Pawn to Save a Chariot, or Drawbridge Into the Fort?
Firms’ Disclosure During Standard Setting and
Complementary Technologies Within Ecosystems

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Research summary: Within an ecosystem, standard setting coordinates development of complementary
technologies across firms. But each firm can itself own multiple of these complementary
technologies. We study how a firm’s own complementary technologies influence its disclosure incli-
nation during standard setting. We identify a tradeoff: disclosure increases value-creation of the
firm’s non-disclosed complementary technologies, but also heightens expropriation risk. Using
data on the U.S. communications equipment industry 1991–2008, we show that the firm’s com-
plementary technologies increase its disclosure inclination when its technological areas are less
crowded, but decrease such inclination when there are SSO members with strong expropriation
abilities. Findings stress that disclosure involves but a piece of the firm’s portfolio; a systemic
perspective of the entire portfolio provides a more comprehensive picture of value-creation during
standard setting.

Managerial summary: Why should a firm disclose its key technology to participate in standard
setting within an ecosystem? We urge managers to think beyond “disclosing to ensure compatibil-
ity with other firms’ complementary technologies within the ecosystem” as a motivation, to also
consider how disclosure affects the firm’s own complementary technologies within its portfolio.
Disclosure in one technological area makes the firm’s undisclosed complementary technologies in
other areas more valuable to itself, especially with fewer rivals competing in these other areas.
But disclosure also renders the firm susceptible to losing these complementary technologies to
rivals, especially when rivals have strong expropriation abilities. Analyzing disclosure decisions
by communication equipment firms, we show that this tradeoff is indeed a relevant consideration
in managers’ strategic calculations when participating in standard setting. Copyright © 2017
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Introduction
When an innovation ecosystem comprises different complementary technologies, coordination is
often required in developing these technologies so

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increasingly managed by standard setting organizations (SSOs), which provide forums enabling firms to disclose their intellectual properties (IP) over particular technologies voluntarily and to establish them as part of the industry standard so as to facilitate coordination within the system (Dokko & Rosenkopf, 2010; Leiponen, 2008).

From a strategy perspective, a key question then arises: what strategic concerns does a firm have as it considers participating in such coordination via disclosures to SSOs? Past research along this inquiry usually starts by depicting, either explicitly or implicitly, situations where the necessary complementary technologies within the ecosystem are all owned by other firms (e.g., Adner & Kapoor, 2015), so that the focal firm’s preoccupation is on coordinating with these other firms (Kapoor & Lee, 2013). Not surprisingly, the firm’s concerns, brought up thus far in past research, are mostly about what happens to the firm’s disclosed technology itself upon disclosure to SSOs, in terms of its subsequent value (Bekkers, Bondard, & Nuvolari, 2011; Rysman & Simcoe, 2008), its survival of the disclosure process, and licensing revenue (Farrell & Simcoe, 2012; Lerner & Tirole, 2006). Few have shed light on, or even taken into account, how other technologies that the firm owns may also be relevant considerations in the firm’s participation in these forums.

In reality, though, it is typical for the participating firm itself to own a variety of the complementary technologies within the ecosystem (Cassiman, Colomb, Garrone, & Veugelers, 2005; Toh & Kim, 2013). Ready examples that come to mind, such as Qualcomm and Nokia within the communications equipment ecosystems, are seldom just specialists in particular technology. In fact, as we demonstrate later, a firm that has a wide range of different complementary technologies is far more likely to be active in SSOs than a specialist. This raises a suspicion that perhaps the firm’s concern is not only to coordinate development of its disclosed technology across firms (Kapoor & Lee, 2013); rather, enhancing returns from its nondisclosed complementary technologies could be just as crucial, if not more so. To date, we know little about how this firm’s concerns about participating in standard setting may differ from that depicted in prior research. Moreover, the disclosing firm often has to agree to license out its disclosed technology to any other firm at a “fair, reasonable and nondiscriminatory” (FRAND) rate, or even royalty-free (Bekkers, Iversen, & Blind, 2012; Updegrove, 2007). Perhaps the disclosed technology per se is no longer the most imperative, or profitable, locus of returns to the firm’s disclosure strategy. We would be remiss by ignoring the disclosing firm’s own complementary technologies.

Accordingly, we shift the focus of inquiry to instead ask: does having complementary technologies make the firm more inclined or less inclined to disclose to SSOs and participate in standard setting? While the answer at first glance may seem straightforward, we argue that it is in fact not so. On the one hand, disclosing a technology to include it as a part of the industry standard may raise the firm’s returns from its other complementary technologies. Hence, the firm with more complementary technologies would be more inclined to do so. But on the other hand, as the obligated out-licensing of the disclosed technology could constitute a “point of access” allowing others to learn about and expropriate the firm’s related (nondisclosed) technologies, the firm with more complementary technologies has “more to lose” and hence could be less inclined toward disclosures. This tradeoff is worth bringing to light. It helps us understand the tension stemming from the firm’s own complementary technologies as it participates in standard setting, and pushes us to examine the conditions under which one influence is accentuated and supersedes the other.

The general idea that “standardization of one technology benefits others in the firm’s portfolio” has indeed hovered broadly in past studies (e.g., Dokko, Nigam, & Rosenkopf, 2012; Rosenkopf & Tushman, 1998). But, to our knowledge, none has examined specifically the influences of a firm’s complementary technologies on its disclosure inclination to SSOs. More importantly, the inherent tradeoff, pointed out above, has not yet been brought to light. The closest exception is Ranganathan and Rosenkopf (2014), who show that a firm centrally positioned in commercialization networks is likely to contest a new standard to prevent it from disrupting and devaluing its existing downstream assets. Their inherent notion that “the firm’s other assets matter in standard setting” has broad similarity, though they focus on the firm opposing new standards to protect its existing downstream
assets, rather than on the firm using a new standard to enhance the value of its complementary technologies or the associated appropriation risk in doing so.

We demonstrate the tradeoff in this article, starting by separately establishing the two opposing influences. To establish the positive influence, we propose that when the firm owns technologies complementary to its focal technology, it will be more inclined to disclose this focal technology to SSOs, as it stands to profit from its (nondisclosed) complementary technologies via such disclosure. To establish the negative influence, we propose that the firm’s complementary technologies will render it less inclined to disclose the focal technology to SSOs, as it risks greater expropriation of its (nondisclosed) complementary technologies via such disclosure. We then examine two contingencies under which the overall effect of the tradeoff is net positive or net negative, respectively. We propose that the less crowded the firm’s technological areas outside of the focal technology’s area, the more positive will be the net effect of the firm’s complementary technologies. Conversely, the greater the other SSO members’ abilities to expropriate the firm’s portfolio of technologies via learning from its disclosed technology, the more negative will be the net effect of the firm’s complementary technologies.

We empirically test these propositions in the context of the US communications equipment industry for 1991–2008. We start with patent-level analyses, using logit and other matching techniques. To check if findings are confounded by selection issues arising from nontraceable patents in blanket disclosures (see a later section), we also conduct analyses at a broader firm level capturing blanket disclosures. We find support favoring the positive (over the negative) influence in the tradeoff. That is, within our context, having complementary technologies makes the firm more inclined to disclose the focal technology during standard setting. Findings also support both our contingency propositions, which help justify the presence of the abovementioned tradeoff.

The broad essence of this study is twofold. First is to stress that what is indirectly impacted by disclosure, in this case the firm’s complementary technologies rather than its disclosed technology, plays a nontrivial role in its decision to participate in standard setting in the first place. Second is to recognize that what the firm discloses is but a piece of the firm’s larger portfolio, and this piece embodies the nature of a double-edged sword. It can serve as a “lever” to increase returns to the rest of the portfolio, even if the disclosed technology itself generates zero returns (which is not unrealistic given the recent trend toward royalty-free licensing of disclosed technologies), mirroring the ancient Chinese military stratagem of “giving up a pawn to save the chariot.” Or, it can end up creating a “window” for others to access the rest of the firm’s portfolio, which would otherwise have been well protected, much like “lowering the drawbridge into the fort.”

The propositions and findings in this article go beyond adding to the disclosure literature broadly (Bhattacharya & Ritter, 1983; Clarkson & Toh, 2010; De Fraja, 1993) or pointing out yet another reason for disclosure, even if it is within a more specific context of standard setting. Rather, it suggests a different firm rationale when participating in standard setting, which has been underemphasized in the literature thus far. This rationale goes beyond “coordinating development across firms within an innovation ecosystem” (Adner & Kapoor, 2015), and beyond “increasing the value of the disclosed technology” (Rysman & Simcoe, 2008). The firm bears the costs of disclosure during standard setting so as to gain elsewhere in its portfolio of complementary technologies; maximizing value-generation occurs over the entire portfolio of complementary technologies rather than with a single (disclosed) technology.

This article also stresses that complementary technologies do not only create value to the firm by providing more combinatorial possibilities for future invention (Ahuja & Katila, 2001; Cassiman et al., 2005) or enabling the firm to survive environmental changes (Teece, 1982; Tripsas, 1997) as past research has typically depicted. As a set within an ecosystem, they act as multiple channels to extract value from a strategy implemented on one of them, in this case, disclosure during standard setting. By bringing a more systemic perspective into the literature on standard setting, which has typically been single-technology focused, we are also stressing that the two literatures—standard setting and ecosystems—are highly related. Standard setting is a relevant phenomenon in strategy research because standards are often situated within complex ecosystems. We elaborate more on these implications at the end of the article.

**Theory and Hypotheses**

A technology-based firm is often embedded within an ecosystem of complementary technologies...
Voice over Internet Protocol (VoIP) in the WLAN system. This is a set of standards over technologies that allow laptops, phones, printers, and so on to join a wireless LAN (local area network). It includes the Carrier-sense multiple access with collision avoidance (CSMA/CA), which is a collision avoidance protocol at the core of the transmission system that allows data to link between two sending nodes so that information can be transferred. All complementary physical layers (such as routers and devices) rely on this protocol. Another related standard is the enhanced distributed channel access (EDCA) protocol, specified in the 802.11e, which is essentially a quality-of-service enhancement. The EDCA process decides which transmission channel should be heard first, and is central to having high-quality voice over Internet Protocol (VoIP) in the WLAN system.

As the complementary technologies in an ecosystem require interoperability, that is, need to work together, their developments need to be coordinated (Rosenkopf & Tushman, 1998). This need is salient in ecosystems where network externalities and switching costs are high (Garud & Kumarawamy, 1995; Katz & Shapiro, 1986; Rosenkopf, Metiu, & George, 2001; Schilling, 2002). Without coordination, the developments could end up along different paths, due to divergent views on the technologies, resulting in incompatible components (Ranganathan & Rosenkopf, 2014), or different parties involved could underinvest in the necessary improvements (Kapoor & Lee, 2013). Past research has also shown that coordination can be impactful on crucial outcomes such as the rate of substitution by new technologies, rate of entry, and direction of investments (Adner & Kapoor, 2015; Kapoor & Furr, 2015; Kapoor & Lee, 2013; Wu, Wan, & Levinthal, 2014).

A common way used to achieve this coordination is through standards. Here, a standard is a set of interaction rules between system components that is shared to facilitate future technological developments (Dokko et al., 2012; Rosenkopf et al., 2001). In the type of ecosystems that this article discusses, it refers to technical design standards that ensure compatibility across components, rather than performance standards specifying certain output parameters (Farrell & Saloner, 1988; Updegrove, 2007). It specifies the system architecture or connecting interface in a particular technology (Henderson & Clark, 1990; Sanchez & Mahoney, 1996), so that other technologies that are supposed to complement it within the system can be developed with some assurance that they will be seamlessly connected. A standard can emerge de facto, as firms offer competing technologies that are incompatible and the market eventually gravitates toward one in particular (Chiao, Lerner, & Tirole, 2007). However, de jure standards set by SSOs are increasingly preferred avenues of coordinating complementary technologies within systems.

Disclosures to SSOs

We discuss key features of disclosures and standard setting via SSOs before going on to theorizing the proposed effects. The SSOs are institutions that allow firms to voluntarily get together to set industry standards (Dokko et al., 2012; Rosenkopf et al., 2001). During standard setting, firms disclose their IP over technologies relevant to the standard in question. Their disclosure letters list components that are “technically essential,” that is, ones where it is difficult for any firm to implement the standard without infringing on the IPs over them (Bekkers, Catalini, Martinelli, & Simcoe, 2012). These letters can take the form of “specific disclosure,” which lists patents and claims over the technically essential components, or “blanket disclosure,” where the firm states broadly its ownership of IP over the particular area without links to

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2 An example in communications network is IEEE 802.11. This is a set of standards over technologies that allow laptops, phones, printers, and so on to join a wireless LAN (local area network). It includes the Carrier-sense multiple access with collision avoidance (CSMA/CA), which is a collision avoidance protocol at the core of the transmission system that allows data to link between two sending nodes so that information can be transferred. All complementary physical layers (such as routers and devices) rely on this protocol. Another related standard is the enhanced distributed channel access (EDCA) protocol, specified in the 802.11e, which is essentially a quality-of-service enhancement. The EDCA process decides which transmission channel should be heard first, and is central to having high-quality Voice over Internet Protocol (VoIP) in the WLAN system.

3 We thank a seasoned industry practitioner for providing immensely helpful insights on the standard-setting process. This practitioner is an R&D manager who has served as the standard-setting representative for Motorola and Nokia on various occasions in the past decade to work on multiple standards related to: Location Interoperability Forum (LIF) for location technologies, Open Mobile Alliance (OMA), browsing technologies (XHTML, HTML4), W3C Internet standards, and so on and has also chaired device capabilities working groups during standard setting.

4 “Commercially essential” IP, such as ones protecting methods of implementation that enable substantial quality improvements or cost reductions, are not required to be disclosed during this process.
patents. “Blanket disclosure” is especially useful to firms with large and complex patent portfolios, who may have incentives to be part of standards but face prohibitively high costs of searching through their portfolios to precisely determine the relevant patents and claims for each disclosure (Updegrove, 2007). Both the process of standard setting and membership to SSOs are typically designed explicitly to be inclusive.

A firm’s disclosure decision is strategic in nature, driven by considerations of potential gains or losses. Disclosure enables the firm to coordinate development across complementary technologies in the ecosystem and to ensure that they are compatible (Chiao et al., 2007; Kapoor & Lee, 2013). This allows other forms of network externalities (Katz & Shapiro, 1986; Schilling, 2002) to emerge, which sustain and enhance value-creation by the firm’s technologies. Past research shows that the firm’s disclosed technology becomes more valuable and central after disclosure, as indicated by citations received and litigation rates (Rysman & Simcoe, 2008; Bekkers, Catalini, et al., 2012). The firm with higher-quality technology tends to “forum-shop” for SSOs more “friendly” toward itself, so that it gets to provide less concessions (e.g., attractive rates to licensees) subsequent to standard formation (Chiao et al., 2007; Lerner & Tirole, 2006). Also, as the process could entail active negotiations between firms with competing technologies vying to be the standard, the firm has to consider its influence in the SSOs (Leiponen, 2008) and be mindful of potential delays and “war of attrition” before consensus is reached (Farrell & Simcoe, 2012).

Disclosures to SSOs are not costless. The disclosing firm has to agree to subsequently make available the use of its technologies, as specified in the essential patent claims, to other firms via licensing. This technically covers even technologies implicitly included in “blanket” disclosures. Most SSOs commit to using FRAND licensing terms, even though they usually do not define exactly what FRAND terms mean. The uniqueness of the technology reduces (Barney, 1991), which is costly to the firm given the typical importance of disclosed technology. The firm loses exclusive use over this technology and the ability to “bottleneck” rivals along its technological trajectory, slow down their development in areas that require this technology, or deter them altogether from a particular technological space (Clarkson & Toh, 2010). Knowledge related to the disclosed technology, and beyond, may be leaked to rivals during the disclosure process and licensing, allowing rivals to expand on its use either in the focal or related areas, in essence to reduce the firm’s generative appropriability (Ahuja, Lampert, & Novelli, 2013; Rosenkopf et al., 2001). These losses may not be fully

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5 In practice, the precise boundaries of IP coverage in patent claims are often ambiguous, especially for broader claims, and determining the relevant set of patents for each standard is far from straightforward.

6 Our understanding is that, in part because of the voluntary nature of SSOs, there is no fixed way that the standard-setting process across SSOs and standards would proceed. A typical process is as follows. It starts with an open call for all members to mention their own IP, or their awareness of others’ IP, over technologies that are relevant to the standard. Not all IP mentioned would necessarily be included in the standard eventually. Technical committees and workgroups are formed, with representatives from participating firms, to develop the exact specifications and direction for the standard. Members who are actively working on the related technologies would tend to be on these committees, as they have incentives to try to influence the development of the standard in their favor, or at least as a defensive move to reject standard developments that would be detrimental to them (Ranganathan & Rosenkopf, 2014). Following that, members with relevant IP then officially disclose to the SSO through declaration letters, so as to formally establish the standard. While members who did not participate in the technical committees can also disclose, most of the essential technologies disclosed would usually come from the participating members.

7 When a standard is being developed by an SSO, all firms that are active developers or users of the standard technologies tend to be members of the SSO. Attaining membership does not come with a high hurdle; the firm pays a nominal fee to be a member. As the main goal of SSOs is to create widely adopted standards and facilitate implementation, all members and nonmembers are given easy access and equal rights to license technologies covered under the standard. The SSOs sometimes impose ceilings on licensing fees, so as to ensure availability. The SSOs also do not restrict members from joining or leaving, and memberships change over time, depending on which standards are being worked on. Not all members are active contributors. For instance, it is not uncommon for incumbent network operators who are mostly users of technologies to remain passive in SSOs.

8 Even when the firm’s representative in standard committees neglected or failed to mention certain patents before, as long as the firm has been in the committee for a certain period of time (e.g., more than 60 days), it is liable to disclose these patents and agree to license them out, if it chooses to be part of the standard.

9 While this ambiguity may put a participating firm at risk ex post (e.g., if other firms with standard essential technologies subsequently renege on the FRAND commitment), there are other mechanisms in place to protect the firm. For example, the “defensive suspension” term often included in these licenses allows the firm to revoke the license to other implementers, who subsequently assert their patent licensing under non-FRAND terms (Updegrove, 2007).

10 Firms are indeed aware of potential leakages and would tend to send only experienced managers, who are better equipped to guard against such leakages, to be representative at standard-setting activities.
recouped through licensing revenue, especially as FRAND terms are ex ante imprecisely stated, and often end up being negotiated “middle-ground” outcomes that are not always favorable to the disclosing firm (Updegrove, 2007). When multiple licensors are involved and patent pools are used, the licensing fees end up being split among many parties. In recent years, there is even a push toward royalty-free licensing. Other costs to the disclosing firm include strategic gaming by rivals or delays (Farrell & Simcoe, 2012; Updegrove, 2007).

The firm can opt against disclosure, and drop out of the technical committees in the middle of development. This happens often because the firm is unwilling to license out its technology, at FRAND rates or at all, or is not satisfied with the direction of the standard development. In this case, the SSO would usually try to remove previous contributions of this firm to the standard, and work the standard around or steer it away from this technology, or halt the development of that standard altogether. This is to avoid costly legal disputes over infringements or subsequent hold-up by nondisclosing parties. The firm would then have to rely on market shares and “bandwagon” effects to try to establish its technology as de facto standard instead (Chiao et al., 2007; Farrell & Saloner, 1988). The firm’s decision not to disclose has no bearing on its membership or its ability to eventually access the standard-essential technologies via licensing.

**Complementary Technologies and Their Effect on Disclosures**

In this section, we discuss complementary technologies and their effect on the firm’s disclosure to SSOs. “Complementary technologies” refers to the different technologies within an ecosystem where the value creation from one increases in the presence of the other (Milgrom & Roberts, 1990). Past research differentiates this term from “similar technologies” (Makri et al., 2010), but sometimes subsumes it under the broader term of “related technologies” (Ahuja & Katila, 2001; Cassiman et al., 2005). To more clearly separate the adjacent terms, it helps to go past the classic notion of value dependence (Milgrom & Roberts, 1990) and specify what leads to this value dependence. One way is to conceive complementary technologies as solutions to different, more narrowly defined modules of problems within a broader overarching problem (Larsson & Finkelstein, 1999). They are related in the sense that they are often used in tandem and built on jointly in subsequent technologies, because they represent separate integral parts of a solution (Ahuja & Katila, 2001; Cassiman et al., 2005). To more clearly separate the adjacent technologies, we differentiate this term from “similar technologies” (Makri et al., 2010), but some-
& Katila, 2001; Galunic & Rodan, 1998). They are closer to horizontal, interdependent knowledge counterparts (Adner & Kapoor, 2010), rather than supporting assets along the vertical value chain like downstream production facilities (Teece, 1982; Wu et al., 2014).

It is common for a firm to own and develop multiple complementary technologies within a system. This is not surprising, given that the firm with invisible and underutilized resources would expand into related technological areas, resulting in the firm having complementary technologies (Levinthal & Wu, 2010; Penrose, 1959). The firm would also consciously acquire these complementary technologies, for the purpose of recombining them to create new technologies (Ahuja & Katila, 2001; Cassiman et al., 2005).

When a firm owns complementary counterparts to a focal technology, it faces a tradeoff in disclosing this focal technology to SSOs. We separately lay out the two opposite effects below. Having complementary technologies exerts a positive influence on the firm’s likelihood of disclosing the focal technology, as the firm stands to profit from these (nondisclosed) complementary technologies as well through the disclosure. Simply put, the firm with complementary technologies has “more to gain” from disclosure. For instance, when Qualcomm discloses its IP over core technology in the Code Division Multiple Access (CDMA) standard, its gains extend beyond the increased value to the CDMA technology per se; the value of its CDMA-based transmission technologies and customer premise equipment may also increase. This happens via the following mechanisms.

First is the increase in overall compatibility. The firm’s disclosed technology is compatible by design to its own complementary technologies, as part of its larger “blueprint” or platform (Baldwin & Woodard, 2009; Rosenkopf et al., 2001). As the disclosed technology becomes the industry standard, other firms designing other parts within the ecosystem outside of the areas of the firm’s disclosed technology and complementary technologies, in fitting to the standard, will tend to align features to the focal firm’s complementary technologies as well. Compatibility of the firm’s complementary technologies to other parts in the ecosystem is enhanced, and their commercialization value rises (Ranganathan & Rosenkopf, 2014).

Second is the increase in gains from influencing future developments. Participating in standard setting increases the firm’s influence, enabling it to remove technical hindrances in its own platform’s development, prevent potential rivals’ technological “road blocks” from surfacing, and shape the direction of technological developments in its favor (Dokko & Rosenkopf, 2010; Leiponen, 2008; Ranganathan & Rosenkopf, 2014). Through coordination, the firm can influence the manner in which the network of technologies evolve (Doz, Olk, & Ring, 2000; Garud, Jain, & Kumaraswamy, 2002). The firm with complementary technologies has more to gain from such influence, as it can shape the standard and steer the direction to fit, not just the disclosed technology, but also its proprietary complementary technologies in the system (Dokko et al., 2012; Rosenkopf & Tushman, 1998). In doing so, it increases future profits from its complementary technologies. Likewise, it can steer the design of system features to block rivals and exclude them (Bekkers, Catalini, et al., 2012) not just for the disclosed technology, but also for its complementary components in the system. Moreover, in terms of shaping technological development to protect the firm’s related downstream assets (Teece, 1986; Mitchell, 1989) and to reduce costly reconfiguration should a competing standard emerge (Eggers, 2012; Toh & Kim, 2013), the firm with complementary technologies again has more to gain, as it likely has more specific downstream assets that go with them.

Even if the disclosed technology by itself ends up generating zero or negative returns to the firm, because of royalty-free licensing agreements or excessive expropriation by others of the disclosed technology per se, the disclosure may still be worthwhile to the firm. This notion arises from the familiar ancient Chinese military stratagem, “Giving up a pawn to save a chariot,” where the basic strategy is to sacrifice an asset of value to protect other assets of greater value. Based on the two above mechanisms, we establish the first hypothesis.

**Hypothesis 1a (H1a): The more that the firm possesses technologies complementary to its focal technology, the more likely it will disclose the focal technology during standard setting, as it stands to profit from these (nondisclosed) complementary technologies via such disclosure.**

We now lay out the other side of the tradeoff. Having complementary technologies also exerts a negative influence on the firm’s likelihood of
disclosing the focal technology, as the firm risks greater expropriation of its (nondisclosed) complementary technologies via such disclosure. As explained earlier, disclosure entails cost—losing uniqueness over its disclosed technology, since it is required to license out the technology to other firms. With this loss comes greater expropriation risk, which has traditionally been a major concern in technology strategy (Clarkson & Toh, 2010; Lieberman & Montgomery, 1988; Rivkin, 2000). As other firms obtain the right to use the firm’s focal technology, they not only exhaust the current market potential of the technology, but also start to build on them and exploit opportunities for further developments (Ahuja et al., 2013; Murray & O’Mahoney, 2007).

Members of SSOs relevant to the firm are likely candidates of such expropriation. Being the most active firms in areas surrounding the standard, they are potential licensees of the disclosed technology. As they use the firm’s technology, they do not only compete with the firm in the market for the technology’s current use, but also, they learn more about the knowledge within the technology. Even if they had a prior sense of the broad premise of such knowledge, with actual use comes greater depth in the understanding of how it works, and what constraints or problems could emerge in its use (Eisenhardt & Tabrizi, 1995; Katila & Ahuja, 2002; Toh, 2014).

An added problem for the disclosing firm with complementary technologies is that these potential expropriators start to learn more about its complementary technologies as well, even if the complementary technologies are not officially part of the disclosure. Initially, the firm’s set of integrated technologies within a “blueprint” may have made it harder for competitors, observing from afar, to figure out how the system works (Rivkin, 2000), much like a well-protected fort that is difficult to penetrate. But with deep knowledge of the disclosed technology comes the understanding of how complementary technologies fit. Once these competitors have access to an integral (disclosed) piece of the set, they start to understand the other pieces as well, ironically because of the integration and relatedness between them. The disclosure has just created an “access point” for competitors to break into the firm’s otherwise well-protected system, much like “lowering a drawbridge to let enemies into the fort.” This leaked knowledge enables competitors to develop their own complementary technologies within the system in a Penrosian sense (Levinthal & Wu, 2010; Penrose, 1959). The natural trajectory then is for them to expand into these complementary areas as well, and start to erode the firm’s returns in these areas. Because of this potential loss, the firm with complementary technologies has “more to lose” from disclosure, and hence may be less inclined toward disclosure in the first place. This leads to the next hypothesis.

**Hypothesis 1b (H1b): The more that the firm possesses technologies complementary to its focal technology, the less likely it will disclose the focal technology during standard setting, as it risks greater expropriation of these (nondisclosed) complementary technologies via such disclosure.**

Next, we examine a contingency that accentuates the relative strength of the positive influence (H1a) over the negative one (H1b). A key logic in H1a is that the firm is more likely to disclose the focal technology as it stands to appropriate greater returns from its other technologies elsewhere in its portfolio. Thus, the appropriation condition surrounding the firm’s other technologies, in areas other than that of its disclosed technology, must matter. We turn to a salient determinant of appropriation—competition, specifically, the extent to which the firm’s technological areas (outside of the area of the focal disclosed technology) are crowded with competitors (Clarkson & Toh, 2010; Katila & Chen, 2008).

The more obviously relevant competition is that within the areas where the firm’s complementary technologies reside. Recall mechanisms in H1a: through disclosure, the firm improves compatibility, of not only the disclosed technology but also its complementary technologies, to the remaining parts of the ecosystem developed by others (first mechanism). This strategy, of improving complementary technologies’ compatibility with the rest of the system, would be more profitable if the firm does not face competition in areas in which its complementary technologies reside. If there are competitors with similar offerings in the complementary areas, and they would also gain in compatibility accordingly as the firm discloses its focal technology during standard setting, then ex ante the firm’s own complementary technologies do not
provide as compelling a case for disclosure. Likewise, disclosing so that the firm can influence development in the rest of the ecosystem to benefit the firm’s complementary technologies (second mechanism) is most beneficial if the firm does not face competitors in the areas where its complementary technologies reside. Again, competitors working with similar technologies in the same space erode the expected profits from, and thus ex ante the reason to employ, this strategy.

Competition outside of the complementary technologies’ areas (and outside of the focal disclosed technology’s area), while less obvious, also plays a crucial role. In fast-moving environments such as the communications equipment industry, alternative technologies emerge rapidly. The firm faces a real threat of rivals coming up with alternative technologies that complement its focal (disclosed) technology but that are based on different approaches (Mitchell, 1989; Polidoro & Toh, 2011; Wade, 1995). For instance, while Microsoft’s software used to be the only complementary ones to the Windows operating system (OS), equivalent web-based software has emerged in recent years that could also complement the Windows OS. As per above, this form of competition also erodes the firm’s expected profits from the improved compatibility and influence over its complementary technologies resulting from its disclosing of the focal technology. Thus, the firm expects the strategy of disclosure, laid out in H1a, to be more effective when it faces fewer competitors in not only the complementary technologies’ areas, but likely all relevant technological areas that it operates in outside of that of the focal disclosed technology.

Conceptually, we may see a more positive main effect overall, with fewer abovementioned competitors, because H1b has weakened rather than because H1a has strengthened, as we argued. In other words, with fewer competitors in areas outside of the focal disclosed technology, maybe the firm sees less threat of rivals learning about its complementary technologies through licensing its disclosed technology, and hence it is more willing to disclose to SSOs. For this argument to hold true, an additional assumption is needed: these competitors, in areas outside that of the focal disclosed technology, are also active in the focal area, so that they are positioned to expropriate the firm’s knowledge as it discloses the focal technology. As we demonstrate later within our empirical setting, this argument does not appear to hold, or to be driving our main findings. Nonetheless, we do not rule out its possibility, and indeed do not need to, as it serves to strengthen our prediction. Based on all above arguments, we arrive at the following contingency hypothesis.

Hypothesis 2 (H2): The less crowded the firm’s technological areas outside of the focal technology’s area, the more the firm’s complementary technologies will increase its likelihood of disclosing the focal technology during standard setting.

We now turn to a contingency that accentuates the negative influence (H1b) over the positive one (H1a). The main logic in H1b is that the firm is less likely to disclose the focal technology when it stands to “lose more,” as SSO members license its disclosed technology and learn about its complementary technologies as well. Not all firms, or in this case SSO members, can equivalently expropriate the focal firm’s technologies. It depends on how quickly and effectively they can learn and absorb new knowledge (Cohen & Levinthal, 1990).

These SSO members’ abilities, to learn and expropriate the firm’s complementary technologies via licensing its disclosed technology, accumulate through their experiences in managing systemic technologies (Helfat & Eisenhardt, 2004). For expropriation to occur, they need to figure how the firm’s set of technologies function individually and are linked together, primarily by observing and using the central piece of disclosed technology. These linkages between technologies are not always easily understood, even if the explicit technical specifications are made clear. Rather, learning requires use and reuse, guided experimentation and repeated trial-and-errors (Clarkson & Toh, 2010; Nerkar & Roberts, 2004). The greater the potential expropriators’ experiences, the more they are able to unpack and comprehend the linkages.

When the firm with complementary technologies senses expropriators (SSO members) with strong
expropriation abilities, its potential loss is greater, and hence it is ex ante less inclined toward disclosure, even if such disclosure could elevate the value of its overall set of technologies. Enhancing its compatibility within, and influence over, the entire ecosystem means less to the firm, when more parts of the firm’s technologies are expropriated by others. This reaches the heart of a fundamental tradeoff that a firm faces with competing systems (Peteraf & Bergen, 2003; Polidoro & Toh, 2011): to control a smaller part of a more dominant system, or to control a bigger part of a less dominant system. Based on the above, we arrive at the next hypothesis.

**Hypothesis 3 (H3):** The greater the SSO members’ abilities to expropriate others’ technologies, the more the firm’s complementary technologies will decrease its likelihood of disclosing the focal technology during standard setting.

**Method**

We test our propositions with data on the US communications equipment industry in 1991–2008. This setting involves multiple types of technologies, such as mobile handsets, wireless local area networks/Wi-Fi, and cellular data technologies, and they often need to be interoperable and thus require coordination in development. Firms in this industry are highly R&D-intensive, and the ability to appropriate returns from technologies is a nontrivial issue within this setting.

We use multiple data sources to construct our sample. We gather data on firms’ disclosures to SSOs in the industry from www.ssopatents.org (Bekkers, Catalini, et al., 2012). Patent data is collected from the US Patent and Trademark Office (USPTO). We obtain citations data from the National Bureau of Economic Research (NBER) (Hall, Jaffe, & Trajtenberg, 2001). Firms’ financial data and SIC codes are from the Compustat database. The sample starts with firms active in the 89 USPTO technology classes related to communications equipment as per the NBER concordance system. After matching with the other databases, the sample consists of 500 firms over the sample period.

**Variables**

As the propositions are tested at both patent and firm level, we separately detail how we construct variables at each level when appropriate. To construct the dependent variables, we first trace firms’ disclosure letters sent to the eight main SSOs in communications standard setting as follows.

The American National Standards Institute (ANSI) coordinates standard organizations in the United States, managing disclosures associated with the telecommunications industry and covering technologies like cellular telephony protocol (TDMA) and digital subscriber line (DSL). The Alliance for Telecommunications Industry Standards (ATIS) sets standards for telecommunications networks and technological interoperability. European Telecommunications Standards Institute (ETSI) operates various telecommunication standards in Europe, such as Global System for Mobile communication (GSM) cellular technology. The Institute for Electrical and Electronic Engineering (IEEE) is involved with notable telecommunications standards, for example, the IEEE 802 LAN/MAN, 802.3 Ethernet standard and the 802.11 Wireless Networking standard. The Internet Engineering Task Force (IETF) focuses on Internet standards and protocol. The International Organization for Standards (IOS) is an international body that coordinates various international standards. The International Telecommunications Union (ITU) works on broadband, wireless technologies, aeronautical and maritime navigation, radio astronomy, satellites, mobile phones, and voice over Internet protocol (VoIP) standards. The Telecommunications Industry Association (TIA) sets standards for cellular towers, satellites, telephone equipment, VoIP, and structured cabling. These eight SSOs cover the main standards in our context; even when a firm discloses to other less-prominent SSOs, it usually discloses to one of these as well.

We trace 4,422 disclosure letters from 1971 to 2008, 97% of which were sent between 1991 and 2008.
2008. Manually matching letters to firms, we identify 1,208 telecommunication-related disclosures from 69 firms. There are 349 firm-year observations in which a firm has at least one disclosure. A firm may make multiple disclosures per year. For the patent-level dependent variable (Disclosure), we restrict to disclosures with traceable patents. Disclosure equals “1” if the patent was ever disclosed to an SSO and “0” otherwise. To minimize right truncation (e.g., patents filed in 2008 and disclosed after), we restrict to patents applied no later than 2004. To create the firm-level Disclosure, we do not impose the restrictions of keeping only disclosures with traceable patents or patents before 2004, so as to include “blanket” disclosures. Firm-level Disclosure equals “1” if the firm makes at least one disclosure in the year and “0” otherwise.

The main independent variable Complementary Technologies captures whether the disclosed technology has complementary technologies across areas within the firm. This measure uses instances of the firm’s patents from different technology classes being jointly cited to indicate complementarities, drawing on the established principle that realized combinations of technologies reflect complementarities between them (Fleming, 2001). We consider two jointly cited patents as complementary only if they are from different classes, since patents in the same class may refer to separate and integral components of the same technology, indicating similar rather than complementary technologies (Makri et al., 2010). The patent-level measure is coded as “1” if the patent in year \( t \) is jointly cited, in the 5 years from (including) \( t \), with at least one other of the firm’s patents from another class in year \( t \), and “0” otherwise. This patent-level measure drops instances where the patent in another class, jointly cited with the focal patent, is itself disclosed, to ensure that it only counts up instances where complementary counterparts to the focal patent are not disclosed. To construct the equivalent firm-level measure, for each year \( t \), we count the instances where a pair of the firm’s patents filed in the year across different classes were cited jointly (by any patent) in the subsequent 5 years (including \( t \)). We treat multiple citations received by a pair as one instance, so as not to conflate the measure with attributes of quality or importance of the pair associated with citation frequency. We then scale the resultant count by dividing it over the total number of potential pairs of the firm’s complementary technologies as defined by the above criteria.\(^{19}\) For ease of interpretation, we report the measure in percentages.

Our Complementary Technologies measures, by capturing joint usage (citations) of patents, represent a refinement on Makri et al. (2010), who treat all patents in different classes but within the same broad technology subcategory as being complementary. They have some similarity with the “combination familiarity” measure in Fleming (2001), though we measure joint citations of the firm’s patents instead of joint citations of classes, since our focus is on the firm’s technologies that are complementary to each other, not whether technologies across two classes are usually complementary. As not all technologies are patented (Cohen, Nelson, & Walsh, 2000), these measures may not completely capture all complementarities within the firm’s portfolio. This problem is somewhat mitigated by our single-industry focus, as patenting propensities tend to be stable across firms within an industry. Moreover, patenting is relatively common in telecommunications and is usually a reliable descriptive of a firm’s technology position (Hausman, Hall, & Griliches, 1984; Henten, Falch, & Tadayoni, 2004).

The first contingency variable (Crowdedness) is the extent that technological areas in which the firm is involved, outside of the focal technology’s area, are crowded with competitors. For each technology class in which the firm files for patents in the year, we count the number of other firms that also file for patents in the class. We then take the average of these counts across all classes in which the firm files for patents in the year. For patent-level analyses, we are able to exclude the technology class of the focal patent from this calculation, so that the measure only captures crowdedness in other areas of the firm as we theorized. For the firm-level analyses, as the dependent variable also captures “blanket” disclosures where the focal technology class cannot be determined, we include all classes that the firm patents in the year in this calculation.

The second contingency variable (SSO Expropriation) refers to the extent that there are other firms

\(^{19}\) For example, suppose a firm has four patents (A, B, C, D) in year \( t \), each assigned to a different class. Thus, there are six pairs of patents potentially being cited jointly, as per the binomial coefficient \( \binom{4}{2} = 6 \). If two pairs, A-B and A-C, are jointly cited in the subsequent 5 years, then the complementary technology measure for this firm-year is 2/6 or 33%.
with strong expropriation abilities that are active in the SSOs that are relevant. For the first part of this measure—"other firms with strong expropriation abilities that are active in the SSOs"—we ideally want to identify all (nonfocal) firms that are active in each SSO in each year. However, the membership list for SSOs is only available for 2013. As a starting point, we use the 2013 list of firms in each SSO and begin by assuming that these firms are also present in the same SSO in prior years. Next, to add active firms in prior years that are not on the 2013 list, for each SSO-year, we supplement the list with firms that have disclosed to the SSO during the year.20 We then identify, for each SSO-year, the (nonfocal) firm with the maximum21 number of disclosures over the prior 5 years. This experience-based measure serves as a proxy for the (nonfocal) firm’s abilities to understand linkages between technologies and expropriate accordingly.22

For the second part of this measure—"SSOs that are relevant"—at the patent level, we need to identify SSOs that are potentially relevant to the focal patent. For each SSO, we compile all traceable patents that were parts of disclosures to this SSO in the year, and identify their assigned technology categories. With this SSO-category match, we then deem an SSO to be relevant to the focal patent, if the focal patent is in one of the matched categories to the SSO. To create the patent-level measure SSO Expropriation, we take the average of the above experience measure across all SSOs to which the focal patent is matched.

For the second part of this measure at the firm level, we need to determine the relevant SSOs to which the firm is at hazard of disclosure. Using the firm’s SSO memberships is inadequate, as the firm may choose not to be a member of, or disclose to, an SSO, if it is deterred by expropriation risks from other firms active in that SSO (as per our prediction), even when the SSO is highly relevant to the firm. Instead, we rely on the nature of IP to link the firm to relevant SSOs. For each SSO, we compile all traceable patents that were parts of disclosures to this SSO in the year, and identify their assigned technology classes. We deem an SSO to be relevant to the focal firm, if the firm files for at least one patent in these classes associated with disclosures to this SSO in the year. Finally, to create a firm-year level measure of SSO Expropriation, we take the average of the above measure across all SSOs to which the focal firm is matched.

We include various firm, technology, and environmental factors as controls. We control for a firm’s R&D expense and Total Patents measured as the natural log of the firm’s total patent applications in the year, as R&D and having more patents may increase the likelihood of the firm having more complementary technologies as well as standard-essential ones. Larger firms may have more incentives to participate in SSOs. We include the natural log of total assets (Firm Size). Firms with wider knowledge bases may create more complementary technologies. To account for such breadth, we include Citation Scope, measured as one minus the concentration ratio of the firm’s backward patent citations to patents across technology classes.23 The firm’s financial structure may affect its ability to commercialize technologies and influence its propensity toward disclosure. We account for this with Leverage, measured as firm’s total long-term debt to equity ratio, and Liquidity, measured as the natural log of the firm’s cash and short-term investments. To account for firms’ Performance, we add earnings per share. Firms’ operating in technologically mature areas may be less likely to participate in standard setting because their focal area is already extensively standardized. To control for this effect, we start with the notion that mature areas tend to have wider breadth of backward citations. For each

\[ \text{Citation Scope is 1-HHI index.} \]

20 By assuming member-firms in 2013 were also members of the same SSO in prior years, the measure potentially overestimates expropriation risk, if the SSO-member-firm in 2013 identified as having the greatest number of disclosures did not actually exist or was not active in the SSO prior to 2013. This is problematic if the second most experienced firm that did exist in prior years had substantially fewer disclosures. To check our measure’s sensitivity to this problem, we replace, in each SSO-year, the greatest number of disclosures with the second greatest, and separately with the average of the top five disclosing (nonfocal) firms instead. All subsequent findings remain robust. Thus, we are reasonably confident that our measure is not sensitive to this problem arising from our starting-point assumption.

21 We use maximum, instead of average, because the nonfocal firm with the most experience represents the more relevant expropriation risk to the focal firm. In the communications equipment setting where new (superior) product introductions are usually rapid and the market exhibits more of the winner-takes-all characteristics, the average, by including nonfocal firms with low expropriation abilities, is likely noisy and less relevant to the focal firm.

22 We alternatively use a similar measure based on other firms’ downstream abilities, rather than on their disclosures, and obtain robust findings. Please refer to Appendix S1.
class in a year, we calculate a concentration ratio, across classes, for all backward citations made in all patents. We then take the average across classes in which the firm patents in during year $t$ to construct firm-level Technological Maturity. To capture unobserved year-specific factors, we include year dummies. In the patent-level analyses, we additionally control for Backward Citations—the number of citations made by the patent, capturing the depth of knowledge used and whether the patent is more or less derivative (Lanjouw & Schankerman, 2004), as well as Breadth of Citations—the number of different technology classes cited by the patent, serving as a proxy for the diversity of knowledge used in the invention. To further control for unobservable characteristics of the technological area the patent is in, we also include Technology Category Dummies in the patent-level analyses.

In the firm-level analysis, we build in a time lag of 5 years between the dependent and explanatory variables, to reflect the time lapse between early stage technology creation and disclosure to SSOs. We chose 5-year lag as it is the median time between patent filing and disclosure for the 4,229 traceable patents in disclosures between 1971 and 2008 in our sample.

### Empirical Models and Findings

Table 1 contains descriptive statistics and correlations. Approximately 0.3% of our sample patents are disclosed to SSOs, while 10% of patents have at least one complementary patent. Seven percent of firm-year observations make at least one disclosure to SSOs. On average, 1.66% of all possible pairs of a firm’s patents across classes are complementary (mean of Complementary Technologies). We separately find (not in table) that about 22% of firm-year observations have Complementary Technologies with a value greater than zero, and among them, the average and standard deviation are 7.5 and 18.8%, respectively.

We examine our claim, early on in the article, that firms involved in disclosures tend to own different technologies within the ecosystem. We separate the sample into specialist firms (single technology class) and wide scope firms (more than one class), and further separate wide scope firms into ones with complementary technologies and ones without. Figure 1 displays the number of disclosures per year by these firms. Wide scope firms disclose almost six times more per year than specialists (0.4 vs. 0.07, $t$ test for difference in means has $p$ value of .000). Much of this difference is driven by wide-scope firms with complementary technologies: they disclose over 10 times more than specialists and 4 times more than wide scope firms without complementary technologies. We then isolate firms with the highest quartile of scope and find even more pronounced abovementioned patterns. We separately compare (not in Figure 1) firms that have complementary technologies with firms that do not. We find that 18.5% of observations with complementary technologies disclose to SSOs, whereas only 3.8% of observations without complementary technologies disclose to SSOs. These findings are in line with H1a.

### Patent-Level Analyses

#### Logit

Logit. Table 2 reports logit regressions of Disclosure using the patent-level data. In the full-sample Model 1, the coefficient of Complementary Technologies is positive ($p$ value .000). Using the average partial effect (APE) (0.004), we find that having complementary technologies more than doubles the probability of being disclosed (0.4%) over the unconditional disclosure probability (0.3%). To account for unobserved firm-specific factors, we reestimate Model 1 with firm fixed-effects, and find similar results (Complementary Technologies coefficient 0.57, $p$ value .005). To control for unobserved firm heterogeneities within specific technological area, we also estimate Model 1 with firm-technology class fixed-effects, and find similar results (coefficient 0.65, $p$ value .003). Overall, these results support and favor H1a over H1b.

Models 2–5 test the contingency hypotheses. We use the split-sample approach instead of the conventional interaction terms, since interpreting coefficients of interaction terms in nonlinear (logit)
models could be erroneous if the main variable value varies systematically at different levels of the contingency variable (Polidoro & Toh, 2011). To test the contingency hypotheses, we split the sample into two subsamples based on whether the observation has above or below median value on the contingency variable (i.e., Crowdedness or SSO Expropriation).

**Complementary Technologies** is negative (APE = 0.002) in Model 2 where Crowdedness is high. In Model 3 where Crowdedness is low, Complementary Technologies increases the likelihood of disclosure by 1% point (APE 0.01; p value .000). This aligns with H2, suggesting that the effect of complementary technologies is more positive when there are fewer competitors in technological areas (outside of focal technology’s area). To formally test H2, we compare the difference in the APE of Complementary Technologies across the two subsamples using Welch’s t test.26 We find

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26 Welch’s t test allows for the split samples to have different size and variance.
that the difference is $-0.01$ ($p$ value of .000). This supports H2.27

We test H3 similarly in Models 4–5. The effect of Complementary Technologies is small in Model 4 where \textit{SSO Expropriation} is high (APE 0.001; $p$ value .093), while much larger in Model 5 where \textit{SSO Expropriation} is low (APE 0.01; $p$ value .000). This aligns with H3, suggesting that having complementary technologies increases likelihood of disclosure less when there are other SSO members with strong expropriation abilities. The difference in APE of Complementary Technologies across the two models is $-0.01$ ($p$ value of .048), which support H3.28

27 To show that findings for H2 are illustrating the increased benefits of disclosure (increased compatibility and influence) and not just decreased cost of disclosure (expropriation risk), we add a control of count of competitors patenting in both the focal as well as complementary technology areas. These competitors are more likely to be expropriators than competitors who are not operating in the focal disclosed technology area. Even with this control, findings remain robust, suggesting that our findings for H2 are not just demonstrating reduced expropriation risk.

28 The dependent variable does not capture attributes (importance) of the disclosed patent. One could argue that having a complementary counterpart results in greater likelihood of being disclosed because the focal technology is more important, rather than because of the mechanisms we theorized. To examine this possibility, we use the total citations a focal patent receives in the 5 years following disclosure (excluding self-citations) as a control for “importance,” and rerun all patent-level logit regressions with this additional control. We also separately use an alternative control of the total citations received by the patent prior to disclosure instead, to capture importance of patent without being affected by disclosure per se. All findings remain largely robust. Next, we directly test whether Complementary Technologies increases a patent’s importance, measured as citations received by the focal patent prior to disclosure, and include as independent variables: Complementary Technologies, Crowdedness, SSO Expropriation, and four additional variables that might drive citations—the firm’s total patents, firm’s R&D spending, firm size, and firm performance (measured as ROA) —and year dummies. We use OLS, OLS with firm fixed effects, Negative Binomial, fixed-effect Negative Binomial, and fixed-effect Poisson with robust standard errors via quasi-maximum likelihood. In all models, we do not find any significant effect of Complementary Technologies. Thus, there is no evidence to suggest that having complementary technologies leads to the disclosed patent being more important.

\textbf{Within-firm matching.} Coefficient estimates in the above logit regressions may be inconsistent, due to remaining unobserved factors (e.g., technology attributes) that systematically select patents into either having or not having complementary counterparts, or that both induce the patent to have complementary counterparts as well as to be standard-essential. Even though we tried to suppress this concern with control variables, contingency effects, and fixed-effects, this selection problem may still exist. To further suppress these unobserved factors, we conduct a within-firm patent matching using the “nearest neighbor” matching method. We begin by separating the sample into treated (Complementary Technologies equal to 1) and untreated (Complementary Technologies equal to 0) patents. We then match each

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Number of disclosures per year by types of firms.}
\end{figure}
treated patent to an almost identical counterfactual(s), that is, untreated patent(s), and compare the difference in likelihood of disclosure between the pair. For each treated patent, we compile a set of untreated patents only from the same firm, technology class, and year. Within this set, we then further match on two continuous variables that reflect attributes of the underlying technologies: Backward Citations and Breadth of Citations. We match the treated patent to a minimum of one “nearest neighbor” untreated patent within the set, based on the lowest Mahalanobis Distance on these two variables. Upon creating these matches, we compute the bias-adjusted average treatment effect on the treated (ATET) (Abadie, Drukker, Herr, & Imbens, 2004; Abadie & Imbens, 2011). This

When there are multiple untreated patents within the set with the same distance, the matching algorithm takes the average across them. It is possible to specify each treated patent to be matched to a higher minimum number of untreated patents, with minimum distance. Choosing a higher number of minimum matched counterfactuals for each treated patent comes with a tradeoff between consistency and efficiency: more matches increases the potential bias but decreases the variance in the estimate. As a robustness check, we separately rerun this procedure using a minimum of three matches and a minimum of five matches, and find very similar results.

Nearest neighbor match using continuous covariates is non-parametric, which makes it flexible. However, it also converges at a rate less than $\sqrt{N}$, which makes it potentially inconsistent even in infinitely large samples. To correct for this potential inconsistency, we use the adjustment that makes the estimate $\sqrt{N}$ consistent and asymptotically normal. This basically combines our nearest neighbor matching and a regression adjustment to create

This technique potentially excludes firms with fewer patents: they may not have both treated and untreated patents in the same technology class in the same year, and hence may be dropped during matching. We use a propensity-score matching method that circumvents this potential problem. Findings remain robust (Appendix S1).

29 This technique potentially excludes firms with fewer patents: they may not have both treated and untreated patents in the same technology class in the same year, and hence may be dropped during matching. We use a propensity-score matching method that circumvents this potential problem. Findings remain robust (Appendix S1).
ATET essentially compares Disclosure between each treated patent and its counterfactual. In other words, ATET indicates how much more likely a patent with complementary technologies will be disclosed, relative to an almost identical patent without complementary technologies.32

Table 3 contains results of this analysis, displaying the estimated ATET, the z-statistics, and the sample size. Test 1 estimates ATET for the full sample. ATET is positive (0.38, p value .001), showing that patents with complementary technologies experience a 0.38% point increase in disclosure rate over what it would have been had the patent not have complementary technologies. This supports H1a over H1b.

To test the contingency hypotheses, we split the sample by the mean of each contingency variable, estimate ATET and standard errors for each subsample, and then compare the estimates across subsamples. When Crowdedness is high in Test 2, there are no instances of disclosure, thus ATET is zero. ATET becomes positive (0.75, p value .001) when SSO Expropriation is low (Test 3). Test 4 shows that the difference in ATET across the two subsamples is significant (p value .001), suggesting that the main positive effect of having complementary technologies (H1a) is only present when Crowdedness is low. This supports H2.

ATET is smaller (0.20, p value .049) in Test 5 where SSO Expropriation is high, while larger in Test 6 (ATET 0.60, p value .007) where it is low. Test 7 shows that this difference in ATET is large (~0.40, p value of .087) relative to the overall ATET. This suggests that the main positive effect of complementary technologies (H1a) is weakened when there are more firms with strong expropriation abilities active in SSOs relevant to the patent, which supports H3.

Firm-Level Analyses

Patent-level analyses exclude “blanket” disclosures (without traceable patents). If firms or technologies associated with “blanket” disclosures are systematically different in their tendencies to have complementary technologies, earlier findings could suffer from selection bias. While we believe this is unlikely given the conservative nature of above tests,33 here we further conduct firm-level analyses.

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32 This patent-level within-firm matching also serves to mitigate a potential omitted variable of “whether the firm or patent have had the opportunity to be disclosed in that year.” The dependent variable of “whether the patent ever gets disclosed,” by collapsing all years, subsumes the problem of “which year the opportunity to disclose arises.” The matched pair being from the same firm, technology class, and year accounts for whether the firm had the opportunity to disclose in that year, and also somewhat get at whether the patent had the opportunity to be disclosed (same technology class). The “close” distance in the two citation attributes between the matched pair further controls for whether the pair of patents have similar opportunities of being disclosed.

33 Excluding “blanket” disclosures earlier likely leads to conservative estimates of H1a, since technologies with complementary counterparts tend to be more complex, such that the firm owning them would more likely use “blanket” disclosures, as it is most costly for it to search through its complex portfolio to determine

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Table 3
Patent-Level Within-Firm Matching

<table>
<thead>
<tr>
<th>Test</th>
<th>Average treatment effect on the treated (pp)</th>
<th>A&amp;I robust standard errors</th>
<th>p Value</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Full model</td>
<td>0.38</td>
<td>0.117</td>
<td>.001</td>
<td>29,906</td>
</tr>
<tr>
<td>(2) High crowdedness</td>
<td>0</td>
<td>n/a</td>
<td></td>
<td>14,147</td>
</tr>
<tr>
<td>(3) Low crowdedness</td>
<td>0.75</td>
<td>0.234</td>
<td>.001</td>
<td>15,759</td>
</tr>
<tr>
<td>(4) High crowdedness–low crowdedness</td>
<td>−0.75</td>
<td>−0.234</td>
<td>.001</td>
<td>29,906</td>
</tr>
<tr>
<td>(5) High SSO expropriation</td>
<td>0.20</td>
<td>0.130</td>
<td>.049</td>
<td>15,395</td>
</tr>
<tr>
<td>(6) Low SSO expropriation</td>
<td>0.60</td>
<td>0.215</td>
<td>.007</td>
<td>14,511</td>
</tr>
<tr>
<td>(7) High SSO expropriation - low SSO expropriation</td>
<td>−0.40</td>
<td>0.233</td>
<td>.087</td>
<td>29,906</td>
</tr>
</tbody>
</table>

Note: Matching is as follows: exact match on firm, year, and technology class. Nearest-neighbor match using backward citations and breadth of citations via Mahalnobis Distance. To correct for bias from nearest neighbor match, we use Abadie & Imbens’s method.
Table 4  

**Firm-Level Logit Regressions**

<table>
<thead>
<tr>
<th></th>
<th>Model 1 Full model</th>
<th>Model 2 High crowdedness</th>
<th>Model 3 Low crowdedness</th>
<th>Model 4 High SSO expropriation</th>
<th>Model 5 Low SSO expropriation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complementary tech.</td>
<td>0.017</td>
<td>−0.065</td>
<td>0.020</td>
<td>−0.890</td>
<td>0.020</td>
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<tr>
<td></td>
<td>(0.011)</td>
<td>(0.127)</td>
<td>(0.002)</td>
<td>(0.024)</td>
<td>(0.094)</td>
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<tr>
<td>Cross sample t-test</td>
<td>−0.006</td>
<td>−0.006</td>
<td>−0.006</td>
<td>−0.009</td>
<td>−0.006</td>
</tr>
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<td></td>
<td>(0.000)</td>
<td>(0.016)</td>
<td>(0.009)</td>
<td>(0.000)</td>
<td>(0.007)</td>
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<tr>
<td>SSO expropriation</td>
<td>−0.014</td>
<td>−0.012</td>
<td>−0.0143</td>
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<td>−0.006</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.119)</td>
<td>(0.076)</td>
<td>(0.008)</td>
<td>(0.830)</td>
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<tr>
<td>Scope of backward citations</td>
<td>−0.759</td>
<td>−2.928</td>
<td>0.999</td>
<td>−0.890</td>
<td>−2.160</td>
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<tr>
<td></td>
<td>(0.229)</td>
<td>(0.000)</td>
<td>(0.303)</td>
<td>(0.308)</td>
<td>(0.0434)</td>
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<td>Total patents</td>
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<td>0.559</td>
<td>0.216</td>
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<td>(0.000)</td>
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<td>(0.000)</td>
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<td>R&amp;D</td>
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<td>0.119</td>
<td>0.584</td>
<td>0.168</td>
<td>0.721</td>
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<tr>
<td></td>
<td>(0.092)</td>
<td>(0.503)</td>
<td>(0.488)</td>
<td>(0.475)</td>
<td>(0.142)</td>
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<td>0.641</td>
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</tr>
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<td></td>
<td>(0.000)</td>
<td>(0.013)</td>
<td>(0.001)</td>
<td>(0.000)</td>
<td>(0.081)</td>
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<td></td>
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<td>(0.035)</td>
<td>(0.003)</td>
<td>(0.190)</td>
<td>(0.039)</td>
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<tr>
<td></td>
<td>(0.852)</td>
<td>(0.234)</td>
<td>(0.126)</td>
<td>(0.458)</td>
<td>(0.348)</td>
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<td>Performance</td>
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<tr>
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<td>(0.012)</td>
<td>(0.158)</td>
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<td>(0.303)</td>
<td>(0.223)</td>
<td>(0.338)</td>
<td>(0.010)</td>
<td>(0.529)</td>
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<td>YES</td>
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<td>1.545</td>
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<td>623</td>
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</table>

* Scaled by 1,000. Note: All independent variables have 5 year lag. Robust p values that account for firm-level clustering are reported in parentheses. Average partial effects in square brackets. Cross-sample comparison is conducted using Welch’s t test of the average partial effects between the two models.

Logit. Table 4 reports logit estimations of firm disclosure. As the disclosure decision may not be independent across time, we use a robust variance-covariance matrix that accounts for potential error clustering within firm.35 Model 1 estimates the effect of Complementary Technologies using classes. To allow for time lags and instances where a firm with relevant technologies to that SSO may not be patenting in the associated classes in every year, we trace if the firm patented in those classes in the past 5 years relative to t. We then rerun all firm-level logit analyses and the Inverse Propensity Score Weighting Method analyses, using this firm-SSO-year data instead. All findings in both sets of analyses remain robust.

35 To check if findings are sensitive to the logit specification, we rerun all five models using a Probit model with robust and clustered errors instead and find similar results. We also rerun the logit models without adjusting for within-firm clustering. Findings remain fully robust.

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Note: All independent variables have a 5-year lag. Robust p values that account for firm-level clustering are reported in parentheses. Average partial effects in square brackets. Cross-sample comparison is conducted using Welch’s t test of the average partial effects between the two models.

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34 A potential issue with using firm-level data is that firms may not always have equivalent relevant (standard essential) technologies or opportunities to disclose within year. The firm with more complementary technologies may have more opportunities to disclose, rather than greater inclination to disclose given opportunities, based on its value creation or appropriation objectives as we theorized. To address this concern, in separate analyses, we retain only observations that have relevant technologies for each SSO in each year and convert our data into a firm-SSO-year level. We use technology classes as a basis for relevance for each SSO-year and compile the list of technology classes that traceable patents, disclosed in that SSO-year, were assigned to. We then retain in our data for each SSO-year only firms that have patented in those technologies that include “blanket” disclosures. We convert the data to a firm-year level.34
the full sample. Complementary Technologies is positive (p value .011), with APE of 0.001, suggesting that a standard deviation increase in the proportion of Complementary Technologies increases the disclosure likelihood by about 1% point. This supports H1a over H1b, showing that firms with more complementary technologies are more likely to disclose to SSOs.

Models 2–5 test the contingency hypotheses. As in the patent-level analyses, we split the sample using the median value of the contingency variables. Complementary Technologies is negative (p value .127) in Model 2 where Crowdedness is high, while strongly positive (APE 0.001, p value .002) in Model 3 where Crowdedness is low. Using Welch’s t test to compare difference in the APE of Complementary Technologies across the two subsamples, we find that the difference is negative (−0.003, p value .023). This supports H2.

We test H3 similarly in models 4–5. Complementary Technologies is negative in Model 4 where SSO Expropriation is high (APE −0.07, p value .023), while positive in Model 5 where SSO Expropriation is low (APE 0.02, p value .093). We find the difference in APE to be negative (−0.072; p value .021), which supports H3. We further address potential selection issues in these firm-level logit arising from unobserved firm heterogeneities (e.g., firm capabilities), using the inverse probability-weighted regression adjustment method (Appendix S1).

Additional Analyses

SSO membership. A potential selection issue is that there may be systematic differences driving firms’ decisions to become members: members are more likely to disclose, and firms with complementary technologies are more likely to be members, not to disclose per se. We believe this is unlikely, as a firm without complementary technologies (specialist) has incentives to be a member too, as it lacks the ability to implement the entire system, and its strategy is precisely to have its technologies be part of standards and then license them out. Nonetheless, we examine this possibility. First, we examine firms that are members of at least one SSO, and find that 77.5% do not have complementary technologies. Second, a firm with complementary technologies could be a member of more SSOs than a firm without, and is thus more likely to disclose in a given year. We focus on firms that are members of at least three SSOs, and find that 66.2% of these firms do not have complementary technologies. Third, we separate firms into SSO members and nonmembers. We find that the average ratio measure of Complementary Technologies for SSO members (mean 0.63, standard deviation 0.17) is actually smaller than that of nonmembers (mean 0.76, standard deviation 0.13). This difference is not statistically significant though (t-statistic −0.59). Thus, evidence does not suggest that firms with more complementary technologies are more likely to be SSO members. We then directly test if SSO membership caused a selection problem in the firm-level tests. We run a two-stage Heckprob model, since the second stage is nonlinear. We find that, in the second stage, Complementary Technologies is still positive after accounting for SSO membership (coefficient 0.011, z-statistic 1.83). We check for selection problems by testing if errors from the first and second stages are correlated, with a Wald test with null hypothesis of zero correlation. We are unable to reject the null hypothesis (p value .84). Thus it is unlikely that selection into SSO membership is an issue in earlier findings.

Disclose to learn/access. Another concern may be that disclosure enables a firm to learn more about other disclosed technologies, and the firm with complementary technologies benefits more from such learning (more avenues of application), and thus is more inclined to disclose. We believe this is unlikely, as the firm does not have to disclose per se to learn about or access others’ disclosed technologies. All disclosed technologies that become parts of the standard are generally available for licensing, by disclosing and nondisclosing members, and nonmembers. We are not aware of procedures in disclosure that favor learning-via-licensing by the disclosing firm over a nondisclosing firm. Moreover, if the “disclose to learn” conjecture is true, then we should see the firm with complementary technologies disclosing more of its “standalone” patents, not its patents that are complementary to other technologies in its portfolio, so that it can learn while minimizing losses due to leakage. This is counter to our findings in the patent-level analyses:
we find that a patent with complementary technologies within the firm is more likely to be disclosed.

Nonetheless, we further examine this “disclose to learn” conjecture. We check if disclosing firms learn more about other disclosed technologies than nondisclosing members of the same SSOs. As a proxy for learning, we trace citations to disclosed patents subsequent to disclosure. For each SSO in each year, we count how many times each firm cites the disclosed patents (excluding any self-citations), and compare the average citations from disclosing firms with that from nondisclosing members of the same SSOs. We find that while disclosing firms cite other firms’ disclosed patents slightly more than nondisclosing firms (0.32 and 0.19, respectively), this difference is not statistically significant (t-statistic 1.22). Thus, this evidence does not support the “disclose to learn” conjecture. We then flip to the disclosed patent’s perspective and trace citations received per firm in the 5 years following its disclosure for each disclosed patent. We split this measure into two groups: (a) firms that disclose in the same SSO and same year as the disclosed patent, and (b) firms that did not disclose. With a sample of 465 disclosed patents, we calculate the average number of citations per firm from disclosing firms and nondisclosing firms. We find that a disclosed patent receives on average 0.4 citations from disclosing firms and 1.7 citations from nondisclosing firms. T test of difference in means shows that disclosed patents receive significantly less citations per firm from disclosing firms than from nondisclosing firms (t-statistic −12.22), that is, the typical nondisclosing firm cites disclosed patents over four times more than the disclosing firm. These findings suggest that the “disclose to learn” conjecture is not likely true.

Another pushback could be the firm is “disclosing to access,” that is, have preferential access to and use of other disclosed technologies, without necessarily learning about and building on (cite) them, and the firm with more complementary technologies have greater need of such access. We think this is unlikely, as the SSOs’ explicit objective is to provide easy access of the standard to all firms, whether or not they have disclosed or are members. There are often more implementers (licensees) than contributors, suggesting that one does not need to disclose to access. We separately examine the MPEG-2 Standard—the main standard for coding moving pictures using lossy video compression and audio compression. Using information from the MPEG-2 patent pool, we find that there are 27 firms that disclosed essential IP to the standard, while there were 1,382 different licensees as of March 2016 (www.mpeglau.com). Then, from our data, we also identify several major standards and disclosures from global telecommunications carriers (e.g., AT&T, Vodafone, British Telecom, NTT DoCoMo). While these carriers are well known to be frequent and extensive users (licensees) of the standard technologies, we find that they are not main or frequent contributors to standards. We list in the following the respective standards/percent disclosures from carriers/number of disclosing carriers: CDMA 2000/0.0, GPRS/0.04/2, GSM/4.46/7, LTE/9.57/3, TD-SCDMA/0/0, UMTS/0.6/4, WCDMA/0/0. These and above evidence of disproportionately low contributions (disclosure) relative to users (licensees) suggest that it is unlikely that firms are disclosing to have preferential access to standard-essential technologies.

We urge readers, given the complexity of the analyses, to interpret findings with discretion. With both explanatory and outcome variables being driven at least in part by firm choices, the inherent selection issues are salient. Much as we have tried to suppress these issues with various methods, we acknowledge that these methods are still individually imperfect. We hope future research will further verify in better ways these findings, which we believe are important.

Conclusions

This article examines a firm’s strategic considerations underlying its disclosure to SSOs during standard setting. We demonstrate that the firm, in deciding whether to disclose a focal technology, faces a tradeoff when it has other technologies that are complementary: these complementary technologies exert a positive influence on the firm’s inclination to disclose the focal technology, as it stands to profit from these (nondisclosed) complementary technologies via such disclosure. But at the same time, they also exert a negative influence on the firm’s inclination to disclose this technology, as it risks greater expropriation of its (nondisclosed) complementary technologies via such disclosure. We illustrate this tradeoff using contingencies that separately skew the net main effect more positively or negatively. We propose that the less crowded the firm’s technological areas outside of the focal
technology’s area, the more the firm’s complementary technologies will increase its inclination to disclose its focal technology. Conversely, the greater the SSO members’ abilities at expropriating others’ technologies, the more the firm’s complementary technologies will decrease its inclination to disclose the focal technology. We test these propositions with data from the US communications equipment industry between 1991 and 2008, at both patent and firm levels. Within our context, we find strong evidence supporting the positive influence (over the negative influence) of complementary technologies. We also find strong support for both the contingency predictions that together illustrate the tradeoff.

A key objective here is to stress that, when we try to unpack reasons behind a firm’s participation during standard setting, we should not restrict our focus on the disclosed technology itself and the process surrounding it, but instead need to consider what else lies in the firm’s portfolio as well. The firm’s motivation to disclose its technology to SSOs goes past making that technology more valuable and central in the industry (Rysman & Simcoe, 2008), and the firm’s concerns in such disclosure span beyond the costs and constraints in the disclosure process (Bekkers, Catalini, et al., 2012; Lerner & Tirole, 2006). Even within the kind of innovation ecosystems to which this article is more relevant (Adner & Kapoor, 2010), the firm’s aim in disclosure is not just to coordinate development of complementary technologies owned by other firms within the ecosystem (Kapoor & Lee, 2013), crucial as that may be. Because a firm can and often does own a variety of these complementary technologies itself, the strategy related to disclosure for standard setting, and the rationale behind it, is different. The idea that “the firm’s technology being part of a standard can benefit its larger portfolio” is an intuitive one that has been broadly invoked in the literature (Dokko et al., 2012; Rosenkopf & Tushman, 1998) but seldom explained in detail. The risk of losing the value of technologies due to expropriation does not stop at what is disclosed, but spreads beyond into the firm’s portfolio of technologies. By largely neglecting how the firm’s portfolio of technologies comes into play, the literature may have missed important nuances of the firm’s strategies in participating in and influencing standard formation. We have but laid out the influence of one specific aspect of the firm’s portfolio—its own complementary technologies within the innovation ecosystem. More can be uncovered in future research.

Our findings are potentially meaningful to the literature on complementary technologies as well (Cassiman et al., 2005; Makri et al., 2010). The discussion in this literature has by and large centered on combinatorial possibilities and resultant inventions that could arise from synthesizing complementary technologies within a firm (Galunic & Rodan, 1998). This leads to the germane issue of parsing out types of “related” technologies to distinguish between “complementary” and “similar” ones (Larsson & Finkelstein, 1999; Makri et al., 2010). Having complementary technologies within the firm may increase combinatorial possibilities and thus inventions, but having too many similar technologies that are overly related may not. Many prior studies in this stream are wedged in the context of firm acquisitions (Ahuja & Katila, 2001), since the premise is that these complementary technologies are firm-specific, not easily traded via markets, and thus have to be built internally or acquired by taking over another firm. What we suggest here is a different lens in which to view value-creation of complementary technologies, beyond that of recombination. Even without combining them, the presence of complementary technologies within the firm’s portfolio alone can alter its strategic calculations, present additional strategies through which the firm creates value, and serve as multiple channels through which the value of a strategy implemented on one technology (in this case disclosure to SSO) can be appropriated by the firm.

This article also contributes to the broader literature on firm disclosure. Using the resource based view lens (Barney, 1991), a simplistic starting point could be that, all else equal, a firm would rather not disclose details of its valuable technologies to other firms, so as to keep its technologies unique and valuable. Naturally, real-world complications render “all else” not always equal, and firms do in fact disclose their technologies to others at various instances. The quest is then to know why a firm discloses in these instances. Researchers have gone far on this front to show that, despite the cost of losing technologies to others, a firm discloses to attain other benefits such as bolstering influence over key institutions, obtaining financing, influencing investors, enhancing reputation, and so forth (Bhattacharya & Ritter, 1983; Harhoff, Henkel, & Von Hippel, 2003; Polidoro & Theeke, 2012). But across these explanations, the direct consequence of
Disclosure by itself—having others know about the firm’s technologies—is still perceived as purely a cost. Yet there are instances where this direct consequence itself serves a useful purpose for the firm; in this case, it helps coordinate developments across firms to reduce subsequent incompatibility problems. As a field, we do not know enough yet about the strategic tradeoff between such positive and negative direct consequences. This article is but a first step, where we essentially suggest in a nutshell that the firm discloses and compromises one technology so that others use and learn about this disclosed technology and coordinate their own developments in ways that help the firm benefit from its other technologies. This is but one way that the firm benefits directly from disclosure per se. There is potential here for future research to explore further on this front.

At the heart of this article lies a call to adopt a more systemic approach, to take into account the firm’s entire portfolio of technologies when examining how any one of these technologies create value or constitute losses for the firm. Even if a strategy on one technology, such as disclosure to SSO, creates no value from that technology, the strategy could still be viable for the firm, as value arises elsewhere in the firm’s portfolio. Conversely, even if a strategy on one technology results in no loss in value from that technology, the resulting loss from elsewhere in the firm’s portfolio of technologies still matter. Strategy on one technology could act as a “lever” for the firm to enhance value-creation across its portfolio, much like “a pawn to save the chariot,” or it could create a “window” for others to access and expropriate the firm’s otherwise well-protected portfolio, much like “lowering a drawbridge into the fort.” Furthermore, adopting this systemic approach pushes us to recognize that appropriation conditions surrounding complementary technologies, not just those surrounding the focal disclosed technology, matters as well. Adopting this systemic approach also better allows us to see that competition occurs between systems of technologies too, not just between individual technologies (Polidoro & Toh, 2011). A firm’s challenge is not simply to obtain “a bigger portion of the pie”; rather, it is to figure out when “a smaller portion of a bigger pie” is better or worse than “a bigger portion of a smaller pie.” We believe there is much to be learned from a systemic approach to view value-generation from a firm’s technologies, and we hope future research will follow our path.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix S1. Additional robustness checks.