Participation in Standard Setting Organizations

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1 Introduction

The adoption or creation of standards, and the particular features selected for standards, can have important consequences for a number of parties. The establishment of a standard can give market power to some upstream firms, or exclude technologies that can be provided by their rivals. Similarly, the decisions of an SSO/SDO can affect downstream firms' options and costs. Firms affected by the decisions of SSOs can have strong incentives to influence standards to promote their own interests through their membership and leadership in SSOs. Among the firms most affected by standardization decisions are the initial innovators, that is, those creating new, breakthrough, or market changing technologies.

The effect of SSOs on investment in technology is an important concern in competition policy. Broadly speaking, antitrust authorities have been willing to allow coordination between firms that are current or potential competitors in research consortia and SSOs, since such coordination can be socially beneficial. Duplicative investments may be avoided, and in the case of markets with network effects, coordination may allow various parties to sink investments and reduce uncertainty for consumers.

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A key concern in SSOs is the incorporation of intellectual property (IP), both patent-protected elements and trade secrets, in a standard. Such ”standard-essential patents” (SEPs) or other IP potentially allow their owners to extract supra-competitive returns, and possibly limit access to essential components, which would tend to reduce investment by other firms. However, SSO policies to mitigate this potential concentration of pwer may affect the incentives of innovating firms to participate in the standards process. Many SSOs require members to disclose their technology; this can entail revelation of trade secrets and patents that may be subject to circumvention, by inventing around, or investment in complementary patents that can limit the innovators ability to earn a return on its investment. SSOs also typically impose requirements that limit participants ability to capture value through licensing fees. For example, the SSO may adopt a policy of royalty-free licensing or licensing on fair, reasonable and non-discriminatory (FRAND) terms. The SSO may also open the standard-setting process to all willing participants.

If such policies reduce or eliminate returns for an innovating firm, this can reduce incentives to participate on an SSO. On the other hand, SSO policies that limit hold-up, can serve to encourage investment by other parties. SSOs typically require that participants commit not to exploit this power. For example, the SSO may adopt a policy of royalty-free licensing or licensing on fair, reasonable and non-discriminatory (FRAND) terms. The SSO may also open the standard-setting process to all willing participants. If such policies reduce or eliminate hold-up, the effect of SEPs in standards on investment may be minimal.

In recent years, the number of patent applications has increased markedly, which may limit the supply of non-patented technologies available for adoption by SSOs. In addition, patent litigation has exploded, and some of this litigation concerns SEPs. There are a number of open questions in the legal and economic literature on the effect of an active market for patents on incentives for investment, litigation, and SSOs. For example, small inventors may have greater incentive to invest, knowing that they can sell their patents to firms better positioned to exploit them. However, there is frequent discussion of potential problems with the sale of patents as well. The acquirers of patents may be non-practicing entities whose business model is difficult to reconcile with royalty-free licensing, for example. Participants in SSOs may want to enhance their bargaining positions by adding to their patent portfolios through acquisitions.

Despite their importance, there is little theoretical or empirical work addressing the interaction of SSO participation, SSO policies on IP and licensing, and incentives to invest in new technologies or trade in existing ones. In this paper, we focus on a small set of voluntary SSOs formed after 2000. We document that the formation of an SSO affects the IP strategies of its participating and non-participating firms. Since we examine new patent applications as well as the purchase or sale of patents by these firms, we provide limited evidence on the incidence of IP strategies that have raised concerns among legal scholars and economists. We then develop a model to explain whether an when an innovator chooses to share its technology with an SSO, and how SSO formation affects investment.

2 Previous literature

Several related topics in the literature on intellectual property are relevant to our study. Research on patent portfolio strategies and business models informs our expectations of the behavior of firms in markets affected by SSOs. This is closely tied to work on patent litigation, since portfolio strategies are both a cause and effect of such litigation. The importance of patents in SSOs has led to a number of studies on the IP policies of SSOs. We discuss each in turn.

There is recent interest, both from academics and practitioners, in patent portfolio strategies and business models. It is widely accepted that strong IP rights facilitate "markets for ideas" or "markets for technology." These terms refer to the ability of firms to protect from innovation through the sale or licensing of their ideas rather than through manufacturing. Trade in ideas is limited by the fact that once an idea is explained, it is easy to copy. Without IP, an innovator would have a hard time convincing a manufacturer to pay for a license, since the manufacturer would pay nothing without knowing more about the innovation, and once that information is revealed the manufacturer has no reason to pay for it. With IP, an innovator can share information about the patented ideas with reduced fear of having them stolen. If firms have different competitive advantages, with some more effcient in the gener- ation of ideas and others more efficient in manufacturing, then markets for ideas allow them each to specialize. This has resulted in important changes in industry structure: whereas sectors like pharmaceuticals and computing were dominated by vertically inte- grated firms, we now see firms that specialize in different vertical activities. This shift also implies a change in patent portfolio strategies. In a study of patenting in semiconductors between 1975 and 1995, Hall & Ziedonis (2001) examine how a change in the incentives to litigate affected the patenting behavior of firms. The establishment of the Court of Appeals for the Federal Circuit (CAFC), which hears patent cases, is generally accepted to have created a pro-patent legal environment: this court has been more likely to issue preliminary injunctions and to find in favor of plaintiffs than its predecessor, and this increased the incentives for patent owners to sue for infringement. Such lawsuits are particularly costs for semiconductor firms because they are especially vulnerable to the "hold-up" problem: they make R&D investment decisions lacking complete information about the IP landscape. As a result, they risk infringing on patents held by others, whether because a patent application was not yet public when the investment decision was taken, the validity of rival patents was unclear, or the propensity of other patent owners to litigate or cross-license was unknown. After sinking investments and committing to a chip design, firms have a very weak bargaining position with respect to the owner of a patent they are found to have infringed, since inventing around the patent would be extremely costly. A "pro-patent" regime, i.e. courts that are more amenable to hearing infringement cases and granting preliminary injunctions, greatly increases the hold-up risk. Hall & Ziedonis (2001) assert that the firms most affected by potential hold-up are those that are particularly capital intensive, as it is these firms that have sunk costs in semiconductor fabs. They find that the shift to "pro-patent" courts was associated with a change in patenting strategies of capital-intensive firms: in order to protect themselves, they sought to increase the size of their patent portfolios. Hall & Ziedonis (2001) also test whether changes in patent policy facilitated the entry of design firms. Patent-friendly policies may have facilitated vertical specialization of firms in the industry; with weaker enforcement, a specialized design firm would face greater difficulties in contracting with specialized manufacturers due to the risk of expropriation. They find that the rate of entry by specialized design firms did not change, but post-1982 design entrants were five times more likely to patent than manufacturing firms that entered at the same time. Design firms that focus on innovation would be expected to have more patentable inven- tions than manufacturing firms, and manufacturing firms may rationally choose to keep some of their innovations as trade secrets rather than disclosing them through patent applications. This paper does not discuss how coordination of R&D effort or commitments to licensing through an SSO might be expected to alter the patent portfolio strategies of firms.

In a related paper, Ziedonis (2004) explores the interaction between what she calls "fragmented" markets for technology and the strategies of capital-intensive firms. Essentially, in technologies with many different patent owners building on related innovations, the total cost of obtaining licenses to all relevant patents can be very high, since it requires negotiating with many firms, none of which internalizes the effect of increasing a license fee on demand for licensing the related patents. As discussed above, capital-intensive firms are those facing the greatest risk of hold-up should such negotiations fail. In response, Ziedonis (2004) finds that these firms patent even more aggressively in fragmented patent classes. While not addressed explicitly in this work, SSOs may lead to efficiency gains by creating a "one-stop shop" for licenses and internalizing the costs of increased fees.

While these results are intriguing, there are some limits of these studies. The data includes only 100 publicly traded US firms whose primary business was in semiconduc- tors, a set which excludes Apple, Google, Samsung, and many other tech giants. In addition, they do not account for changes in patent portfolios driven by patent transfers between firms. The only aspect of patent strategy examined is the propensity to apply for/receive patents, not enforcement, licensing, litigation or acquisition. Simcoe et al. (2009) address the relationship between business models, litigation and SSOs more directly in a study of patents disclosed to 13 SSOs between 1980 and 2004. They find that disclosed patents have a high rate of litigation overall but particularly for small firms. Their interpretation is that small firm are more aggressive in enforcing their IP because unlike large firms with a presence in complementary markets, small firms profit either from licensing revenues or from supplying a very specialized component in a shared technology platform. The patent holdings of the stakeholders in the case of the 56K modem have been studied by Gandal et al. (2006) and Augereau et al. (2006). We take a somewhat different focus here in focusing on the timing of SSO formation and the associated patent activity.

A very recent summary of patent portfolio business models in mobile telephony is provided in Layne-Farrar (2012). While patent "trolls" have attracted considerable attention in the press, one study finds that litigation involving non-practicing entities (NPEs) accounted for only 17% of all patent lawsuits between 2000 and 2008 (Chien (2009). However, they can be costly. Bessen et al. (2011) find that the losses imposed by litigation from patent trolls on defendants are not simply transfers to the original inventors, i.e. the loss to defendants is not balanced by gains to original inventors, which would preserve incentives for innovation. However, this analysis does not consider the effect of deterring future infringement and inducing firms to license instead, which could be welfare-enhancing. According to Layne-Farrar (2012), much of the recent litigation is driven not by trolls but by established firms that are recent entrants to a particular sector, such as Apple and Google in wireless. As they battle for these new markets, they engage in aggressive acquisition of patents, notably from exiting firms, and aggressive use of patent courts and the US International Trade Commission to prevent rivals from gaining a foothold. In mobile, she lists 24 lawsuits active in 2011-2012Q1 across at least 10 countries. Layne-Farrar suggests that this activity is likely to be temporary, because it is just a response to a disruptive change in the industry. However, disruptive change is arguably a regular event in some sectors. The implications for the overall rate of innovation and the sustainability of other business models are unknown.

Scott Morton (2012) suggests that NPEs might play a more important role, particularly if they acquire patents from practicing entities that have committed to FRAND or royalty-free licensing in an SSO. If the acquiring firm (whether an NPE or not) is not bound to those initial commitments, then the acquisition and aggressive enforcement of a standard-essential patent would likely increase the prices of licenses and undermine some of the welfare gains possible through an SSO. In other words, the owner of important patents may want to "outsource" aggressive enforcement to a third party through the sale of patents, whose value is higher to a firm with no FRAND obligations. Kesan & Hayes (2012) provides a legal analysis of this sort of maneuver. Acquisition by another SSO member would not introduce the same problem, although other distortions may result. For example, the sale of patents to another practicing entity active in the downstream market is like a vertical merger involving important inputs (the technology covered by the patents) and a downstream competitor, which may have anticompetitive effects. Serrano (2010) finds that patents involved in trade are more valuable on average. These papers highlight that transfers of patents merit further attention.

Much of the literature on standard setting decisions explicitly or implicitly assumes that there is an evolving technology, and firms are competing to have their technology included in the standard. The decisions about standards can affect investment in R&D, development of complementary products, consumer adoption decisions and welfare. David & Greenstein (1990) and Stango (2004) provide extensive reviews of the literature.

Many papers examine the impact of timing of standards adoptions decisions on investments and welfare, in a context where there were competing technologies, and early adoption can lead to premature lock-in (Katz & Shapiro (1985), Farrell & Saloner (1985), and Arthur (1989). Choi (1996) models the decision about timing of standard setting as one in which there is a tradeoff between the short run benefits of coordination and the longer run benefits of experimentation. Erkal & Minehart (2007) also examine the decision to share technology in a multi-stage innovation model with competing firms investing in competing technologies. Simcoe (2006) studies cooperation and competition in SSOs. His focus is intra-SSO interactions of firms that compete to earn a return on the new technology. Krechmer (2007) distinguishes between anticipatory, participatory and responsive standards, but takes as given the decision to include the technology in a standard. Cabral & Salant (2012) also examine the case in which two competing firms can choose to invest in compatible or incompatible technologies. They find that the firms will often have incentives to invest in incompatible technologies, and that this can be welfare improving. The reason for this result is that in a race, the innovating firm will gain more absent an ex ante agreement to pool technologies. This increased investment speeds innovation and can improve consumer and social welfare. Salant and Seabright (2012) consider a multistage model in which competing firms make initial investment in research in a new technology, but one that requires follow up development. In their model, a standards organization can commit to one technology or another early or late. The paper examines investment incentives under different policies by the SSO. This model essentially adds a development stage to the Cabral & Salant (2012).[1]

The importance of IPR policies in SSOs has been discussed at length in several recent works. Bekkers & Updegrove (2012) provide very detailed descriptions of such policies in 10 SSOs, two of which we include in our study. Blind et al. (2011) supplement an analysis of IPR databases with stakeholder interviews on IPRs in SSOs. They recommend that SSOs establish clear and binding IPR policies, strive for legal certainty regarding FRAND commitments with patent transfers, and provide data on IPR disclosures in an accessible and transparent format.

3 SSO case studies

In information and communications technology, standards do not emerge overnight. Generally, they result from years of research and development, and rely on a few major innovations followed by many smaller, but often crucial, incremental steps. Firms engaged in that research choose whether and when to collaborate with other firms in the development of a standard. There are many examples of cases in which the innovator did not

[1] Salant & Rey (2012) also find more general conditions under which the Lemley & Shapiro (2007) patent thicket argument applies, and cases where it does not.

participate in an SSO, but managed to achieve market dominance for its standard:[2] the iTunes file format; iOS; the IBM 360 operating system and standards for complementary components such as punch cards; Microsoft Office from the 1980s through about 2005; etc. What we want to model and explore empirically is the decision of innovating firms to establish standards unilaterally or to contribute their technology to an SSO.

Empirical studies of standards and SSOs are challenging for several reasons. First, there are few sources of information on the population of SSOs, leading to a concern about the representativeness of any sample of SSOs studies. Second, SSO policies and membership may change over time, and collecting retrospective data is not always possible. Third, SSOs vary along important dimensions that can be difficult to characterize for quantitative study. For example, they may be engaged in a standards battle with a competing technology; the competition between HD-DVD and Blu-Ray is one such instance. But in many other cases, there may be multiple technologies in development by different SSOs that have some elements of substitutability, but are not direct competitors. Fourth, information on the potential market size for products incorporating a standard is not always available. With these limitations in mind, we focus on three SSOs, all founded after the year 2000, with different organizational structures and IPR policies.[3] In all three cases, there are alternative standards in the market, but they do not represent the prototypical standards battles with winner-take-all outcomes.

3.1 NFC Forum

The NFC Forum was formed in 2004 by Philips (or NXP Semiconductors, which was spun off by Philips in 2006), Nokia and Sony to develop standards for near-field communications (NFC), and to promote the use of this technology. NFC allows exchange of data over short distances, similar to RFID and contactless smartcards, and has received most attention for its potential use in payments using smartphones. It also has uses in health applications and ticketing on transit systems. The NFC Forum released its first specification in 2006,

[2]The term *de facto* standard is sometimes used for this case, although any voluntary standard that achieves a position of market dominance could be described as a *de facto* standard.

[3]Unlike larger SSOs such as ETSI and TIA Online, disclosures of IPR are not publicly available for the three we describe here.

and has issued 15 since.

There are five membership levels, ranging from non-profit ($1500 annual fee) to sponsor ($50,000). Each level carries different privileges. There are more than 170 members as of 2012. Current "sponsors" and "principals" are listed in 1. The number of sponsor-level members is capped at 17, but membership at the other levels is open. Upper tiers of membership include 10 semiconductor firms, 5 firms specializing in financial services or payment systems, and a few firms specializing in NFC technology specifically. The balance are mostly large, diversified electronics firms or handset manufacturers.

The IPR policy of the NFC Forum requires members to identify any of their granted or pending patents that they are **unwilling** to license on RAND terms during the adoption phase, and the Forum attempts to find alternatives. This information is not made public. A new implementation of the NFC standard requires a $2000 license fee.

Shipments of NFC-enabled phones is expected to be around 300 million in 2013, according to some analysts.[4].

3.2 HDMI Forum

Hitachi, Panasonic, Philips, Silicon Image, Sony, Technicolor, and Toshiba formed HDMI Licensing, LLC in 2002 to manage the licensing of their high-definition multimedia interface (HDMI) standard. HDMI transmits high-definition sound and video between devices such as computers, monitors, televisions, cameras, gaming consoles, and smartphones. It is a substitute for S-video and DVI.

The original owners of HDMI technology established an SSO, the HDMI Forum, in October 2011, allowing members to participate in the development of subsequent HDMI standards.[5] Annual membership is $15,000 per year, and members number more than 70 as of 2012. There is a single level of membership, with equal voting rights. The founders and current members of the board of directors are listed in 2.

[4] www.cnbc.com/id/100406583

[5] The Office Open XML standard for Microsoft Office has a similar chronology. For twenty-plus years, the unilaterally sponsored Microsoft Office format was the dominant standard in the marketplace. Faced with increasing competition from alternatives that used the Open Document Format (ODF) standard, Microsoft announced in November 2005 that it would co-sponsor a new standard in the non-profit SSO Ecma International.

The IPR policy of the HDMI Forum does not include a disclosure requirement, but members must agree not to assert patent claims of current or future IPR that is included in the standard, and it is not clear from the IPR policy whether they receive any license or royalty in that event (see Bekkers & Updegrove (2012)). Adoptors of the HDMI standard pay an annual fee of $10,000 and a royalty of between 4 and 15 cents per unit.

IHS iSuppli estimated that HDMI penetration into the global television market in 2010 was more than 75%. In the coming years, the HDMI standard may face additional competition from a technology called DiiVA; Sony, a founder of HDMI, has joined a consortium that includes Samsung and some Chinese manufacturers of televisions to develop this.

3.3 SD Association

The SD Association was founded by Panasonic, Sandisk, and Toshiba in 2000, and defines itself as an open industry standards association to promote the development of standards for secure disk memory cards and devices, and the adoption of this technology. SD cards are commonly found in digital cameras and smartphones. Other external storage options, such as USB keys, are potential substitutes. SD cards have a smaller form factor and can be configured for digital rights management, although the licensing of the technology required for the latter is managed by a different SSO (4C Entity).

There are more than 1000 members as of 2012. General members pay $2000 in annual dues, while executive members, which have additional voting and leadership privileges, pay $4500. The firms currently serving on the board of directors are listed in 3. The representation of specialist firms (those whose primary business is memory and storage) is somewhat higher than in the other SSOs discussed above, but in all three, we see participation by firms of varying sizes and business models or vertical position.

The SD Association IPR policy requires members to disclose their IPR holdings that are necessary to the standard and to commit to RAND terms of licensing. Licensees who discover they hold essential patents after an SD standard has been adopted are also required to license on RAND terms or to terminate the license. The cost to license the

SD standard is an annual fee of $1000.

Global Industry Analysts Inc. predicts that the market for SD cards will be in excess of $23 billion by 2018.

4 Patterns of IP activity

4.1 Data description

We focus on patent applications as a proxy for current investment in a technology, rather than patent grants. There are several reasons for this choice. First, patents often pend at the patent office for several years before issuing. The investment required for the initial application often significantly lags the issuance. Second, the use of grants would introduce a truncation issue for recent years, since many recently filed applications would not yet be granted. In contrast, since 2001, patent applications are usually published 18 months after the filing date.[6] We collected data on all patent applications published from 2001-2012 from the USPTO Bulk Downloads page maintained by Google, as well as patents granted after 2000. In total, this includes 2,376,361 patents granted and 3,262,283 applications.

Reassignments of patents are recorded at the USPTO based on information provided voluntarily by the parties involved in the transactions. While not required by law, parties generally have an interest to notify the USPTO of a reassignment, particularly if they intend to assert the patent in the future. The USPTO publishes the reassignments of issued patents and published patent applications for which it has been notified. For our purposes, reassignments by one firm to another are treated as acquisitions or sales. In practice, reassignment activity is fairly substantial, particularly in technology areas related to mobile phones. For example, Google's purchase of Motorola Mobility included the acquisition of more than 17,000 patents. Google's patent portfolio changed considerably not as a result of its own R&D activity, but through the acquisition of outside IP. We collected data on all reassignments during the 2000-2012 period from Google's

[6] There are some circumstances under which an applicant can request that the application remain unpublished. We ignore this issue in the current draft.

USPTO Bulk Downloads webpage.

Unfortunately, the names of patent application assignees, assignors, inventors, etc. are not standardized in the USPTO data. Even restricting our focus to a small number of technologies required substantial cleaning of these fields to identify firms. The reassignment data is particularly complicated, since many transactions involve the reassignment of rights from an inventor to his employer, or reassignment between different divisions of the same firm.

To determine the initial owner of a patent application, we used the assignee field and, since this was frequently missing, the party listed as the correspondent on the application. Next, we identified reassignment transactions that appeared to be an inventor to his employer by whether an inventor was listed as the assignor in the reassignment record and the reassignment occurred within one year of the filing date. This set may occasionally include sales by small inventors to other organizations, and will be refined in future drafts. Subsequent reassignments due to mergers, acquisitions, or reassignment of assignor's interest between firms are considered as patent acquisitions by the designated assignee. The assignor and assignee names were then adjusted for different spellings of the same organization.

From the full data, we extract only the patents related to the technologies of the SSOs described above. This presents a key challenge for anyone not intimately familiar with the technologies. One approach is to identify the relevant patent classes for each SSO, and treat all patents assigned to those classes as potentially related to the SSO. The approach we took in this draft was to choose a set of keywords for each SSO, and identify all patents with those keywords in their titles or abstracts. We also examine several other subsets of data. First, we selected all patents with a primary International Patent Classification (IPC) corresponding to those particularly common for mobile communications, listed in 4. Next, we selected a number of prominent firms in mobile telephony, and look at all patenting activity by this set of firms. These are listed in the top panel of 5. Finally, to assess the importance of NPE activity, we examine the application and acquisition activities of the eight firms identified by *Business Insider* as large patent-holding companies, listed in the bottom panel 5. The latter includes some firms whose business model is based on the licensing of technology developed by internal R%D labs, and some firms that specialize in enforcement, like Rockstar Consortium.

We emphasize that this work is preliminary, and there is much we do not (and in some cases, cannot) account for. We consider only US patents, and we don't analyze the geography of invention. Although patents may have multiple owners, particularly if the patent is the outcome of joint R&D efforts, we treat the first named assignee as the primary owner. As noted earlier, we can only examine patent transfers that were recorded at the USPTO. The definition of subgroups requires considerable refinement in the future.

4.2 Descriptive statistics

Issued patents assigned to one of the IPC codes listed in 4 account for roughly one-fifth of the total during 2000-2012, consistent with a high rate of innovation (and litigation). Patent applications in these classes are an even higher share (27%). Among the nine major firms in wireless listed in 5, there are 70,635 issued patents and 84,581 applications. Anecdotally, patent transfers have featured prominently in recent developments in the wireless industry. For example, Google transferred several of the patents it obtained through the acquisition of Motorola Mobility to the Android handset manufacturer HTC, after Apple initiated an infringement lawsuit against it. Rockstar Consortium, which receives funding from a number of practicing entities including Microsoft, Apple, and Sony, purchased a portfolio of patents from Nortel in 2011 and now specializes in identifying infringement of its IP holdings. We estimate that roughly 6% (or just over 5400) of the patents initially assigned to one of the major mobile firms were traded to another organization. The NPEs listed in 5 were responsible for 3481 patent applications, but more than 15,000 acquisitions of patents.

A summary of patenting activity for each SSO is presented in the final three tables. For the case of the NFC Forum, which was founded in 2004, the sale of patents was rather insignificant (see 6). Prior to its establishment, few patent applications mentioning the technology were filed, either by its founders, subsequent sponsors, or other firms. This could be an artifact of the keywords used to identify relevant patents;[7] many firms may already have been active in technlogies related to NFC, such as RFID. However, after the creation of the SSO, new patent applications increased markedly. The increase by firms that were not in leadership roles in the NFC Forum was even more dramatic following the release of the first standard in 2006. The founders themselves do not seem to have controlled a large share of the intellectual property, although the value of their portfolios is not necessarily captured by a simple count of patent applications.

The HDMI standard (see 7 was controlled exclusively by six firms from 2002 until 2011, when participation in the development process was opened to others. As with NFC, there were few patent applications filed prior to the release of the first standard, although the same caveat regarding keywords applies, and patent transfers account for a small share of activity. Applications by the founders and current sponsors represent a large share of total applications than in the NFC case, but there is insufficient time to observe post-SSO investment given how recently it was established and the lag in publication of patent applications.

The SD standard (see 8is slightly older than the other two, as the SD Association dates to 2000. The most striking difference is in the level of patent applications and acquisitions by firms that are neither founders nor serve on the board of directors of the SSO. About 16% of the patent applications related to SD were involved in a transfer between firms.

In all three cases, investment (to the extent patent applications reflect this) increased following the SSO's founding, both by founders and by potential complementors or other users of the technology. Since these three standards have been relatively successful, the increase may simply be a response to the size of the downstream market, which may itself be endogenously determined by SSO policy. While the presence of NPEs is important in wireless technology overall, it is relatively minor in these subfields. A larger sample of SSOs and information about litigation rates are necessary to evaluate more thoroughly

[7]The keywords used were NFC, near-field communivations, Manchester coding, and modified Miller coding.

the impact of NPEs in this area.

5 Theoretical model

We develop a *recursive* type theoretical model to examine the determinants of when, or even if, a standard is formed, and the effects on investment in a technology. Much of the previous literature looks at competition between standards, or participation or control of standards for strategic reasons. We assume that there is a single innovator, with a new product or technology.[8] The innovator may elect to contribute its technology to a standards organization,[9] where contribution or participation in an SSO will typically require some commitments that are unattractive to the innovator, such as sharing with potential competitors; to create an SSO; or to attempt to establish a standard unilaterally. The base case assumes static market conditions, and characterizes the determinants of when a firm would choose to create a standard. A new standard can then be explained by unforeseen changes in the technology or market conditions, or successful innovation that changes the factors governing whether or not a firm would want to include its technology in a standard.

The approach we take looks at a narrow set of economic incentives - specifically the incentive to open up a standard to a broader set of participants or to restrict participation, and to invest in intellectual property (IP). The model assumes a single firm has created a new technology, but needs further investment to develop and bring it to market. The additional investment can involve complementary products, and can also include other firms. When other firms provide complementary products, the inclusion of the new, core technology into the SSO can have two effects: (1) it will tend to increase investment by the other firms, which benefits the innovator; and (2), the adoption of the standard by other firms may increase the competition faced by initial innovator, which dissipates the innovator's profits. In this case, the innovator may have a disincentive to share. Offering

[8] Much of the analysis and data can be applied to small group of innovators.

[9] We will use the terms Standard Setting Organization (SSO), but the term Standards Development Organization (SDO) is also used. The role of an SSO or SDO may differ. As our focus is on the core innovation and not complementary, more developmental ones, we prefer the term SSO.

the technology to an SSO requires disclosures, and usually (fair), reasonable and non-discriminatory (FRAND or RAND) licensing commitments. Both expose the innovator to competition that it might not encounter should it choose to keep its technology out of any SSO.

The model can be applied to joint research initiatives in which the group of contributing firms acts as a single decision maker. However, we do not attempt to model interactions between group members, nor of intra-organizational structures, decisions about the form and level of royalties and other license payments, or voting rules. We have kept the model highly general, choosing not to work out too many specific examples. The overall structure is useful in explaining incentives, and our goal is not, at this stage, to explore each one separately. The model is similar to others of technology investment, and very close to that of Cabral & Salant (2012), the main difference being that here we start with a single decision maker rather than two uncoordinated ones. Here we assume that there is only one technology leader, and, at least initially, the decision to share entails only a decision to attract complementary investment and adoption, but with certain costs.[10]

We consider the case in which a firm (or a group of firms) with a new technology can choose to create an SSO and/or to open the standard to third party contributions.[11] The decision to open up the standard to third party entities will generally result in greater third party investment but will reduce the share of profits for those having initial control of the standard. This need not result in higher social welfare as reduced profits can result in less investments.[12]

We consider an infinite horizon discrete time framework. Initially, the innovating firm, $i = 0$, has access to a technology, but that the value of the technology, and the services it provides, depends on development of complementary products and technology, both of which require further investment. Moreover, any such investment is risky in that it might fail to produce innovation in any given period. Further, we suppose that the innovating

[10] See, for example, Farrell et al. (2007) for a discussion of some of the costs.

[11] iOS is a closed standard for smart phones and tablets, because Apple has not shared its technology in an SSO and does not allow others to contribute to its development. In contrast, Google elected to establish an SSO that other firms may influence.

[12] See Cabral & Salant (2012).

firm can choose to allow third parties to access to the technology. If it does not do so, the third parties may still develop complementary products and technology, but we normalize this investment to zero in our model.

After the innovating firm decides on its policy toward an SSO, investment occurs. We consider the case of one potential rival. And for simplicity, we assume that the probability of successful innovation in any one period is $\frac{1}{2}\rho_i^2$, where ρ_i is firm i's investment level.

The innovator will earn a profits of π_0 in the first period. In period 2, if investment is successful, it earns profit of π^N absent a decision to create a standard, and π^S should it have chosen to create a standard. Should investment not succeed, it will continue to earn a profit π_0 in period 2. This firm can then invest again in period 2, and the payoff again depend on whether there is success in period 2. This process repeats at least until there is a successful innovation. We suppose that the non-innovating firm chooses a level of investment $\frac{\tilde{\rho}}{2}$, (which results in a probability of success of $\tilde{\rho}$.)

Thus, the discounted (at rate $\delta \in (0,1)$) present value of the innovator's expected profits is

$$V^N(0) = \pi_0 + \delta\Big[(1-\rho^N)V^N(0) + \rho^N \frac{\pi^N}{1-\delta}\Big] - \frac{1}{2}(\rho^N)^2 \tag{1}$$

when there is no standard, and

$$V^S(0) = \pi_0 + \delta\Big[(1-\rho^S)(1-\tilde{\rho})V^S(0) + (\rho^S + \tilde{\rho} - \rho^S\tilde{\rho})\frac{\pi^S}{1-\delta}\Big] - \frac{1}{2}(\rho^S)^2 \tag{2}$$

when there is a standard. $\rho^k, k = N, S$ are chosen to maximize (1) and (2) respectively. It will typically be the case that post innovation profits are lower with the standard, i.e., $\pi^N > \pi^S$. The main difference in the two cases is the term $\tilde{\rho}$. This represents the benefit of creating a standard, which results in a higher probability of innovation due to investment by other firms.

When there is no standard, the firm will want to choose ρ^N so as to maximize (1). And when there is a standard, the firm will choose ρ^S so as to maximize (2). Notice that market structure, e.g. vertical integration, the presence of competing technologies, etc., can affect these expressions, as we explain below.

The expressions (1) and (2) can be written as:

$$V^N(0) = \Big(\frac{1}{[1-\delta(1-\rho)]}\Big) \times \Big(\pi_0 + \delta\Big[\rho\frac{\pi^N}{(1-\delta)}\Big] - \frac{1}{2}\rho^2\Big) \quad (3)$$

$$V^S(0) = \Big(\frac{1}{[1-\delta(1-\rho)(1-\tilde{\rho})}\Big) \times \Big(\pi_0 + \Big[(\rho+\tilde{\rho}-\rho\tilde{\rho})\frac{\delta\pi^S}{1-\delta}\Big] - \frac{1}{2}\rho^2\Big) \quad (4)$$

The optimal investment level in both the standard and non-standard case is determined by maximizing (1) and (2). The level of investment will be higher in the case of non-standard if and only if the solution to (3) is larger than (4).

The first order conditions for an optimum value of ρ^N, in the case of non-standard, can be written as:

$$\big[1-\delta(1-\rho)\big]\big[\frac{\delta\pi^N}{(1-\delta)} - \rho\big] - \delta\big[\pi_0 + \frac{\delta\rho\pi^N}{(1-\delta)} - \frac{\rho^2}{2}\big] = 0 \quad (5)$$

And in the case of a standard, the first order conditions for ρ^S are

$$\big[1-\delta(1-\rho)(1-\tilde{\rho})\big]\big[\frac{\delta\pi^S(1-\tilde{\rho})}{(1-\delta)} - \rho\big] - \delta(1-\tilde{\rho})\big[\pi_0 + (\rho+\tilde{\rho}-\rho\tilde{\rho})\frac{\delta\pi^S}{(1-\delta)} - \frac{\rho^2}{2}\big] = 0 \quad (6)$$

Proposition 1 *Whether $\rho^S < \rho^N$ where $\rho^j, j = N, S$ is determined by (5) and (6). Other things equal, the larger is π^N the larger the investment incentives without a standard. And the larger is π^S the larger are investment incentives with the standard.*

The above follows from differentiation of expressions (3) and (4). These expressions allow some relatively straightforward comparisons about when standardization is desirable or increases investment incentives. First, consider the case in which $\tilde{\rho}$ is small or zero. In this case, creating a standard or contributing a new technology to a standard will tend only to reduce profits, and not increase likelihood of success, as long as $\pi^N > \pi^S$. Thus, a firm that does not rely on complementary technologies provided by rival firms or for which there are no network effects that increase profits will want to keep its technology outside of any standards process: contributing its technology to a standard would dilute its profits.

Proposition 2 *When $\tilde{\rho} = 0$, and $\pi^S < \pi^N$, than a firm will invest more without a standard if $\rho^S < \rho^N$, and will also prefer not to share its technology with an SSO.*

The above considers the case in which there is little benefit in sharing technology through participation in an SSO. At the other extreme, suppose there is not much profit dissipation post-innovation, i.e., π^S is not much less than π^N, and in which both the new technology owner and the firm that would share would invest the same amount if there were an SSO. In this case, it can be seen from comparing (3) and (4) when $\rho = \tilde{\rho}$ and $\pi^N = \pi^S$ that marginal incentives to invest will be higher in the case in which there is a standard.

Proposition 3 *Suppose $\rho = \tilde{\rho}$ and $\pi^N = \pi^S$, so that once the leading firm shares its technology, there would be a symmetric duopoly, the two firms would invest the same amount, and the sharing firm's profits are not dissipated by sharing. Then the investment levels will be larger, and innovation will occur sooner when the leading firms shares its technology in an SSO.*

Proof: Notice that whether sharing or not results in larger investment incentives depends on a comparison of (5) and (6). Let $x = \frac{\delta\pi}{1-\delta}$ where $\pi = \pi^S = \pi^N$. Then first term in (6). is always larger than the first term in (5). And, the second term is smaller. □

In the first case, the initial technology owner has an obvious incentive to share technology in an SSO, and this will tend to result in increased investment; the SSO then has an unambiguously positive effect on social welfare. In the second proposition, the technology owner has the opposite incentives, and the sharing of technology in an SSO may instead reduce welfare.

Various other factors can affect both the incentives to contribute technology to an SSO and the subsequent impact on investment. For example, either a vertical or horizontal merger will tend to increase profits both in the standard and non-standard cases.

Similarly, the emergence of a competing technology (e.g. Android for iOS or Open Office for MS Office) will tend to reduce the profits most in the non-SSO case. In what follows, we outline a few of the effects of mergers, and exogenous changes can have on incentives to support a standard. This entails a comparison of expected profits with and without the standards.

We now consider the case in which the net impact of the new technology is to reduce costs for end users. Then, the innovating firm will want to share its technology in an SSO when its expected profits are higher than without a standard. The terms (1) and (2) indicate that investment will be greater with greater post-innovation profits. As noted above, the innovating firm's expected profits can be larger or smaller with standardization. In addition, the terms $\pi^k, k = S, N$ above will depend on competition in the marketplace downstream. With strategic substitutes (e.g., Bertrand duopoly of the form $q = \alpha - \beta p + \gamma \tilde{p}$, where p denotes price, q denotes quantity, and $\tilde{p}$ is the rival's price) then the monopoly will result in larger investment incentives. This will tend to make non-standardization more profitable. In contrast with strategic complements (e.g., Cournot duopoly of the form $p = a - bq + \gamma \tilde{q}$, where $\tilde{q}$ is the rival output), monopoly can result in either higher or lower investment incentives. The incentives tend to be lower under monopoly when the industry starts out more asymmetric. These type of comparisons are relevant when evaluating the effects of a horizontal merger.

The effects of vertical merger can be modeled as a successive monopoly, such as in Cournot (1838) orLemley & Shapiro (2007). In this case, a vertical merger results in higher profits, ceteris paribus, due to the elimination of double marginalization. Vertical integration can make a standard irrelevant, as the coordination between an upstream supplier and a downstream producer can be internalized, but should increase the investment incentives.[13] When integration is partial, so that the integrated firm has a downstream affiliate competing against unintegrated rivals,[14] it can be the case that vertical integration

[13]It is straightforward when downstream inverse demand is $p = a - bq$, and the only costs are upstream, cq, to see that upstream profits are $\frac{(a-c)^2}{16b}$ without integration, and $\frac{(a-c)^2}{4b}$ with vertical integration. Thus, there are larger incentives to invest in cost-reducing investments with integration.

[14]Google produces handsets using Android, as well as provide Android to competing handset vendors. Nokia owns 3G patents and sells licenses to those patents to competing handset vendors.

has no effect on investment incentives and for creating a standard.

The following proposition summarizes the above discussion.

Proposition 4 *a) A vertically-integrated firm, so that π^N tends to be larger than π^S, sharing technology is not needed to capture benefits of innovation will have lower incentives to share technology in an SSO than is the case in which the sharing is essential to its profits. b) The appearance of new potential competitors, which reduces the difference between π^N and π^S, will also tend to result in a larger incentive to contribute to an SSO.*

Note that the above model suggests that the sharing of a technology in an SSO should affect investment, although causation can be reversed. Industry conditions may change in a way that causes a firm to contribute new technologies to an SSO, or to found an SSO, and this decision is in part motivated by how it affects aggregate development and investment by other firms.

6 Conclusion

This paper explores the decision of innovators to establish or participate in voluntary SSOs. We begin by summarizing some of the important issues surrounding SSOs. While there exist a few empirical papers that examine some of these, the salience of others in practice is less certain. For example, the role played by NPEs and the magnitude of trade in intellectual property between firms involved in SSOs is largely unknown. We present very preliminary and limited evidence on these factors for three small SSOs and for the wireless industry more broadly defined. Some of the more prominent NPEs appear to purchase more IP than they develop internally, but their patent portfolios are dwarfed in size by the major firms in the wireless industry. Since the size of a portfolio may not always reflect its true value, there is much more analysis required to assess the effects of NPEs in this market.

In a theoretical model that draws on these cases and others described in the literature, we focus specifically on when an innovator chooses to share its technology with others, and the subsequent effect on investment. We find that an innovator's incentive to share depends on factors such as the reliance on complementors, vertical structure, and competition from substitute technologies. Since these may change over time, an innovator's willingness to contribute his technology to an SSO will also vary; thus we may expect to see SSO membership policies or leadership reflect these forces. Future work requires a much larger sample of SSOs and more detailed information about the timing and extent of participation by firms.

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Member name	Membership level	Type
Broadcom Corporation	Sponsor	Semiconductor firm
Intel Corporation	Sponsor	Semiconductor firm
MasterCard Worldwide	Sponsor	Financial services
NEC Corporation	Sponsor	Diversified IT/electronics
Nokia Corporation	Sponsor/Founder	Handset manufacturer
NXP Semiconductors	Sponsor/Founder	Semiconductor firm
QUALCOMM Inc.	Sponsor	Semiconductor firm
Renesas Electronics Corporation	Sponsor	Semiconductor firm
Samsung Electronics Co.	Sponsor	Diversified IT/electronics
Sony Corporation	Sponsor/Founder	Diversified IT/electronics
STMicroelectronics	Sponsor	Semiconductor firm
Visa Inc.	Sponsor	Financial services
American Express	Principal	Financial services
AT&T	Principal	Mobile operator
Barclays	Principal	Financial services
Canon	Principal	Imaging/optical products
CSR	Principal	Semiconductor firm
Dai Nippon Printing	Principal	Imaging/optical products
Google	Principal	Internet services
HP	Principal	Hardware
Huawei	Principal	Telecommunications/networking
Infineon	Principal	Semiconductor firm
INSIDE Secure	Principal	NFC specialist
Kovio	Principal	NFC specialist
LG	Principal	Diversified IT/electronics
Marvell	Principal	Semiconductor firm
NTT Docomo	Principal	Mobile operator
PayPal	Principal	Financial services
RIM	Principal	Handset manufacturer
Rogers	Principal	Mobile operator
Texas Instruments	Principal	Semiconductor firm
Yahoo	Principal	Internet services

Table 1: Board members of the NFC Forum

Member name	Membership level	Type
Hitachi	Founder, board member	Diversified IT/electronics
Panasonic Corporation/Sanyo	Founder, board member	Diversified IT/electronics
Philips Electronics	Founder, board member	Diversified IT/electronics
Silicon Image	Founder, board member	Semiconductor firm
Sony Corporation	Founder, board member	Diversified IT/electronics
Technicolor	Founder, board member	Media services
Toshiba Corporation	Founder, board member	Diversified IT/electronics
Apple	Board of directors	Computer/handset manufacturer
LG Electronics	Board of directors	Diversified IT/electronics
Motorola Mobility	Board of directors	Handset manufacturer
NVIDIA	Board of directors	Semiconductor firm
Samsung	Board of directors	Diversified IT/electronics
Sharp	Board of directors	Diversified IT/electronics

Table 2: Board members of the HDMI Forum

Member name	Membership level	Type
Panasonic	Founder, board member	Diversified IT/electronics
Sandisk	Founder, board member	Storage/memory
Toshiba	Founder, board member	Diversified IT/electronics
ATP	Board member	Storage/memory
Canon	Board member	Imaging/optical products
Cardwave Services Ltd	Board member	Technology services
China UnionPay	Board member	Financial services
Giesecke & Devrient	Board member	Financial services
Hewlett-Packard	Board member	Diversified IT/electronics
Kingston	Board member	Storage/memory
Lexar Media	Board member	Storage/memory
Motorola Mobility	Board member	Handset manufacturer
Netac Technology	Board member	Consumer electronics
Samsung Electronics	Board member	Diversified IT/electronics
Phison Electronics	Board member	Memory chip controllers
Silicon Motion	Board member	Memory chip controllers
Tokyo Electron Device	Board member	Semiconductor firm
Trek Technology	Board member	Storage/memory

Table 3: Board members of the SD Association

IPC	Description
G06F	ELECTRIC DIGITAL DATA PROCESSING
G06K	RECOGNITION OF DATA; PRESENTATION OF DATA; RECORD CARRIERS; HANDLING RECORD CARRIERS
G09G	ARRANGEMENTS OR CIRCUITS FOR CONTROL OF INDICATING DEVICES USING STATIC MEANS TO PRESENT VARIABLE INFORMATION
G11B	INFORMATION STORAGE BASED ON RELATIVE MOVEMENT BETWEEN RECORD CARRIER AND TRANSDUCER
H01L	SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES NOT OTHERWISE PROVIDED FOR
H01Q	AERIALS
H04B	TRANSMISSION
H04J	MULTIPLEX COMMUNICATION
H04L	TRANSMISSION OF DIGITAL INFORMATION
H04M	TELEPHONIC COMMUNICATION
H04N	PICTORIAL COMMUNICATION
H04Q	SELECTING
H04W	WIRELESS COMMUNICATION NETWORKS

Table 4: Common mobile telephony IPC codes

Major firms in mobile	Apple Ericcson Google HTC Nokia Nortel Qualcomm Research in Motion Samsung
Major NPEs	Intellectual Ventures Round Rock Research Rockstar Consortium Interdigital Wisconsin Alumni Research Foundation Rambus Tessera Technologies Acacia Technologies

Table 5: Firms included in analysis of subgroups

	Founder		Sponsor		NPE		Other	
Year	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions
2000	.	.	.	.	.	.	1	.
2001	.	.	.	.	.	.	4	.
2002	.	.	1	.	.	.	2	.
2003	2	.	1	.	.	.	7	.
2004	4	1	.	.	.	.	4	2
2005	14	.	3	.	.	.	17	.
2006	13	.	7	.	.	.	60	3
2007	15	4	14	.	.	.	41	.
2008	9	1	17	.	.	.	69	3
2009	16	.	16	.	.	.	56	1
2010	10	.	20	.	.	.	78	2
2011	8	.	20	.	.	.	135	1
2012	16	.	13	10	.	.	38	7

Table 6: Patent activity in NFC

	Founder		Sponsor		NPE		Other	
Year	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions
2001	.	.	.	1	.	.	.	.
2002	1	.	.	.	.	.	.	.
2003	1	.	.	.	.	.	2	1
2004	3	.	1	.	.	.	11	.
2005	5	.	3	.	.	.	16	.
2006	8	.	10	.	.	.	28	.
2007	24	.	19	.	.	.	41	.
2008	27	.	4	.	.	.	51	2
2009	16	.	2	.	.	.	49	2
2010	19	.	10	.	.	.	59	.
2011	8	.	2	.	.	.	49	1
2012	3	.	1	.	.	.	16	1

Table 7: Patent activity in HDMI

Year	Founder		Sponsor		NPE		Other	
	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions	Applications	Acquisitions
1998	.	.	1	.	.	.	.	.
2000	.	1	.	.	.	.	2	.
2001	2	.	.	.	.	.	10	2
2002	4	2	.	.	.	.	22	4
2003	3	.	.	.	.	.	10	5
2004	5	1	.	.	.	.	23	2
2005	7	.	2	.	.	.	21	1
2006	2	.	1	.	.	.	25	9
2007	6	.	3	.	.	.	29	1
2008	2	.	2	.	.	.	22	.
2009	2	.	1	.	.	.	14	.
2010	.	.	3	1	.	.	13	5
2011	3	.	.	.	.	.	7	6
2012	1	.	.	.	.	.	1	.

Table 8: Patent activity in SD