.

Granting Access to Complementary Development. The variable requiring the greatest effort and care to construct was that measuring the liberalness with which platform owners licensed complementary hardware developers. Research into the industry revealed vast differences in the firms' approaches to licensing. I divided the policies into four broad and logically distinct categories: (0) outright exclusion of outsiders from complementary development; (1) restriction of licenses to a small number of outsiders, and also restriction of development to specific niche applications and markets;[20] (2) restriction of the number of licenses, but no restriction on the application or market; and (3) indiscriminate licensing to all comers. The variable *COMPLEMENT_ACCESS_DEGREE* takes on one of these four values—0, 1, 2 or 3—to describe each company's category at any given time. This variable was constructed through a detailed review of press releases by platform owners and all articles in Factiva mentioning one of the platforms. Financial records (10-k filings) and websites devoted to the industry (e.g., Brighthand.com) helped by providing supplemental and corroborating information. To validate the measure, I conducted in-person and phone interviews with Palm's top-level executives in 2005, including its CEO. I also spoke with multiple vice-presidents and directors at Psion and Symbian, and several industry analysts. These experts were able to corroborate the measure for other platforms. This research uncovered no patterns that were not already somewhat well known in the industry.[21]

COMPLEMENT_IP is an indicator variable set to one when IP was shared with outsiders in the form of reference designs. This variable was constructed from announcements of the availability of reference designs appearing in company press releases.

[20]For example, in addition to the mainstream devices used for personal contacts, calendars, and productivity applications, there were also devices intended for retail, commercial, or industrial applications (real estate, medical, etc.); devices specialized in games; devices tailored to low-end/low-price users; and devices intended to be used by students.

[21]I also confirmed that *COMPLEMENT_ACCESS_DEGREE* is strongly correlated with the number of complementors, controlling for system fixed effects, covariates, and time trends.

5.2 System Covariates and Controls

Additional variables were constructed to control for time-varying system, platform, and platform owner characteristics. Annual sales estimates (total units) from 1990 to 1995 were provided by the market analyst firm IDC from its archives. Estimates for later years were provided by Gartner Dataquest.[22] Total units sales figures for each system, *SYSTEM_SALES*, were used to calculate market share and growth, *SYSTEM_SHARE* and *SYSTEM_GROWTH*. *SYSTEM_AGE* is the number of months since the initial launch of a system. The R&D expenditures of platform owners, *PLATFORM_R&D*, were collected from COMPUSTAT. These data were available for the firms EPOC, Microsoft Mobile, Newton, Palm and RIM.[23] These R&D data cover all of the company's activities, and therefore reflect the overall strength and scale of the company rather than its investment in the handheld operating system platform. For these same systems, I determined which versions of the platform were available at each point in time (version/release numbers such as 1.0, 2.0, and 2.1[24]). The variable *PLATFORM_VERSION* is simply the decimal number corresponding to the version; major changes are reflected by increasing the first digit, and minor changes by increasing decimal values.[25] These data were hand-collected from sources similar to those used for the hardware release data. While *PLATFORM_VERSION* is an imperfect measure of platform performance, it is monotonically related to advancements in the platform.

6. Econometric Approach

The goal of the analysis is to characterize the reduced-form relationship between the observed rates of new device development and alternative measures of openness in company policies, using a count data panel framework. A range of considerations justify this modeling and measurement approach.

Given the industry's emphasis on generating a steady stream of novel and improved devices (Section 4), the analysis focuses on product innovations rather than cost or process improvements.[26] However, modeling

[22]Sales figures were available in annual increments, but all other data were monthly. Neither smoothing the annual data to monthly increments nor adding individual month dummies affected the results reported in this paper.

[23]Given the ownership changes at Palm, this meant piecing together data from US Robotics, 3COM and Palmsource (an independent spin-off). Psion owned the largest share of EPOC throughout the sample period.

[24]For example, Palm OS 1.0 was the original version. Palm 2.0, introduced roughly a year later, added networking capabilities (a TCP/IP "stack") and support for a back-lit screen. It also removed minor bugs from the earlier version. Incremental improvements were added in "decimal place" versions; for example, the update from version 3.2 to 3.3 added faster PC synchronization and the ability to do infrared synchronization between devices or with a PC.

[25]There are no two-digit sub-versions.

[26]In any case, the industry's widespread use of outsourced, specialized device manufacturers, particularly from Asia, led to relatively uniform production costs.

and measuring the stream of innovations presents signficant challenges. Handheld devices can be understood as bundles of attributes, any of which could have improved from one release to the next. Some innovations consisted of incremental advances in known and quantifiable dimensions (e.g., physical volume) or widening variety and functions (e.g., a rugged version intended for industrial applications). Other dimensions were rather intangible (e.g., "elegance of design") or added inobvious and unforeseen functions (e.g., a jog-dial control for selecting applications)—effectively expanding the definition of the product space. Devices also often embodied new combinations of existing performance attributes. In many cases, an innovation's value would become known only *ex post* (sometimes after considerable time had passed, when the new advance or feature was sufficiently refined by its originator or perhaps by another developer). Nonetheless, even failed experiments in innovating new devices generated useful lessons on consumer preferences and technical possibilities.

These innovation characteristics limit the usefulness of several modeling and measurement approaches. For example, modeling innovation as an endogenous product entry and positioning choice would provide a precise structural interpretation, but conflicts with the expanding (*ex ante* unknown) product space. Further, it is difficult to specify a reasonable hypothesis for the driving mechanisms *a priori* (cf. Sections 3 and 8). Using a sort of hedonic measure, or even simply distinguishing between "major" and "minor" innovations, are approaches that suffer from similar limitations as well as presuming a correspondence between *ex post* and *ex ante* valuations. To overcome these obstacles one might take a purely supply-side view of innovation, modeling individual dimensions of the multi-dimensional technical frontier without regard to *ex post* valuation. However, this approach relies on complex econometric modeling and data manipulation techniques that may obscure the basic patterns in the data.[27]

Bearing these challenges in mind, I adopt a modeling and measurement approach that is transparent and faithful to the nature of innovation during the sample period. I simply model the rate of new device releases in each system to assess how openness affected the *stream* of new development.[28] Of course, development rates are not always comparable across systems and platform suppliers. The panel data framework meaningfully assesses whether period-to-period changes in openness policies are systematically related to shifts in development rates over time, *within a given system*. While this approach might not recognize the development of a truly one-of-a-kind device, it is useful in estimating the regular and systematic relationships that

[27] Boudreau (2007) explored this approach in an earlier working paper. The results are consistent with those presented here.

[28] A detailed examination of products in leading systems found that almost all devices possessed some form of improvement in existing characteristics, a novel feature, or new combination of existing features and functions.

are the focus of this study (Section 3.3).

6.1 The Model

$NEW\_DEVICES_{it}$ denotes the number of new devices in system i in month t. O_{it} denotes a vector of measures describing the openness of system i in month t. The unknown partial relationship between the dependent variable and openness, theorized in earlier discussion, is given by the function $g(\cdot)$. Multiple specifications of $g(\cdot)$ will be assessed in the following analysis. The expected count of new devices is presumed to depend upon a number of factors, including openness:

$$E[NEW\_DEVICES_{it}] = \eta_i \cdot exp\{g(O_{it}) + \beta \cdot X_{it} + \delta_t\}. \tag{1}$$

X_{it} is a vector of time-varying system characteristics, η_i denotes multiplicative system fixed effects, δ_t denotes additive time dummies, and β is a vector of parameters. The exponential relationship in expression 1 is consistent with *NEW_DEVICES* taking only non-negative values. I model the process generating monthly counts for *NEW_DEVICES* as a Poisson distribution (Cameron and Trivedi 1998). As clarified by Wooldridge (1999), a Poisson fixed effects model with heteroskedasticity-autocorrelation robust standard errors provides stable, consistent estimates under a range of distributions for the dependent variable. (Wooldridge refers to "distribution-free" estimates.)[29]

6.2 Endogeneity of Open Policies

Open policies are endogenous, in that they are *decisions* made by platform owners.[30] A naïve regression of development rates on openness measures may therefore result in biased estimates, as I will explain below. An ideal natural experiment would i) shock the vector of openness measures, and ii) do so in a manner unrelated to the dependent variable. For statistical purposes, the shocks would also have to iii) explain a relatively large fraction of period-to-period variation. Finally, given the focus of this paper, we would want this shock to iv) result in independent and orthogonal changes in the different measures of open policies. No natural experiment fulfills all these requirements in this context. The approach I take is therefore to simply

[29] I explicitly assessed the robustness of results in relation to this point. The dependent variable appears to have more zeroes than a Poisson distribution (a result of relatively fine-grained monthly observations). Thus, I created a "zero-inflated" model by supplementing the Poisson model with a binary process. The binary process is also a function of the system covariates included in the main model. The coefficients remain statistically significant and unchanged, despite larger standard errors.

[30] In perhaps the starkest example of endogenous responses, both Psion and Palm (in separate incidents) changed their openness policies following a decline in market share. While there were differences in the extent, timing and approach of this action, taken in a context of considerable uncertainty, both companies made essentially the same decision. Boudreau (2006) documents shifts in open strategies and their rationales in more detail.

add controls for potential sources of endogeneity bias. The variation exploited to estimate coefficients on open policy variables is therefore the system-specific, period-to-period changes that are not explained by the vector of system covariates (X_{it}).[31] The discussion to follow identifies potential sources of bias and describes how these are addressed using control variables.

Unobserved Variation in System, Platform and Platform-Owner Characteristics. A most basic concern is that some changes in system (or platform, or platform owner) characteristics may have been omitted from the model. The presence of unobserved variation should not be a concern on its own; but the model coefficients will be biased if the unobserved characteristics are correlated with *both* open policies *and* development rates. For example, companies whose systems were in a weaker market position, perhaps with less innovation, might have been more willing to open (cf. Parker and Van Alstyne 2008). Thus, it is important to control for system-specific changes in market demand and competitive position, as I do with *SYSTEM_SALES*, *SYSTEM_SHARE* and *SYSTEM_GROWTH*. A platform owner might also be more inclined to open if it is not able to keep up with innovation on its own (Gawer and Henderson 2007). This is the rationale behind including the control *PLATFORM_R&D*, which indicates the company's overall resources and capacity for innovation. *SYSTEM_AGE* and *SYSTEM_SALES* should also serve as helpful proxies for relevant resources. As a means of assessing whether changes in the technology of the platform somehow influenced both innovation and openness, I introduce a measure of platform advances, *PLATFORM_VERSION*. *SYSTEM_AGE* should also partly control for evolving characteristics. All system covariates are lagged to avoid the most obvious forms of bias.[32]

Non-Independence and Asymmetric Interactions across Systems. If opening affected the intensity of inter-system competition (e.g., Matutes and Regibeau 1988; Tag 2008) or if inter-system competition created strategic motivations for opening and closing (e.g., Eisenmann et al. 2009, Nahm 2004), then inter-system competition could lead to spurious correlations and biased coefficients. Time controls address general changes across the industry, but do not address asymmetric responses across systems in different market positions or with different characteristics (cf. Casadesus-Masanell and Ghemawat 2006; Economides and Katsamakas 2006). In relation to competition in the consumer market for devices, I include the aforemen-

[31] Past research on handheld computing in this era reports patterns consistent with abundant exploitable random variation in important policy variables (apart from any endogeneous variation). Changes to openness policies were often clumsy, blunt, ill-timed, made in an uncertain environment, and lacked management team consensus. After the fact, they were often believed to be ill-advised (Boudreau 2006, Butters and Pogue 2002, Casadesus-Masanell et al. 2008, Kaplan 1996).

[32] For example, without lagging *SYSTEM_SALES*, the coefficient estimate would measure how much a new release directly expands the market rather than the other way around.

tioned *SYSTEM_SHARE* as a control. In relation to interactions in the "market" of potential complementors (cf. Huang et al. 2009, Venkatraman and Lee 2004), I investigate this possibility using a measure of the company's response to other companies' licensing policies: the average value of *LIBERAL_LICENSING* for all *other* systems.[33] (I only include switchers in constructing this measure, given that they are the sole source of variation.)

Apart from observable licensing policies, we might also worry about unobservable price-setting competition in licensing. Here I appeal to my interviews with third-party industry watchers and top-level managers, who uniformly reported that pricing policies changed very little over the sample period. License prices hovered around $10 per unit for nearly all companies, with a slightly downward trend. There were no overt price shocks or attempts to undercut competing platforms. An exception was the high price charged by Microsoft just after the launch of its Windows CE platform (roughly $40 per unit). This pricing model was close to its practices in personal computing. Microsoft quickly adjusted its policies to conform to handheld computing norms. Dummying out these early years of Microsoft's history has no effect on the results.[34]

Reverse Causality. In addition to open policies affecting development, the state of technology might have affected open policies. For example, past innovation may exhaust opportunities at the frontier, affecting returns to both innovation and opening (cf. Parker and Van Alstyne 2008). None of the control variables discussed so far can deal fully with this concern. In relation to the particular concern of spurious correlation associated with an exhausted frontier, *SYSTEM_AGE* might partially attend to the resulting bias. Providing further assurance, analyses by Boudreau (2007) and Chwelos et al. (2004) suggest that technical advances continued unabated during the sample period without any indication that technical opportunities were being exhausted. In a subsample of systems, I also found no statistical correlation between openness measures and lagged measures of the advancing technical frontier (RAM, processor speed, the number of novel features) after controlling for the time trend. Taken together, these points provide a strong indication (albeit not unequivocal proof) that reverse causality does not unduly influence the coefficient estimates.

Broader Industry Change. In a dynamic industry such as this one, we might also be concerned that long-term evolution could impact the relationships being studied. I estimate the model in pre-1996 and

[33]Fortunately for this analysis, during the sample period platform owners did not routinely attempt to "steal" device developers from each other. Efforts to attract complementors largely consisted of persuading computer and electronics manufacturers to enter into handheld computers for the first time.

[34]My conversations with industry executives and analysts suggest a widespread belief among platform owners that any sudden changes or perceived unfairness (gouging) in license prices would have dissuaded new developers from joining their platforms and might have caused the commitment of existing licensees to falter.

post-1996 subsamples (bracketing the emergence of the iconic Palm Pilot in 1996), and find no significant difference in the coefficients.[35]

6.3 Comparing Switchers with Non-Switchers

In estimating $g(\cdot)$, the model would ideally compare the observed development rates after a change in open policy to *what would have happened had a change not taken place*—the "counterfactual". Ideally, we would observe the counterfactual case along with the actual change in policy; $g(\cdot)$ could then be directly measured by comparing the outcomes. However, in naturally occurring data, the counterfactual is not observed and must be approximated. As shown in expression 1, it is approximated by adding the general time trend during the period of a switch to the fixed effects of the switcher, while correcting for the vector of system covariates.[36] These estimates are based on coefficients estimated with variation across the entire sample, including those systems that never changed their policies (the non-switchers). The problem of estimating counterfactuals is not unique to my analysis.[37] However, because switchers represent just one-third of the sample, we should ask whether non-switchers provide a useful basis of comparison when we estimate the counterfactual.

To the extent that switchers resemble non-switchers in observable characteristics, we need not rely on the model to correct for systematic differences. However, in the data analyzed here, there are clear differences between switchers and non-switchers. The systems that never switched include several relatively successful platforms such as Rex and Windows, but the majority were smaller, short-lived platforms that released fewer products.[38] Trying to using matching procedures to systematically compare similar switchers and

[35]Uncertainty may have produced non-random patterns of behavior when companies tried to improve their open policies. For example, platform owners experiencing poor performance might have been more inclined to experiment with alternative policies. If on average such experimentation led to more (less) successful strategies, we would expect less (more) residual variation among observations of low development rates. Whatever the pattern, this effect is a question of heteroskedasticity rather than endogeneity bias, and is dealt with by estimating robust standard errors.

[36]The points raised in Section 6.3 relate in subtle ways to those in Section 6.2. In principle, if the counterfactual were perfectly estimated, there would be no endogeneity bias associated with omitted variables. However, the converse is not necessary true: dealing with endogeneity concerns (in the sense of isolating some exogenous sources of variation using explanatory variables) does not ensure that a relevant econometric comparison is being made.

[37]A typical multiple regression analysis implicitly makes comparisons across the sample, relying on some combination of the following assumptions: i) the sample itself serves as a meaningful comparison group for each data point; ii) changes in the explanatory variables are randomly distributed across the sample, so *on average* the sample provides a relevant comparison; and iii) the control variables correct for any systematic differences. The comparisons are starker in one-time policy shock studies, where estimation of the counterfactual relies heavily on a comparison group of non-switchers (e.g., Murray et al. 2009). Roughly speaking, this study lies somewhere between these two cases. We have multiple switches in each explanatory variable, but also a clear distinction between switchers and non-switchers.

[38]Switchers sold about twice as many units as non-switchers (626 thousand versus 335 thousand per year, on average) and their development rate was about twice that of non-switchers (.92 versus .48 devices per month, on average). They were also somewhat longer-lived (106.5 versus 74.2 months in the data set, on average).

non-switchers would do more to complicate and obfuscate than to clarify and convince; there are just 21 systems in the sample, some of which switched multiple times, and there are few natural matches between switchers and non-switchers.

Fortunately, the analysis does not depend on non-switchers being exactly the *same* as switchers. The exponential form of expression 1 implies that non-switchers need to provide an unbiased estimate of deviations in the log transform of the dependent variable (something close to a percentage change from the mean values), while accounting for control variables. Given this criterion, it is enough to cautiously assess whether non-switchers *as a group* provide a meaningful comparison for switchers (instead of distorting the estimates by introducing irrelevant comparisons). The approach I take (Section 7.3) is to show that 1) there are no statistical differences in the trending of switchers and non-switchers prior to switches, and 2) the results hold when running regressions on the subsample of switchers (disregarding non-switchers altogether).

7. Results

The results are divided into two main sets, followed by robustness checks. The first set of models relates to discrete policy changes between open and closed strategies. The second set analyzes graduated and continuous shifts in the degree of openness. The unit of observation in all regressions is the system-month.

7.1 The Discrete Decision to Open or Close

This subsection analyzes whether device development rates systematically changed after discrete changes between open and closed policies. Here, I model $g(\cdot)$ of expression (1) with indicator variables for opening the platform and complementary hardware, $g \equiv \beta_1 OPEN\_COMPLEMENT_{it} + \beta_2 OPEN\_PLATFORM_{it}$. (The variable *OPEN_COMPLEMENT* is zero if *COMPLEMENT_ACCESS_DEGREE*=0, and one otherwise.) These changes can be understood as a system moving out of the bottom row or left-hand column of Figure 3. Palm, Psion, RIM and Royal shifted in this manner during the sample period.[39] The coefficients of these indicators can be directly interpreted as the mean changes in log development rates associated with discrete changes in openness policies. The results suggest a strong positive relationship between development rates and opening complementary hardware, but a much weaker relationship with opening the platform (Table 3). All results are based on fixed-effect Poisson models with heteroskedasticity-autocorrelation robust standard errors (Wooldridge 1999).

[39] Other "switcher" systems in the sample varied their open policy, but only as a matter of degree.

Model (3-1) simply controls for cross-sectional heterogeneity with fixed effects.[40] The coefficient on *OPEN_COMPLEMENT* is positive and statistically significant, indicating that development rates were higher during periods of open hardware development. The coefficient on *OPEN_PLATFORM* is not statistically distinguishable from zero.[41]

Table 3

Model (3-2) adds year dummies to control for secular trends and general shocks affecting all systems. These controls are jointly and individually significant, and result in smaller standard errors on the openness variables. The coefficient of *OPEN_COMPLEMENT* remains positive, significant and almost unchanged; the coefficient of *OPEN_PLATFORM* becomes positive but remains statistically indistinguishable from zero. Therefore, while industry development rates changed over time, the similarity of models (3-1) and (3-2) suggests that this trend was statistically orthogonal to general industry shifts in open policies.[42]

Next, I add system covariates (*SYSTEM_SALES*, *SYSTEM_SHARE*, *SYSTEM_GROWTH* and *SYSTEM_AGE*). As reported in model (3-3), the coefficients of *SYSTEM_SHARE* and *SYSTEM_GROWTH* are negative. The coefficient of *SYSTEM_SALES* is positive. Only the coefficient of *SYSTEM_SHARE* is significant in model (3-3), but the significance and signs of these three coefficients are sensitive to the inclusion or exclusion of particular system controls. (The three variables are closely related and collinear.) In model (3-3), the negative sign on *SYSTEM_SHARE* might plausibly be associated with a tendency for platform owners in widely adopted systems to pursue more conservative development strategies. On the other hand, the coefficient might be picking up a strong second-order effect related to sales. While it is difficult to interpret the signs on these control variables, controlling for these sources of system-specific variation does not change the main finding—apart from making the coefficient of *OPEN_PLATFORM* slightly more positive.

[40] Wald chi-squared tests are significant at $p = 1\%$ for all reported models.

[41] Controlling for cross-sectional differences has an important impact on estimates. Not doing so leads to a significantly negative coefficient on *OPEN_PLATFORM* (-0.59; $p = 0.01$). As a simple descriptive correlation, this implies that systems with low development rates were more likely to open the platform, consistent with the idea that weaker platform owners were more willing to open (Section 6.1). The coefficient on *OPEN_COMPLEMENT* is larger when not controlling for cross-sectional heterogeneity.

[42] This is not very surprising, given that the simple correlations between open policies and development rates (Table 2) are not strong. Also underlining this point, the openness coefficients are insensitive to alternative specifications of the time trend (linear, quadratic, or individual dummies for each month in the sample).

7.2 Degrees and Modes of Openness

This second set of regressions measures the relationship between device development rates and varying degrees and modes of openness. The analysis exploits all switchers in the sample: EPOC, Microsoft Mobile, Montavista Linux, Newton, Palm, RIM and Royal Consumer. Broadly speaking, I find a strong inverted-U relationship between development rates and the degree to which complementary hardware was opened. I also find a much smaller positive relationship with opening the platform. The results are presented in Table 4.[43]

Model (4-1) follows model (3-3), but replaces the discrete measures of openness with more nuanced measures. Recall that together *OPEN_COMPLEMENT* and *COMPLEMENT_IP* distinguish an open policy that grants licenses to outside developers from a policy that also shares IP with licensed complementors. *PLATFORM_CONTROL* and *PLATFORM_CONTRIBUTIONS* distinguish two forms of platform openness: one where complementors hold equity ownership in the platform, and one in which outsiders contributed to the development of the platform.[44] These four measures cover the main distinctions that appeared in this industry, as was illustrated in Figure 3.

In model (4-1), the coefficient of *OPEN_COMPLEMENT* is positive, significant and large. The coefficients of the three other measures of openness are also positive, but much smaller and statistically insignificant. These results again suggest that while the effect of opening the platform was small, the effect of opening the complement was large and mostly related to granting access.

Table 4

To more closely study the relationship with *OPEN_COMPLEMENT*, which is clearly the most important variable, model (4-2) introduces a four-level measure of liberalness: *COMPLEMENT_ACCESS_DEGREE*.[45] (Recall that this variable ranges from complete exclusion of outsiders to liberal licensing of all comers, intermediate levels indicating some restrictiveness.) The variable is incorporated in a flexible manner, as four individual indicator variables. Therefore, the model estimates (additive) differences in the expected mean of the dependent variable associated with given levels of *COMPLEMENT_ACCESS_DEGREE*.

[43] For simplicity, the coefficients of system covariates are not reported.

[44] During the sample period, *OPEN_COMPLEMENT* changed in Psion, Palm and RIM; *COMPLEMENT_IP* changed in Microsoft and RIM; *PLATFORM_CONTROL* changed in Psion, Montavista and Palm; and *PLATFORM_CONTRIBUTIONS* changed in Psion and Royal Consumer.

[45] Within the sample period, *COMPLEMENT_ACCESS_DEGREE* changes multiple times in Psion, Microsoft, Newton, Palm and RIM—with relatively even coverage of different levels of this variable.

As reported in model (4-3), the coefficients of different levels of *COMPLEMENT_ACCESS_DEGREE* trace out an inverted-U relationship. The coefficients of *COMPLEMENT_IP, PLATFORM_CONTROL* and *PLATFORM_CONTRIBUTIONS* remain positive but insignificant in this model.

To explicitly test whether the highest development rates occurred at an intermediate level of *COMPLEMENT_ACCESS_DEGREE*, I re-ran the model after excluding the indicator variable with the largest coefficient (*COMPLEMENT_ACCESS_DEGREE* = 2). The relationship will be confirmed if deviations from the peak (i.e., *COMPLEMENT_ACCESS_DEGREE* = 1 and 3) have significant negative effects on the dependent variable. This is indeed the case; as reported in model (4-3), the deviation is significant at $p = 10\%$ for *COMPLEMENT_ACCESS_DEGREE* = 1 and at $p = 5\%$ for *COMPLEMENT_ACCESS_DEGREE* = 3. The joint probability that both levels are equivalent to the peak is of course more significant, at $p = 1\%$. Therefore, the relationship between development rates and *COMPLEMENT_ACCESS_DEGREE* is non-monotonic.

Given the literature's considerable emphasis on opening the platform (Section 3.2), it is perhaps surprising to find that platform-related variables have only a faint relationship with the rate of innovation. To ensure that this trend is not a statistical aberration, the result of limited variation, or somehow related to imperfect measures, I investigate several alternative variables related to platform openness. I begin by introducing a continuous variable, the Herfindahl-style measure of platform ownership *PLATFORM_CONTROL_HHI*.[46] As reported in model (4-4), this is the only instance where the coefficient of an open platform variable is negative.

Next I introduce a measure of the platform owner's participation in hardware development: *PLATFORM_ DISINTEGRATION*.[47] This indicator is set to one when the platform owner does *not* participate in hardware development alongside independent outsiders (Section 5.1). As reported in model (4-5), the coefficient of this variable is positive, small, and insignificant. Summing the variables *PLATFORM_CONTROL* and *PLATFORM_CONTRIBUTIONS* creates a new variable with similar meaning, but one which allows us to exploit more variation. As reported in model (4-6), running the model with this measure of platform openness also generates a positive coefficient, but the coefficient is neither larger in magnitude nor more statistically significant. Given that the model is now quite a bit different from model (3-3), in model (4-7) I try re-introducing the simple, discrete measure *OPEN_PLATFORM*. Once again, I find a small, positive,

[46] During the sample period, *PLATFORM_CONTROL_HHI* changed in Psion, Montavista and Palm.
[47] During the sample period, *PLATFORM_DISINTEGRATION* changed in Psion and Palm.

and insignificant relationship. Given that the coefficients of this model are slightly more significant (they have smaller standard errors compared to model (4-2)), I choose to regard (4-7) as the preferred model.[48]

Finally, given the consistently positive relationships with various measures of platform openness, I consider whether statistical significance might instead be attained by reducing the standard errors with additional controls. In model (4-8), I investigate this possibility by including the remaining system covariates (*PLATFORM_RD* and *PLATFORM_VERSION*). Introducing these variables also reduces the sample to a subset that includes just switchers; these variables were collected only for some systems, as explained in Section 5.2. The basic pattern of relationships between development rates and openness measures is unchanged. However, the significance of the coefficient of *OPEN_PLATFORM* increases slightly to $p = 15\%$. As for the control variables, the coefficient of *PLATFORM_RD* is negative and highly significant. This is consistent with the idea that successful (resource-rich) companies tended to pursue more conservative development strategies, and perhaps with a number of alternative explanations. The coefficient of *PLATFORM_VERSION* is insignificant. Any effect of version numbers may have been absorbed, at least in part, by other model controls.

Figure 4 summarizes the incidence rate ratios implied by the coefficient estimates of model (4-7). This is regarded as the preferred model, because it uses the entire sample and because it has slightly smaller standard errors than model (4-8). Opening complementary hardware had the strongest relationship with innovation rates, peaking at intermediate levels of openness ($COMPLEMENT\_ACCESS = 2$). This policy was associated with a factor of 4.6 acceleration in the innovation rate. Sharing IP in this context increased the innovation rate by another 16%. Opening the platform implied an increase of 22%. The latter two effects are statistically insignificant in the preferred model. However, I still judge them to be meaningful because their signs and magnitudes were consistent across many specifications and because both coefficients are significant in at least some specifications (see Table 4 and Table 5).

Figure 4

[48] I also tested the interaction of *PLATFORM_CONTROL* and *OPEN_COMPLEMENT*, but found no statistically significant effect.

7.3 Robustness Tests

There remain several possible sources of bias in the model coefficients and alternative explanations of the results, as discussed in Sections 6.2 and 6.3. Their corresponding robustness tests are reported in Table 5. The first concern is that some omitted, unobserved variable partially accounts for the changing characteristics of platforms, platform owners and systems. Model (4-8) already shows that adding controls for R&D expenditure and platform version (along with controls for sales, growth, share, age and fixed effects) did not change results. In model (5-1) I check for a bias arising from possible asymmetric interactions in licensing policies by introducing a measure of *other* systems' open policies (Section 6.2 describes the variable). Adding this variable has no impact on the results. As there may be a delay in responding to competitors' licensing policies, I repeated this test for various lags. Of course, one can never rule out the possibility of omitted variables simply by adding more controls, but the large number of controls, the clear importance of the controls that are included, and the stability of the model coefficients under various specifications provide reassurance that the estimates are meaningful.

To assess the stability of the relationships over time, I ran model (4-7) on pre- and post-1996 subsamples. Model (5-2) reports results for the post-1996 period (i.e., 1997 to 2004). The basic patterns are unchanged, but the significance of some coefficients increases—most noticeably for *OPEN_PLATFORM*.[49] There is insufficient variation in the key variables pre-1996 to estimate coefficients, even after simplifying the model. Thus, it is not possible to verify whether the relationships were different in this earlier period. To more stringently assess whether general time trends may have resulted in biased coefficients, I apply 180 individual month dummies rather than the 15 individual year dummies used in the main regressions. The coefficient estimates, presented in model (5-3), confirm the same patterns.[50]

Table 5

Comparing Switchers and Non-Switchers. As discussed in Section 6.3, we need to ensure that non-switchers provide a meaningful basis of comparison for switchers and for estimating the counterfactual. One way to assess this possibility is to re-run the model using only data on switchers. In fact, this was

[49] I do not regard this regression as preferred, despite its higher significance, as there is no strong justification for throwing out earlier data and the overall goodness of fit decreases.

[50] Model (5-3) is estimated with additive fixed effects—a series of dummies—rather than the multiplicative fixed effects described in expression 1. The full model with multiplicative fixed effects fails to produce coefficient estimates. The model with multiplicative fixed effects and individual time dummies, but dropping the system covariates, successfully estimates coefficients and corroborates the patterns.

already done in model (4-8), with no change in the estimated coefficients. (The inclusion of additional system covariates narrowed the sample to several leading systems, all switchers.)

A second way to address this point is by testing whether switchers and non-switchers followed a similar trend prior to a switch. A challenge of this analysis is to avoid conflating the pre-switch period with the post-switch period in cases where firms switched more than once. I first implement this idea over a short period of time, introducing a "pre-switch" month indicator that is set to one for switchers in the month prior to a switch. This variable allows us to infer whether there is a statistical difference in the trending of switchers (in relation to the rest of the sample) just prior to a switch. As reported in model (5-4), this dummy's coefficient is indistinguishable from zero. Model (5-5) applies the same test for discrete changes of openness (i.e., model (3-3) with an added pre-switch month indicator). Again, the pre-switch month indicator is insignificant.[51]

Comparing pre-switch and post-switch trends in relation to discrete policy changes better avoids the problem of conflating pre-switch trends of one change with the post-switch trends of a preceding change. Therefore, I again estimate the discrete model (3-3) with a longer sample of pre-switch time trends by focusing on an important variable that switches at most once in any system: *OPEN_COMPLEMENT*. In this case, I can use the *entire* pre-switch trend of each platform, and this period should provide a meaningful comparison of how switchers and non-switchers trended.

Ideally, I would be able to examine independent time dummies for switchers and non-switchers. However, to avoid inflating the number of degrees of freedom, I instead estimate independent time trends for switchers and non-switchers, before and after policy changes. To ensure that the parametric form of the model does not artificially constrain or distort the estimated curves, I also investigated non-linear specifications (polynomial, log and exponential) for both the general time trend and the trend for switchers. As these differ very little from the linear specification, I simply report the results of the linear specification. Figure 5 presents the difference in trending between switchers and non-switchers, in periods before and after a switch.[52] The results are presented in terms of the incidence rate ratio (a ratio of one indicates no

[51] If I redefine the pre-switch indicator so that it covers *all* time periods prior to a given switch and following any prior switches in the sample, I obtain similar results.

[52] The results summarized in Figure 5 are based on coefficient estimates obtained after adding two distinct time trends for switchers, each dependent on the number of months prior to or following a switch. Formally, we added the following terms to model (3-3): $I\{switcher, before\} \cdot (\alpha_1 + \alpha_2 \times No. Months Before\, a\, switch) + I\{switcher, after\} \cdot (\alpha_3 + \alpha_4 \times No. Months Following\, a\, switch)$. The fixed difference between switchers and non-switchers prior to a switch (α_1) drops out, as this term is redundant with the system fixed effects. The coefficient of the pre-switch (differential) time trend of switchers (α_2) is small (0.007) and insignificant. The post-switch time trend (α_4) is roughly three times larger (0.022) and significant at $p = 1\%$. The intercept, or fixed difference between switchers and non-switchers after a switch (α_3), is 0.58. This coefficient is also significant at $p = 1\%$.

difference). This test again supports the assumption that non-switchers serve as a meaningful comparison group, as there is no statistical (or even substantive) difference in the pre-switch trends of switchers and non-switchers.[53]

Figure 5

8. Discussion and Interpretation of the Estimated Patterns

The main task of this paper has been accomplished in showing a stark difference in the development rates of systems that opened their platform and those that opened to complementary development, compared to each other and to systems that did not switch their policy during the sample period. These patterns are consistent with the idea that different mechanisms are set in motion by alternative modes and degrees of openness. I reflect more on this general point in the Conclusion. Here, I comment on the specific patterns revealed by the models.

Granting Access to Independent Developers of Complementary Hardware. By far the largest effect (associated with a development rate up to 4.6 times faster than the system's preceding closed policy) is the inverted-U relationship between innovation and the level of access granted through licensing to complementary developers. This pattern might also be the most difficult to interpret. There are any number of plausible explanations for a non-monotonic relationship with widening access. Plausible factors include strategic interactions and spillovers among complementors, transaction and coordination costs between the platform owner and complementors, and the diversity of suppliers.

Indeed, an earlier historical account of the handheld computing industry (Boudreau 2006, Ch. 2) suggests that a combination of these factors might have been at work. Granting access to outsiders clearly introduced heterogeneous skills and experience to this industry. Mobile phone makers, low-cost consumer electronics manufacturers, and even health and real estate specialists entered the industry. Each complementor produced hardware directly related to its past experience in production and development. In interviews,

[53]While the pre-switch trend provides a relatively direct comparison of switchers and non-switchers, it is more difficult to interpret the post-switch trend in Figure 5. This is because the post-switch trend is also influenced by shifts in the degree of openness and other measures not captured by *COMPLEMENT_ACCESS_DEGREE*. However, against the possibility that the upward sloping line in Figure 5 reflects some true post-switch "take off", I verified that the inverted-U relationship in the degree of openness to complementors was robust to including a control for the number of months following a switch.

executives of platform vendors also described their belief at the time that opening up hardware development could establish a platform as an industry standard—consistent with an interpretation that emphasizes network effects and agglomeration economies. However, subsequent research and experience challenge this idea; network effects do not appear to have been very important in hardware development.[54] Strategic interactions and competition among the hardware suppliers also clearly played a role.

Perhaps the most well-known example illustrating this point is that of Palm, Sony and Handspring. All three produced hardware devices on the Palm OS platform. In a sense, they depended on one anothers' success to demonstrate the viability and success of the platform. Their products were differentiated in industrial design, certain applications, multi-media and communications ports, aesthetics, brand, and price point. Nonetheless, they were pursuing the same mainstream consumers and thus directly competed for market share (Boudreau 2006).

Anecdotal histories from the industry also highlight the considerable costs associated with supporting and coordinating a network of external hardware developers. These networks involved not just mundane investment and engineering resources, but also disagreements and conflicts between platform owners and complementors. Therefore, it is not possible to confirm a particular interpretation of the inverted-U relationship using historical evidence or the results of this study. The evidence suggests that multiple mechanisms may have played a role.

The positive relationship between innovation rates and sharing IP with complementors (a 16% increase) through reference designs is consistent with the simple idea of lowering entry barriers in hardware development. It is also consistent with a historical trend of growing interest in and incidence of reference designs over the sample period (and afterwards). However, great caution should be taken in interpreting this particular pattern, for several reasons. First, reference designs only appeared towards the end of the sample period; the 16% estimate therefore only hints at an unobserved long-term trend. Further, insofar as the effects of granting access are not fully understood (see above), the effects of lowering entry barriers should be less clear still. The 16% increase in device development rates associated with this policy might also be associated with less differentiated designs (i.e., slightly more standardized, and plausibly less innovative), as might be expected when developers worked from the same reference design. Perhaps the most important caveat is that the reference design policy was associated with shifting production and design overseas to

[54] Research on network effects in this industry has instead focused on third-party software applications development (McGahan et al. 1997; Nair et al. 2004). The current-day example of the iPod and iPhone, offered by a single supplier (Apple), underlines the point that having a great many hardware developers is not necessary for the success of a platform and system.

Asian manufacturers. Thus, the short-term trend in new product introductions may not fully signal more profound changes associated with the global (re)distribution of design, development, and production.

Giving up Platform Control. Opening the platform in this context was also associated with an increase in the rate of new device introductions. The most useful measure of platform openness in these models was a simple binary variable. In the preferred regression, the estimated coefficient implies a 22% increase in the innovation rate, but was not statistically significant. The two statistically significant estimates (in a subsample of leading systems and in the post-1996 subsample) implied accelerations of comparable magnitudes (13% and 39% respectively). A series of alternative measures and specifications generated estimates with consistent signs and for the most part comparable magnitudes, but these were statistically insignificant.

This relatively small effect (compared to that of opening the complement) is surprising given the considerable attention devoted to devolving the platform owner's control in the literature (Section 3.2). Further, executives at platform vendors believed that there was a link between platform control and maintaining the commitment and support of their complementors (Boudreau 2006).[55] The various mechanisms surveyed earlier in this paper could have simply worked against one another, resulting in a small net effect. It might have also been the case that platforms were not opened *enough*. Research on sponsored and unsponsored systems, for example, focuses on more extreme forms of opening: placing crucial intellectual property in the public domain, making a system fully compatible with competing systems, and the like (Katz and Shapiro 1994; Shapiro and Varian 1998). Varying *degrees* of openness might therefore be only weakly relevant to bottleneck platforms, compared to these more extreme forms of opening. This thesis is consistent with some prior empirical findings, which have found that incremental shifts in formal control may not have sufficed on their own to produce major changes in innovation (Gawer and Henderson 2007).

9. Conclusions

In this paper, I studied the relationship between open strategies and the rate of new hardware device introductions in a panel of handheld computing systems from 1990 to 2004, an archetypal hardware-software industry. The central objective of the analysis was to untangle the effects of various modes and degrees of opening on innovation rates, as measured by the appearance of new devices on the market. Essentially,

[55] For example, Palm separated its software business with the intent of more effectively supporting complementors as a platform owner. The new platform owner, Palmsource, had profits that were an order of magnitude smaller than the formerly integrated company. There are numerous other examples.

I characterized a range of tactics in terms of two strategies: granting complementary hardware designers access to the platform, and giving up some measure of control over the platform itself.

In terms of granting access, I found an inverted-U relationship between innovation rates and platform owners' liberalness in licensing complementary hardware developers. Sharing IP with complementors in the form of reference designs had a much smaller positive effect. In relation to platform control (giving up equity control, narrowing vertical scope, or allowing direct contributions to the platform), the overall effect of opening was small and positive. In the preferred model, granting access to complementors accelerated the introduction of new devices by a factor of roughly five; giving up control over the platform increased the innovation rate by roughly 20%. Both results are robust to system fixed effects and covariates, various specifications of time controls, alternative functional specifications of the mean and model error, and regressions on subsamples.

Broadly, the distinct effects and patterns associated with giving up platform control and granting access to complementary development are consistent with the idea that different economic mechanisms are set in motion by these two policies, as discussed earlier in the article. Further, it is apparent that very different contractual and technical instruments were used to implement the various policies of platform owners in this study. The results presented in this paper thus challenge the use of an all-encompassing metaphor of "openness" when considering the organization and governance of distributed innovation in a multi-component system.

Notwithstanding the number and range of instruments studied in this analysis, it should be noted that the particulars of an open strategy will vary from context to context. Further, this analysis also focused on a rather narrow measure of innovation: the rate at which new handheld devices were introduced. This measure is highly relevant within this context and in relation to the research questions studied here. Another important aspect of the sample is that it focuses on a period of innovation *after* the initial establishment of the systems. During this period, a steady stream of new devices was emerging "on top of" relatively stable platforms (rather than a period in which carefully orchestrated cross-component design was crucial). Outside the context studied here, we might consider the direction, nature, locus and distribution of technical change across components and actors in a system—and how this relates to the particulars of the open strategy in question. Finally, the industry was relatively stable, with mainly incremental variations in openness and market outcomes. Thus, my analysis has measured effects of "tweaking" open policies. The paper does not contemplate more extreme shifts in industry trajectory that might be set in motion by opening (such as when a market "tips" toward one system or another).

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References

Almirall, E., R. Casadesus-Masanell. 2010. Open vs. Integrated Innovation: A Model of Discovery and Divergence. *Acad. Management Rev.* **35**(1) 27-47**.**

Arora, A., F. Bokhari. 2007. Open versus Closed Firms and the Dynamics of Industry Evolution. *J. Indust. Econom.* **55**(3) 499-527.

Augereau, A., S. Greenstein, M. Rysman. 2006. Coordination versus Differentiation in a Standards War: The Adoption of 56K Modems. *RAND J. Econom.* **37**(4) 887-909.

Baldwin, C., K. Clark. 2000. *The Power of Modularity*. MIT Press, Cambridge, USA.

Baldwin, C., J. Woodard. 2009. The Architecture of Platforms: A Unified View. A. Gawer, ed. *Platforms, Markets and Innovation*. Edward Elgar, London, UK, 19-44.

Becchetti, L., L. Paganetto. 2001. The Determinants of Suboptimal Technological Development in the System Company-Component Producers Relationship. *Inter. J. Indust. Organization* **19**(9) 1407-1421.

Besen, S., J. Farrell. 1994. Choosing How to Compete: Strategies and Tactics in Standardization, *J. Econom. Perspectives* **8**(2) 117-131.

Boudreau, K. 2006. *How Open Should an Open System Be? Empirical Essays on Mobile Computing*. Doctoral dissertation, MIT Sloan School of Management, Cambridge, USA.

Boudreau, K. 2007. Does Opening a Platform Stimulate Innovation? The Effect on Systemic and Modular Innovations. *MIT Sloan Research Paper No. 4611-06*.

Boudreau, K., A. Hagiu. 2009. Platform Rules: Multi-Sided Platforms as Regulators. A. Gawer, ed. *Platforms, Markets and Innovation*. Edward Elgar, London, UK, 163-191.

Boudreau, K., K. Lakhani. 2009. How to Manage Outside Innovation: Competitive Markets or Collaborative Communities? *Sloan Manage. Rev.* **50**(4) 69-76.

Bresnahan, T., S. Greenstein. 1999. Technological Competition and the Structure of the Computer Industry. *J. Indust. Econom.* **47**(1) 1-40.

Butters, A.. D. Pogue. 2002. *Piloting Palm: The Inside Story of Palm, Handspring. And the Birth of the Billion Dollar Handheld Industry*, Wiley, New York, USA.

Cameron, C., P. Trivedi. 1998. *Regression Analysis of Count Data*. Cambridge University Press, Cambridge, UK.

Casadesus-Masanell, R., K. Boudreau, J. Mitchell. 2008. Palm (A): The Debate on Licensing Palm's OS. *Harvard Business School Case 708-514*.

Casadesus-Masanell, R., P. Ghemawat. 2006. Dynamic Mixed Duopoly: A Model Motivated by Linux vs. Windows. *Management Sci.* **52**(7) 1072-1084.

Chesbrough, H. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business School Press, Boston, USA.

Chesbrough, H., W. Vanhaverbeke, J. West. 2006. *Open Innovation: Researching a New Paradigm*. Oxford University Press, Oxford, UK.

Choi, J., G. Lee, C. Stefanadis. 2003. The Effects of Integration on R&D Incentives in Systems Markets. *Netnomics* **5**(1) 21-32.

Christensen, C., M. Verlinden, G. Westerman. 2002. Disruption, Disintegration and the Dissipation of Differentiability. *Indust. Corporate Change* **11**(5) 955-993.

Chwelos, P., E. Berndt, I. Cockburn. 2004. Faster, Smaller, Cheaper: An Hedonic Price Analysis of PDAs. *NBER Working Paper 10746*.

Cohen, W., R. Nelson, J. Walsh. 2000. Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). *NBER Working Paper No. 7552*.

Cusumano, M., Y. Mylonadis, R. Rosenbloom. 1992. Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS over Beta. *Bus. Hist. Rev.* **66**(1) 51-94.

Cusumano, M., R. Selby. 1995. *Microsoft Secrets: How the World's Most Powerful Software Company Creates Technology, Shapes Markets and Manages People*, Free Press, New York, USA.

Davis, S., K. Murphy. 2000. A Competitive Perspective on Internet Explorer. *Amer. Econom. Rev.* **90**(2) 184-187.

Economides, N., 1996. Network Externalities, Complementarities and Invitations to Enter. *Eur. J. Political Econom.* **12**(2) 211-233.

Economides N., E. Katsamakas. 2006. Two-Sided Competition of Proprietary vs. Open-Source Technology Platforms and the Implications for the Software Industry. *Management Sci.* **52**(7) 1057-1071.

Eisenmann, T., G. Parker, M. Van Alstyne. 2009. Platform Envelopment. *Harvard Business School Working Paper 07-104*.

Eisenmann, T., G. Parker, M. Van Alstyne. 2010. Opening Platforms: How, When and Why? A. Gawer, ed. *Platforms, Markets and Innovation*. Edward Elgar, London, UK, 131-162.

Evans, D., A. Hagiu, R. Schmalensee. 2005. A Survey of the Economic Role of Software Platforms in Computer-Based Industries. *CESifo Economic Studies* **51** 189-224.

Farrell, J. 2007. Should Competition Policy Favor Compatibility? S. Greenstein,V. Stango, eds. *Standards and Public Policy*. Cambridge University Press, Cambridge, UK, 372-388.

Farrell, J., N. Gallini. 1988. Second-sourcing as a Commitment: Monopoly Incentives to Attract Competition. *Quarterly J. Econom.* **103**(4) 673–69.

Farrell, J., M. Katz. 2000. Innovation, Rent Extraction and Integration in System Markets. *J. Indust. Econom.* **48**(4) 413-432.

Farrell, J., H. Monroe, G. Saloner. 1998. The Vertical Organization of Industry: Systems Competition versus Component Competition. *J. Econom. Manage. Strat.* **7**(2) 143-182.

Farrell, J., P. Weiser. 2003. Modularity, Vertical Integration and Open Access Policies towards a Convergence of Antitrust and Regulation in the Internet Age. *Harvard J. Law Tech.* **17**(1) 83-134.

Feller, J., B. Fitzgerald, S. Hissam, K. Lakhani. 2005. *Perspectives on Free and Open Source Software*. MIT Press, Cambridge, USA.

Fixson, S., J. Park. 2008. The Power of Integrality: Linkages between Product Architecture, Innovation, and Industry Structure. *Research Policy* **37** 1296–1316.

Franke, N., E. von Hippel. 2003. Satisfying Heterogeneous User Needs via Innovation Toolkits: The Case of Apache Security Software. *Research Policy* **32**(7) 1199-1215.

Garud R., A. Kumaraswamy. 1995. Technological and Organizational Designs for Realizing Economies of Substitution. *Strategic Management J.* **16** 93-109.

Gawer, A., M. Cusumano. 2002. *Platform Leadership: How Intel, Microsoft and Cisco Drive Industry Innovation*. Harvard Business School Press, Boston, USA.

Gawer, A., R. Henderson. 2007. Platform Owner Entry and Innovation in Complementary Markets: Evidence from Intel. *J. Econom. Manage. Strat.* **16**(1) 1-34.

Greenstein, S. 1996. Invisible Hands versus Invisible Advisors: Coordination Mechanisms in Economic Networks. E. Noam, A. Nishuilleabhain, eds. *Public Networks, Public Objectives*. Elsevier Science, Amsterdam, Netherlands, 538-549.

Greenstein, S. 2009. Open Platform Development and the Commercial Internet. A. Gawer, ed. *Platforms, Markets and Innovation*. Edward Elgar, London, UK, 219-248.

Hagiu, A. 2009. Proprietary vs. Open Two-Sided Platforms and Social Efficiency. *Harvard Business School Working Paper 09-113.*

Heeb, R. 2003. Innovation and Vertical Integration in Complementary Markets. *J. Econom. Manage. Strat.* **12**(3) 387-417.

Huang, P., M. Ceccagnoli, C. Forman., D. Wu. 2009. Participation in Platform Ecosystem: Appropriability, Competition and Access to the Installed Base. *NET Institute Working Paper 09-14*.

Iansiti, M., R. Levien. 2004. *The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability*. Harvard Business School Press, Boston, USA.

Jacobides, M., T. Knudsen, M. Augier. 2006. Benefiting from Innovation: Value Creation, Value Appropriation and the Role of Industry Architectures. *Research Policy* **35**(8) 1200-1221.

Kaplan, J. 1996. *Startup: A Silicon Valley Adventure*. Penguin Books, New York, USA.

Katz, M., C. Shapiro. 1986. Technological Adoption in the Presence of Network Externalities. *J. Political Econom.* **94**(4) 822-841.

Katz, M., C. Shapiro. 1994. Systems Competition and Network Effects. *J. Econom. Perspectives* **8**(2) 93-115.

Kende, M. 1998. Profitability Under an Open Versus a Closed System. *J. Econom. Manage. Strat.* **7**(2) 307-326.

Kim, D., B. Kogut. 1996. Technological Platforms and Diversification. *Organization Science* **7** 283–301.

Kuan, J. 2002. Open Source Software as Lead User's Make or Buy Decision: A Study of Open and Closed Source Quality. *Stanford Institute for Economic Policy Research Working Paper*.

Langlois, R. 1992. External Economies and Economic Progress: The Case of the Microcomputer Industry. *Bus. Hist. Rev.* **66**(1) 1-50.

Langlois, R. 2007. Competition Through Institutional Form: The Case of Cluster Tool Standards. S. Greenstein,V. Stango, eds. *Standards and Public Policy*. Cambridge University Press, Cambridge, UK, 60-86.

Laursen, K., A. Salter. 2006. Open for Innovation: The Role of Openness in Explaining Innovation Performance among UK Manufacturing Firms. *Strategic Management J.* **27**(2) 131-150.

Lerner, J., J. Tirole. 2002. Some Simple Economics of Open Source. *J. Indust. Econom.* **52**(2) 197-234.

Macher, J. 2006. Technological Development and the Boundaries of the Firm: A Knowledge-Based Examination in Semiconductor Manufacturing. *Management Sci.* **52**(6) 826-843.

Marschak, T. 1962. Strategy and Organisation in a System Development Project. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, a report by the National Bureau of Economic Research. Princeton University Press, Princeton, USA, 509-548.

Martin, A., M. Orlando. forthcoming. Barriers to Network-Specific Investment. *Rev. Econom. Dynamics*.

Matutes, C., P. Regibeau. 1988. Mix and Match: Product Compatibility without Network Externalities. *RAND J. Econom.* **19**(2) 219-234.

McGahan, A., L. Vadasz, D. Yoffie. 1997. Creating Value and Setting Standards: The Lessons of Consumer Electronics for Personal Digital Assistants. D. Yoffie, ed. *Competing in the Age of Digital Convergence.* Harvard Business School Press, Boston, USA, 227-264.

Merges, R. 2008. IP Rights and Technological Platforms. Working paper, Berkeley Center for Law and Technology, Berkeley, USA.

Meyer, M., A. Lehnerd. 1997. *The Power of Product Platforms*. Free Press, New York, USA.

Meyer, M., J. Utterback. 1993. The Product Family and the Dynamics of Core Capability. *Sloan Manage. Rev.* **34**(3) 29-47.

Morris, C., C. Ferguson. 1993. How Architecture Wins Technology Wars. *Harvard Bus. Rev.* **71**(2) 86-96.

Murray, F., P. Aghion, M. Dewatripont, J. Kolev, S. Stern. 2009. Of Mice and Academics: The Role of Openness in Science. *NBER Working Paper No. w14819*.

Nahm, J. 2004. Open Architecture and R&D Incentives. *J. Indust. Econom.* **52**(4) 547-568.

Nair, H., P. Chintagunta, J. Dubé. 2004. Empirical Analysis of Indirect Network Effects in the Market for Personal Digital Assistants. *Quantitative Marketing and Economics* **2**(1) 23-58.

Niedermayer, A. 2007. On Platforms, Incomplete Contracts and Open Source Software. *University of Bern Discussion Paper dp0707*.

Nocke, V., M. Peitz, K. Stahl. 2007. Platform Ownership. *J. Eur. Econom. Ass.* **5** 1130-1160.

Novak, S., S. Eppinger. 2001. Sourcing By Design: Product Complexity and the Supply Chain. *Management Sci.* **47**(1) 189-204.

O'Mahony, S., F. Ferraro. 2007. The Emergence of Governance in an Open Source Community. *Acad. Management J.* **50**(5) 1079-1106.

Parker, G., M. Van Alstyne. 2008. Innovation, Openness and Platform Control. Working paper, Available at SSRN: http://ssrn.com/abstract=1079712.

Perrons, R. 2009. The Open Kimono: How Intel Balances Trust and Power to Maintain Platform Leadership. *Research Policy* **38**(8) 1300-1312.

Pierce, L. 2009. Big Losses in Ecosystem Niches: How Core Firm Decisions Drive Complementary Product Shakeouts. *Strategic Management J.* **30**(2) 323-347.

Rey, P., D. Salant. 2008. Abuse of Dominance and Licensing of Intellectual Property. *MPRA Paper* 9454*,* University Library of Munich, Germany.

Roberts, J., I.-H. Hann, S. Slaughter. 2006. Understanding the Motivations, Participation and Performance of Open Source Software Developers: A Longitudinal Study of the Apache Projects. *Management Sci.* **52**(7) 984-999.

Robertson, D., K. Ulrich. 1998. Planning for Product Platforms. *Sloan Manage. Rev.* **39**(4) 19-31.

Rochet, C., J. Tirole. 2004. Two-Sided Markets: An Overview. *DEI Working Papers,* Institut d'Économie Industrielle (IDEI), Toulouse.

Rysman, M. 2009. The Economics of Two-Sided Markets. *J. Econom. Perspectives,* **23**(3) 125-144.

Schilling, M. 2009. To Protect or to Diffuse? Tradeoffs in Appropriability, Network Externalities and Architectural Control. A. Gawer, ed. *Platforms, Markets and Innovation*. Edward Elgar, London, UK, 192-218.

Shapiro, C., H. Varian. 1998. *Information Rules: A Strategic Guide to the Network Economy*. Harvard Business School Press, Boston, USA.

Simpson, T., Z. Siddique, R. Jiao. 2006. *Product Platform and Product Family Design: Methods and Applications*. Springer Science, Berlin, Germany.

Spulber, D. 2008. Unlocking Technology: Antitrust and Innovation. *J. Competition Law Econom.* **4**(4) 915-966.

Strahilovetz L. 2006. Information Asymmetries and the Rights to Exclude. *Michigan Law Rev.* **104**(8) 1834-1898.

Tåg, J, 2008. Open Versus Closed Platforms. Working Paper Series 747, Research Institute of Industrial Economics.

Teece, D. 1986. Profiting from Technological Innovation: Implications for Integration Collaboration, Licensing and Public Policy. *Research Policy* **15**(6) 285-305.

Tucker, C. forthcoming. Growing Two-sided Networks by Advertising the User Base: A Field Experiment. *Marketing Sci*.

Valloppillil, V. 1998. Halloween Documents, Microsoft Corporation.

Venkatraman, N., C. Lee. 2004. Preferential Linkage and Network Evolution: A Conceptual Model and Empirical Test in the U.S. Video Game Sector. *Acad. Management J.* **47**(6) 876-892.

von Burg, U. 2001. *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford University Press, Palo Alto, USA.

von Hippel, E. 2005. *Democratizing Innovation*. MIT Press, Cambridge, USA.

von Krogh, G., S. Spaeth, K. Lakhani. 2003. Community, Joining and Specialization in Open Source Software Innovation: A Case Study. *Research Policy* **32**(7) 1217-1241.

West, J. 2003. How Open is Open Enough? Melding Proprietary and Open Source Platform Strategies. *Research Policy* **32**(7) 1259-1285.

West, J. 2007. The Economic Realities of Open Standards: Black, White and Many Shades of Gray. S. Greenstein, V. Stango, eds. *Standards and Public Policy*. Cambridge University Press, Cambridge, UK, 87-122.

Wheelwright, S., K. Clark. 1992. *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*. Free Press, New York, USA.

Wolter, C., F. Veloso. 2008. The Effects of Innovation on Vertical Structure: Perspectives on Transaction Costs and Competences. *Acad. Management Rev.* **33**(3) 586-605.

Wooldridge, J. 1999. Distribution-Free Estimation of Some Non-Linear Panel Data Models. *Journal of Econometrics* **90**(1) 77-97.

Yoffie, D., P. Yin, C. Darwall. 2004. PalmSource, Inc. *Harvard Business School Case 704-473*.

Figures

Figure 1 Cumulative New Devices Released

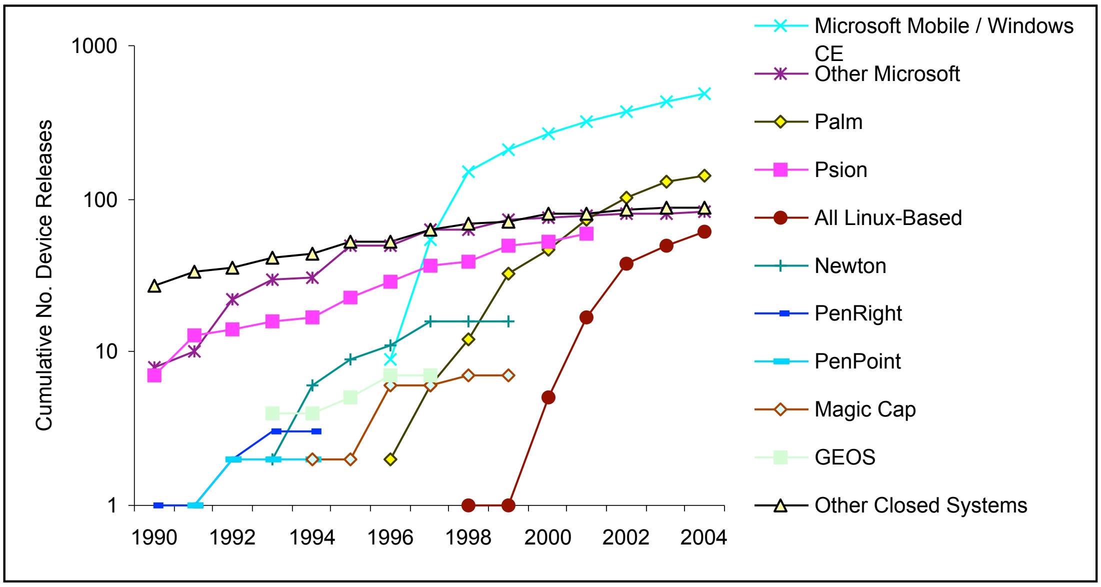


Figure 2 Handheld Systems over Time, Broken Down by Open Strategy

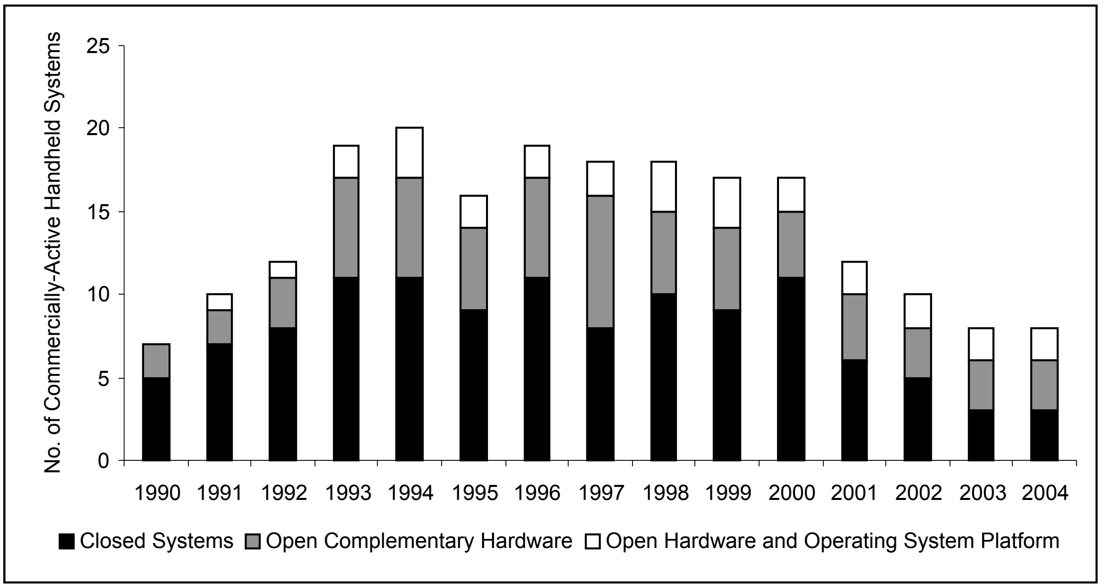


Figure 3 Examples of Broad Distinctions in Open Policies

Opening Complementary Hardware	Monopoly Control	Shared Control	Shared Development
Shared IP	RIM (2004) Microsoft Mobile (2003)		EPOC (2001) LynuxWorks Montavista (2005) Palm (2005) *Other Linux Reference Designs*
Granted Access	DOS GEOS Microsoft Mobile Palm (1997) Newton Penright! RIM (2004) Windows	EPOC (1998) Palm (1999)	Montavista Mizi Linuette Lineo *Other Mobile Linux Platforms*
Foreclosed Entry	Cybiko EPOC Hewlett Packard Palm RIM REX *Other Proprietary*		Royal Consumer (2002) *Other Custom Linux*

Opening the Operating System Platform

* The listing of a year indicates a change from some earlier policy to an altogether different category.

Figure 4 Coefficient Estimates Expressed in Incidence Rate Ratios (Model 4-7)

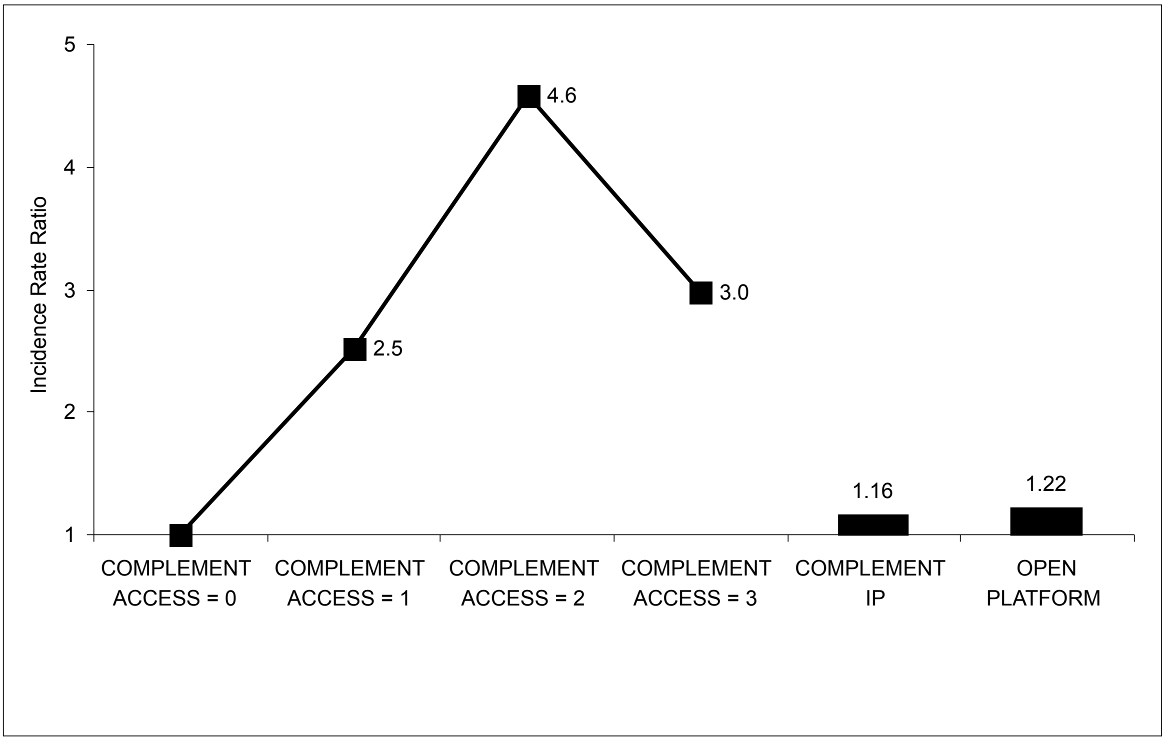
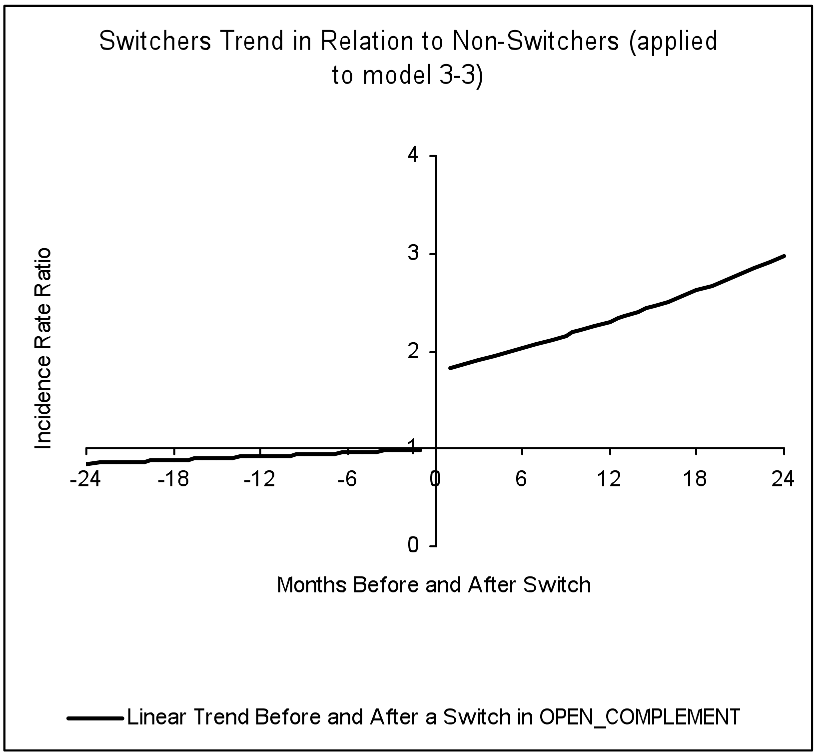


Figure 5 The Difference Between Switcher and Non-Switcher Trending



Tables

Table 1 Variable Definitions

	Variable	Definition
Dependent Variable		
(1)	*NEW_DEVICES*	The dependent variable; a count of new handheld devices released within a system in a given month
Measures of Opening the Platform		
(2)	*OPEN_PLATFORM*	A discrete indication of whether the platform was opened (at all); an indicator variable switched on when either PLATFORM_OWNERSHIP or PLATFORM_CONTRIBUTIONS are switched to 1
(3)	*PLATFORM_CONTROL*	The primary measure of how much control is concentrated under the platform owner; an indicator variable switched to 1 if any equity in the platform (owner) is held by independent complementary hardware developers
(4)	*PLATFORM_CONTROL_HHI*	A more continuous measure of platform owner control; a Herfindahl measure of the ownership stakes in the platform (owner) (see Section 5.1); a value of 0 indicates perfectly concentrated ownership (closed); a value of 1 indicates perfectly diffuse ownership (open)
(5)	*PLATFORM_DISINTEGRATION*	An alternative measure of control concentrated under the platfom owner; an indicator variable switched to 1 when the platform owner is no longer integrated into complementary hardware development, alongside independent outsiders
(6)	*PLATFORM_CONTRIBUTIONS*	An indicator variable switched to 1 if outsiders contribute to any of the following elements of the platform: graphical user interface (GUI); operating system kernel; or software "drivers" and utilities used to control analog devices (RF, ports, screen, etc.)
Measures of Opening Complementary Hardware		
(7)	*OPEN_COMPLEMENT*	A discrete indication of whether complementary hardware development was opened (at all); an indicator variable switched to 1 when COMPLEMENT_ACCESS was greater than 0 (Note: this measure was not affected by the second measure of opening complementary hardware development COMPLEMENT_IP, as this second measure was conditional on COMPLEMENT_ACCESS being greater than 0)
(8)	*COMPLEMENT_ACCESS*	A categorical measure of the liberalness with which the platform owner granted licenses: (0) a policy of not licensing outsiders; (1) restricted number of licensees and also restricted to developing products for particular market niches; (2) restricted number of licensees, but without restrictions to particular niches; (2) licensing to all comers
(9)	*COMPLEMENT_IP*	An indicator variable switched to 1 when reference designs for building complementary hardware were made available by the platform owner
Control Variables		
(10)	*SYSTEM_SALES*	Millions of units of handheld computers sold globally in a given system, within the year
(11)	*SYSTEM_SHARE*	*SYSTEM_SALES*, divided by total unit sales within the period
(12)	*SYSTEM_GROWTH*	Annual growth rate in *SYSTEM_SALES*
(13)	*SYSTEM_AGE*	Number of months since the initial launch of the system
(14)	*PLATFORM_R&D*	Total annual R&D expenditure for the platform owner, including businesses other than the platform
(15)	*PLATFORM_VERSION*	The numerical value assigned to the version of the platform available at that point in time (i.e. version 1.0, 2.0, 3.0, 3.1, etc.)

Table 2 Variable Means, Standard Deviations and Correlations (N=1706)

	Variable	Mean	Std. Dev.	(1)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1)	*NEW_DEVICES*	.53	1.80	1.00												
(3)	*PLATFORM_OWNERSHIP*	.18	.39	-.02	1.00											
(4)	*PLATFORM_OWNERSHIP_HHI*	.86	.34	-.04	.90	1.00										
(5)	*PLATFORM_INTEGRATION*	.50	.50	.19	.25	.23	1.00									
(6)	*PLATFORM_CONTRIBUTIONS*	.07	.25	-.06	.01	-.17	-.21	1.00								
(8)	*COMPLEMENT_ACCESS*	1.69	1.40	.17	.22	.11	.85	.07	1.00							
(9)	*COMPLEMENT_IP*	.02	.13	.26	.05	.06	.04	-.04	.13	1.00						
(10)	*SYSTEM_SALES*	.37	1.2	.36	-.22	-.43	.17	-.04	.19	.31	1.00					
(11)	*SYSTEM_SHARE*	.11	.51	.06	-.08	-.10	-.11	-.06	-.12	.04	.20	1.00				
(12)	*SYSTEM_GROWTH*	.01	.14	.03	-.09	-.07	-.02	-.03	-.03	-.01	.00	.01	1.00			
(13)	*SYSTEM_AGE*	63	68	.01	-.04	-.05	.44	-.02	.41	.02	.03	-.09	-.02	1.00		
(14)	*PLATFORM_R&D*	968	1721	.50	.33	.40	.50	-.09	.49	.47	.28	-.09	.03	-.09	1.00	
(15)	*PLATFORM_VERSION*	2.74	1.72	.13	-.18	-.25	.29	.15	.32	.11	.26	.02	.00	.80	-.04	1.00

Notes. Variables No. 2 and 7 were excluded as they are functional transforms of other variables.

Table 3 Poisson Regressions of Handheld Device Development on Discrete Measures of Open Strategies (Dependent Variable = *NEW_DEVICES*)

Explanatory Variables	(3-1) System Fixed Effects	(3-2) Year Dummies	(3-3) System Covariates
OPEN_COMPLEMENT	1.15***	1.21***	1.18***
	(.40)	(.35)	(.37)
OPEN_PLATFORM	-.07	.00	.02
	(.58)	(.09)	(.13)
SYSTEM_SALES			.10
			.00
SYSTEM_SHARE			-.27***
			(.12)
SYSTEM_GROWTH			-.26
			(.16)
SYSTEM_AGE			-.001
			(.01)
System FE	Yes	Yes	Yes
Year Dummies		Yes	Yes
Log likelihood	-1183	-1099	-1099

Notes. *, **, and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively. Wooldridge (1999) fixed effects Poisson with heteroskedasticty-autocorrelation robust standard errors reported; explanatory variables are lagged; No. of systems = 21; No. of observations = 1706.

Table 4 Poisson Regressions of Handheld Device Development on Measures of Degrees of Openness (Dependent Variable = *NEW_DEVICES*)

	(4-1)	(4-2)	(4-3)	(4-4)	(4-5)	(4-6)	(4-7)	(4-8)
Explanatory Variables	Modes of Opening	Degrees of Access	Test Peak	Degrees of Platform Control	Alternative Platform Control Measure	Amalgam Measure of Platform Openness	Preferred	Other System Covariates
OPEN_COMPLEMENT								
COMPLEMENT_ACCESS	1.14***							
	(.39)							
COMPLEMENT_ACCESS_DEGREE								
level = 0			-1.51***					
			(.40)					
level = 1		.92**	-0.59*	0.91**	0.85*	0.93*	0.93**	1.18**
		(.45)	(.32)	(.44)	(.47)	(.46)	(.45)	(.53)
level = 2		1.51***		1.63***	1.46***	1.52***	1.52***	1.52***
		(.40)		(.33)	(.43)	(.39)	(.38)	(.33)
level = 3		1.09***	-0.43**	1.31***	1.07***	1.10***	1.09***	0.86**
		(.35)	(.17)	(.27)	(.38)	(.35)	(.34)	(.39)
COMPLEMENT_IP	.11	.15	.15	.09	.09	.13	.15	.10
	(.25)	(.21)	(.21)	(.22)	(.22)	(.22)	(.21)	(.10)
OPEN_PLATFORM							.20	.12+
							(.19)	(.08)
PLATFORM_CONTROL	.23	.20	.20					
	(.33)	(.19)	(.19)					
PLATFORM_CONTROL_HHI				-.32				
				(.41)				
PLATFORM_DISINTEGRATION					.23			
					(.39)			
PLATFORM_CONTRIBUTIONS	.06	.10	.10	.21	.21			
	(.23)	(.33)	(.33)	(.34)	(.34)			
OWNERSHIP+CONTRIBUTIONS						.16		
						(.18)		
PLATFORM_R&D								-.0002***
								(.00)
PLATFORM_VERSION								.12
								(.16)
System FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
System Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	-1098	-1092	-1092	-1092	-1092	-1092	-1092	-533

Notes. +, *, **, and *** indicate statistical significance at the 15%, 10%, 5% and 1% levels, respectively. *SYSTEM_SALES*, *SYSTEM_SHARE*, *SYSTEM_GROWTH* and *SYSTEM_AGE* are included in the models, but not reported for simplicity. Heteroskedasticty-autocorrelation robust standard errors reported in parentheses; Explanatory variables are lagged; *No. of systems = 21; No. of observations = 1706 (except model 4-8 with 484 observations and 5 systems).*

Table 5 Robustness Checks (Dependent Variable = *NEW_DEVICES*)

Explanatory Variables	(4-7) Preferred	(5-1) Other Systems' Open Policies	(5-2) Years 1997-2004	(5-3) Individual Month Dummies	(5-4) Assess Control Group (I)	(5-5) Assess Control Group (II)
OPEN_COMPLEMENT						1.27***
						(.32)
COMPLEMENT_ACCESS_DEGREE						
level = 1	0.93**	0.91**	1.25***	1.02***	1.02***	
	(.45)	(.46)	(.26)	(.31)	(.31)	
level = 2	1.52***	1.49***	1.79***	1.61***	1.61***	
	(.38)	(.39)	(.20)	(.29)	(.29)	
level = 3	1.09***	1.07***	1.34***	1.29***	1.29***	
	(.34)	,34	(.16)	(.33)	(.33)	
COMPLEMENT_IP	.15	.16	.21	.01	.01	
	(.21)	(.21)	(.20)	(.23)	(.23)	
OPEN_PLATFORM	.20	.21	0.33***	.13	.13	.05
	(.19)	(.20)	(.10)	(.30)	(.31)	(.22)
Other Systems' Degree of Access		-.04				
		(.17)				
Pre-Switch Month					.00	.62
					(.36)	(.83)
System FE	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes		Yes	Yes
Month Dummies				Yes		
System Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	-1092	-845	-845	-929	-929	-915
No. Observations	1706	1706	882	1706	1706	1706

Notes. *, **, and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively. Heteroskedasticty-autocorrelation robust standard errors reported in parentheses; Explanatory variables are lagged; for all models except for the preferred model, system fixed effects are implemented as additive dummies; No. of systems = 21; No. of observations = 1706 (except model 5-2 with 882 observations).