Generative or Exclusionary? How Ecosystems Evolve with Coordination and Standardization

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ABSTRACT

The literature typically depicts ecosystem evolution as "generative", with coordination fueling growth in complements and complementors. We suggest that it could instead be "exclusionary", where complements increase but complementors do not grow meaningfully and core component owners dominate the complementary areas with their own complements. Using a descriptive approach and data on ICT ecosystems adopting standard setting as coordination mechanism, we systematically trace how ecosystems evolve alongside standardization, indicating signs of "exclusionary" growth. We further describe how exclusionary growth occurs – core component owners exploit standardization and litigation to crowd out other complementors over time. Findings suggest that core component owners' strategy to coordinate across complementors is interdependent with their choice to integrate into complementary areas, and that standardization is not merely a coordination mechanism but can be used strategically to stifle competition from complementors. Findings also help substantiate the practical threat that core components owners could exhibit monopolistic behavior in ecosystems.

INTRODUCTION

How does an ecosystem evolve? Prior research posits that an ecosystem's growth and evolution rely critically on complements and the ease with which they connect to the ecosystem (Iansiti and Levien 2004, Adner and Kapoor 2010, Baldwin 2012). Enabling this connection of complements can be challenging though, as the ecosystem may not be equipped with coordination mechanisms usually available in traditional industry structures or vertical value chains (Kapoor, 2018). For example, the owners of the ecosystem's core components may not have direct buyer-supplier contractual relationships with complementors, i.e. developers of complements, that could have otherwise helped coordinate and governed the way complements are to be connected (Dyer 1997, Poppo and Zenger 1998).

Instead, a typical way to achieve this coordination in ecosystems is through standardization (Baldwin 2012, Teece 2018). In an ecosystem without a clear "platform leader" (Bresnahan and Greenstein 1999, Miller and Toh 2020), firms increasingly use standard-setting organizations (SSO) to standardize technical specifications of core components, which clarify to complementors how to connect their products to these core components (Rysman and Simcoe 2008, Dokko and Rosenkopf 2010). In a platform-based ecosystem with a clear, single platform owner, e.g. iOS ecosystem owned by Apple, the platform owner is responsible for standardizing the connection interface, creating an "alignment structure" (Adner 2017) that enables more complements to join the ecosystem, e.g. Apple standardizes interfaces through its APIs, enabling more apps to join the iOS platform (Baldwin 2012, Kapoor and Agarwal 2017).

With standardization in place, we would then logically expect to see the ecosystem evolve following a pattern of pronounced growth in *complements*. But does that mean that we would see a corresponding growth in *complementors*? The former points to the areas within the ecosystem where we expect growth to occur, whereas the latter indicates how the competitive structure within the ecosystem will evolve over time. The literature thus far has not addressed this separation but typically equates the two, assuming implicitly that more *complements* means more *complementors*. In fact, recent research seems quick to celebrate the "generative" property of an ecosystem (Zittrain 2008, Cennamo and Santalo 2019), projecting that ecosystem evolution will be fueled by participation from a broad variety of 'a thousand blooming' heterogeneous complementors (Zammuto et al. 2007, Boudreau 2012, Parker et al. 2017), and that ecosystems will take on a meta-organizational form coordinating across many modular, specialized, legally autonomous but interdependent complementors (Gulati et al. 2012, Jacobides et al. 2018).

However, this projection ignores a key observation from a separate but related stream of literature—*complements* are not necessarily developed only by separate *complementors*; the platform leader or owner of core components in the ecosystem frequently enters the complementary area at a later stage and produces its own complements as well (Gawer and Henderson 2007, Toh and Miller 2017, Zhu and Liu 2018). This observation has practical, urgent relevance in reality—this form of entry is currently sparking concerns among regulators and complementary producers fearing that the platform leader or owner of the ecosystem's core components is exploiting unfair advantages as it competes with complementors.[1]

If standardization somehow enables the platform leader or owner of core components to crowd out other complementors with its own competing complementary products, we may see an alternative pattern of ecosystem evolution where *complements* grow significantly over time but *complementors* do not. The ecosystem, rather than being "generative", may exhibit an "exclusionary" property where at least some of the complementors are excluded from participating in meaningful ways in the ecosystem over the long run. To date, to the best of our knowledge, there has been no systematic trace within the literature of how ecosystems evolve over time, such that we do not yet have a basis to project which of the two ways—generative or exclusionary—a given ecosystem will evolve.

In this paper, we address the above gap in the literature. Our overarching objective is to raise awareness that an ecosystem may evolve in an exclusionary way, in which fewer, not more, complementors get to participate meaningfully over time. Using a largely descriptive approach, we do so with two demonstrations based on data from ICT ecosystems which rely on standard setting as a coordination mechanism over the 1993-2010 period. First, using descriptive figures, we document the evolution of these ecosystems over time, in terms of growth in *complements* and *complementors* along with standard setting.

[1] For example, app developers in the iOS ecosystem are alleging that Apple is accessing and exploiting their data to learn about the complementary areas and subsequently creating its own competing apps with exclusive access to core parts of the iOS operating systems which they do not have. Likewise, Amazon is currently expanding majorly into numerous 3rd-party suppliers' markets and producing its own competing private labels, in ways that clearly contradict its own stated policies, and the EU has launched an antitrust investigation looking at whether Amazon is doing so in unfair, monopolistic ways.

In essence, our data shows signs of an exclusionary pattern of ecosystem evolution. Specifically, we find that post-coordination via standard setting, an ecosystem tends to experience substantial growth in *complements*. *Complementors*, on the other hand, while growing in numbers, mostly remain small and continue to account for few complements. The innovation concentration ratio rises with few large developers of complements accounting for greater overall share of innovations over time. Notably, an owner of the core components in the ecosystem on average accounts for substantially more complements than a non-owner, and this number further exhibits an upwards spike with standardization.

Second, we go further to illustrate the central tenet in this “exclusionary” ecosystem evolution – coordination via standardization enables the owners of the core components to crowd out other complementors over time. In our standard-setting context, the core components are the standard essential patents (SEPs), and standardization enables their owners to subsequently use litigation involving SEPs to exclude complementors from complementary areas within the ecosystem. Our data shows signs of this central tenet – on average, the litigation rate of an SEP owner’s patents in the complementary areas exhibits a pronounced increase post-standardization, as compared to non-SEP owner’s patents. We further describe this central tenet with regression analyses showing that, post-standardization, standards-based litigation (involving SEPs) in a complementary area is followed by a subsequent increase (reduction) in complements created by SEP owners (non-SEP-owners) in the area, and also a reduction (increase) in entry into (exit from) the complementary area.

We believe this paper has meaningful implications for ecosystem and platform research as well as strategy theories about coordination and standardization. At the very least, findings here suggest that the typical characterization of “generative” ecosystem evolution (Zittrain 2008, Cennamo and Santalo 2019) does not always hold in practice. The core component owner does not only get to decide how to coordinate *across* firms and to manage a whole system of separate complementors using some form of meta-organization designs (Gulati et al. 2012, Hoehn-Weiss, Karim and Lee 2017, Jacobides et al. 2018). Rather, this decision is interdependent with its choice of whether to integrate into the complementary areas itself in order to appropriate value it creates in these areas (Zhu and Liu 2018, Miller and Toh 2020). By explicitly separating complements from complementors, we hope to shift the focus of discussion away from value-creation across different loci of growth, and instead encourage more purposeful consideration of market structure in complementary areas and other value-appropriation issues. In examining value-appropriation issues, we also highlight that standardization is not just a coordination mechanism to help create value; rather, it can also be a strategic tool to stifle competition from complementors.

We clarify that, even with a fair amount of regression analyses conducted, this paper remains largely descriptive in nature. Readers should be cautious against over-interpreting causal effects in our findings. Our aim is simply to describe that exclusionary evolution exists and to describe a mechanism through which it does. We also clarify that we are not saying ecosystems will always evolve in exclusionary ways; we are but stressing the possibility that it can. While this paper does trigger thoughts on welfare and fairness across ecosystem participants and related policy matters, it is not set up to address these issues frontally. We leave them to be explored by more capable minds in future research.

The rest of the paper is structured as follows. The next section lays out the theoretical background of our central thesis. We then describe key features of the standard setting context in which we conduct this study. This is followed by description of data and our documentation of ecosystem evolution, where we indicate signs of "exclusionary" growth. Upon laying out this systematic trace, we then go deeper to examine the mechanism through which exclusion occurs – how coordination via standardization enables the core component owners to use litigation to crowd out complementors. In this section, we discuss the theoretical mechanisms, construction of dataset for analysis, followed by reporting of results. The last section concludes.

THEORETICAL BACKGROUND

Ecosystem and Coordination

An ecosystem consists of core components and their complements (Adner and Kapoor 2010, Baldwin 2012). This depiction is clear when the ecosystem is platform-based, such as the iOS ecosystem (Wareham *et al*. 2014, Kapoor and Agarwal 2017) – its core component is the platform, usually with a clear platform leader, e.g. Apple, and its complements refer to other components connected to and operating on this platform, e.g. the apps. The platform leader is also known as the "hub" or "keystone" firm or "ecosystem manager" (Iansiti and Levien 2004, Dhanaraj and Parkhe 2006). An ecosystem is not necessarily platform-based though, and it does not always have a single platform leader. Miller and Toh (2020) provide examples of ecosystems with multiple owners of the core components, such as the WIFI ecosystem.

A main challenge that owners of the core components face is in coordinating development with complements to ensure connectedness (Kapoor and Lee 2013, Adner 2017, Jacobides et al. 2018). As Kapoor (2018) points out, the key feature that renders an ecosystem distinct from other traditional forms of industry organization, e.g. vertical value chain, is the relative absence of buyer-supplier contractual relationships between core component owners and developers of complements (Brandenburger and Nalebuff 1996, Miller and Toh 2020). Often, complementors' outputs are not direct inputs into the core components' production or vice versa; both core and complementary products are instead sold direct to users. Complementarity relationships in ecosystems tend not to fit the typical upstream-stream depiction as characterized in value chain perspective, value-based models or classic theories of vertical integration (Williamson 1975, Porter 1985, Hart and Moore 1990, Chatain and Zemsky 2011). This key defining feature, by depriving the parties involved of the contractual mechanisms that could have been used to specify and govern how the complements are to be built and connected to the core components, effectively raises the hurdle for coordination (Dyer 1997, Poppo and Zenger 1998, Gulati et al., 2012).

Yet, it is crucial to overcome this coordination challenge, as the ecosystem's growth relies critically on complements. Their presence generates network effects, both direct and indirect, drawing parties and users into the ecosystem, enabling growth, and sometimes helping to lock-in parties as well (Schilling 1999, Parker and Van Alstyne 2005, Zhu and Iansiti 2012, Boudreau 2012). The ecosystem's value to users, and thus demand, depends on whether the ecosystem has sufficient complements that are attractive (Bensen and Ferrell 1994, Rochet and Tirole 2003, Suarez 2004, Armstrong 2006).[2,3] Unsurprisingly, prior research has argued that core components' owners have clear incentives to want more complements to join their

[2] For instance, the value of and demand for Apple's iOS ecosystem are largely fueled by the existence of attractive complementary apps. Likewise, a mobile communication ecosystem is successful when there is widespread adoption of its mobile standard by complementors producing components and technologies necessary to implement the standard, such as network operators, networking gear, phones, rf chips, etc.

[3] Notably, scholars have also argued recently that not all complementors add value to the ecosystem equivalently, as some may free-ride or have less incentives to invest in the ecosystem (Boudreau 2012, Cennamo and Santalo 2019).

ecosystem (Iansiti and Levien 2004, Hagiu 2007). Also, prior research has examined what would bolster complements' performances (Kapoor and Agarwal 2017) and what governance or promotion systems, pecuniary or non-pecuniary, could be put in place induce them to join the ecosystem (Rochet and Tirole 2003, Evans 2003, Parker and Van Alstyne 2005, Hagiu 2014, Rietveld et al., 2019. See Dushnitsky et al. 2020 for a review). Notwithstanding these inducements drawing complements to 'want to join' the ecosystem, the technical coordination challenge of 'how to join' remains.

Standardization in Ecosystems

This coordination challenge is typically overcome with standardization (Baldwin 2012, Teece 2018). By standardizing the connecting interfaces or rules of connection to the ecosystem's architecture, developers of complements can more easily connect to and gain access to the core components (Ceccagnoli et al. 2012, Cennamo and Santolo 2013), bypassing the need to negotiate customized contracts for coordination (Gulati et al. 2012). This concept of standardized interface is well established within studies of modular systems (Baldwin and Clark 2000, Ethiraj and Levinthal 2004, Karim 2006) and more recently picked up in discussions within the ecosystem literature on why standardized roles or rules are needed (Helfat & Raubitschek 2017, Jacobides et al 2018) especially when complements are not generic (Helfat and Lieberman 2002). The task of standardization is more straightforward in platform-based ecosystems where there is a single platform leader. For example, in the iOS ecosystem, Apple designs and creates application programming interfaces (APIs) that standardize the way different apps connect to its platform. Likewise, Amazon determines the rules and procedures for 3rd party sellers to transact via its digital platform. In non-platform-based ecosystems where the core components are owned by multiple parties, standardization is less straightforward as multiple parties would have to agree on how the core components are to be standardized. Increasingly, this is achieved via standard-setting (Rysman and Simcoe 2008, Miller and Toh 2020. See later section for details).

With standardization in place, we would then expect to see more complements joining the ecosystem, spurring its growth. To date, to the best of our knowledge, research has not yet offered any systematic trace of an ecosystem's growth or evolution over time. Nonetheless, there are many recent studies that seem to align with this notion of complements-driven growth. Scholars proclaimed ecosystems to exhibit a "generative' property, defined as 'the capacity to foster complementary innovation from autonomous, heterogeneous firms' (Cennamo and Santalo 2019). With connectivity enabled, the "generative" property would draw 'unfiltered contributions from broad and varied audience' (Zittrain 2008). The corresponding surge of a 'thousand blooming' new complements produced by these specialized complementors (Boudreau 2012) would extend the ecosystem's possible uses and in doing so enhance the value for final users (Zammuto et al. 2007, Yoo et al. 2010). In fact, scholars have already gone further to think about meta-organizational designs the ecosystem would need in order to manage this collection of modular, specialized, legally autonomous but interdependent complementors (Gulati et al. 2012, Jacobides et al. 2018, Kretschmer et al 2020).

Implicit in the above characterization is the notion that *complements* and *complementors* are equivalent, i.e., that somehow enabling more complements to connect means there will be more complementors. However, even if more complementors all else equal lead to more complements produced (Boudreau 2012), a parallel research stream has made clear that complements do not all have to be produced by complementors that are separate entities, in both platform-based and non-platform-based ecosystems (Farrell and Katz 2000, Zhu 2019, Miller and Toh 2020). Zhu and Liu (2018) demonstrates Amazon's tendency to enter higher value-generating 3rd-party sellers' (complementors') markets and offer its own competing products while mindful of not overly stifling these complementors (see also Iansiti and Levien 2004, Gawer and Henderson 2007). Toh and Miller (2017) studies non-platform-based ecosystems that use standard setting and finds that owners of core components often own complements in the ecosystem as well. Core component owners have various incentives to own complements within their ecosystems. Doing so enables them to generate additional value via bundling. For example, Microsoft achieved early success in internet browsers partly by bundling it with its own Windows operating system (Chio and Stefandandis 2001, Economides 2001). It also allows them to capture complementarity value they helped create, which is crucial when their investments end up generating more value in the corresponding complements rather than in the core components themselves (Miller and Toh 2020).

This calls for the need to separate *complements* from *complementors*, and to recognize that an ecosystem's evolution, while fueled by growth in complements, may not accompanied by an equivalent growth in separate complementors if it ends up being the core components owners dominating the production of these complements. In other words, the ecosystem, instead of being "generative", may exhibit an "exclusionary" attribute where fewer, not more, complementors get to participate meaningfully over time.

CONTEXT: STANDARD SETTING

Before researchers can effectively theorize about why and when ecosystems evolve in "exclusionary" or "generative" ways, it would be helpful to first have a systematic trace of how an ecosystem grow in terms of its complements and complementors over time. We attempt to be the first to provide this trace, within the context of standard setting. In this section, we describe the key attributes of standard setting, before documenting our findings in the next. We focus on *de jure* standards (Shapiro and Varian 1999, Baron and Spulber 2018), i.e. cooperative, multiple-party standard setting that typifies many standards in the ICT industry (rather than *de facto* standard setting via market competition. See Katz and Shapiro 1985).

The standard setting process involves multiple parties (firms) voluntarily working in an SSO to cooperatively develop and codify technological specifications of a core platform so that products can interconnect (Leiponen 2008, Dokko and Rosenkopf 2010, Vasudeva et al. 2015). SSOs coordinate development and promulgation of the standard by providing rules to adjudicate the development process, managing and disseminating technological documentation, and promoting the finalized standard (Chiao et al. 2007). Committees staffed by representatives from participating firms develop and approve the technical specifications for each section of the standard (Leiponen 2008). When a specification nears completion, SSOs typically require participating firms to disclose SEPs, which are patents that read on the functionality of the standard and must be licensed to adopt the standard (Rysman and Simcoe 2008).

Standards set via SSOs facilitate coordination with complements, enabling their connection to the core components. For developers to adopt a standard in their complementary products, they need to identify and access the necessary IP over the core components within the standard. For instance, to market a Wi-Fi compatible device, the developer would have to license the essential technology behind the IEEE 802.11

standard.[4] Disclosure of SEPs during standard setting allows adopters to identify these IP.[5] Patent pools are sometimes formed to further reduce search and negotiation costs associated with standards adoption (Vakili 2016).[6] Along with disclosure mandates, most SSOs' IP policies require SEPs to be licensed out on a fair, reasonable, and nondiscriminatory (FRAND) basis, which helps mitigate patent holdup and facilitate adoption (Chiao et al. 2007, Contreras 2011, Taffet and Harris 2018).[7]

Owners of core components have strong incentives to participate in standard setting. Other than facilitating complements to connect to the ecosystem and enabling network effects that follow, the disclosed SEPs themselves gain in intrinsic value after disclosure, evidenced by increased patent citations (Rysman and Simcoe 2008, Bekkers et al. 2017) and litigation rates (Simcoe et al. 2009, Lemley and Simcoe 2019), and generate licensing revenue (Pohlmann et al. 2015). Further, the disclosed SEPs allow the core component owners to steer the industry's technological trajectory in their favor (Leiponen 2008, Dokko et al. 2012, Ranganathan & Rosenkopf 2014), which is beneficial when user switching costs and chance of creating lock-ins are high (Garud & Kumaraswamy, 1995; Schilling, 2002). Studies have also shown that standard setting helps the SEP-owners access knowledge spillovers (Delacamp and Leiponen, 2014) and identify alliance partners (Rosenkopf et al. 2001, Leiponen 2008). Notably, recent findings by Miller and Toh (2020) show that much of the returns to the SEP-owners during standard setting arise through enhanced value of their complementary IP that are not part of the standards, less so through the disclosed SEPs *per se*.

DOCUMENTING ECOSYSTEM EVOLUTION

In this section, we use a descriptive approach to document ecosystem evolution over time. In particular, we trace growth trajectories of *complements* and *complementors* along with standard setting,

[4] See https://www.vectis.com/programs-2/ for an example of a licensing program.

[5] In some instances, firms do not directly list IP but rather make blanket disclosures (Bekkers and Martinelli 2013). Blanket disclosures presumably increase adopters' search costs (Bekkers et al. 2017).

[6] For example, MPEG LA manages the pool of SEPs for licensing video compression technology. See https://www.mpegla.com/

[7] In the absence of such licensing policy, the adoption of the standard and development of complementary products could be diminished because SEP owners could charge exorbitant licensing fees or discriminate against certain adopters (Simcoe 2005). However, even with FRAND licensing policy in place, defining a 'fair' price is difficult in practice and has been subject to litigation (Lerner and Tirole, 2015).

changes in market structure within complements' areas, and relative ownership of complements by core component owners versus complementors. Below, we describe our data set and then document our descriptive findings.

Data

We use the Disclosed Standard Essential Patents (dSEP) database version 1.3 (Bekkers et al 2012) to collect information on standards, patents and applications disclosed to SSOs, disclosing firms, and disclosure dates. The dSEP database contains over 45,000 IP disclosures made to SSOs worldwide. The U.S. Patent and Trademark Office (USPTO) and the Patent Network Dataverse (Lai et al. 2011) provide data on patents and applications. We collect information on IP lawsuits from Thompson Westlaw and data on firm financials from Compustat.

To create a dataset on standards-based ecosystems in the ICT industry over the 1990-2009 period, we begin by assigning IP disclosures (to SSOs) to standards using information from the dSEP database, SSO websites and industry publications.[8] Through this, we compile a set of standards for which the first and last IP disclosure date fall within the 1990-2009 period. Within this set of standards and corresponding IP disclosures, we link the disclosed SEPs to the USPTO and IP lawsuit data using patent numbers. We measure technological area – for core components or complements – using USPTO 3-digit technology class.[9] We infer that a class is complementary to a core class (where SEPs are assigned, total of 30 core classes identified in our sample) if there were at least one patent in this class jointly litigated with SEPs from the core class at some point during sample period (1990-2009). We used a total of 332 lawsuits in our sample used to identify these complementary classes. We believe this procedure of identifying complementary class using lawsuits is meaningful. IP lawsuits involving SEPs often also involve other IP covering implementation of a standard (e.g., implementation patents) or features pertaining to products functioning on the standard, which point to components that likely complementary to the SEPs.[10] Moreover,

[8] When a disclosure letter does not clearly indicate which overall standard it pertains to (e.g. GSM) but instead cites a sub-standard or a particular version of the standard, we used information from the dSEP database on standard and committee to map it to the overall standard. In some instances where disclosure letters do not list any information about relevant standards, we are unable to utilize the letters.

[9] Details on patent classification is available at: https://www.uspto.gov/web/patents/classification/

[10] Two potential drawbacks to using joint IP lawsuits to infer complementary area: first, this restricts our analysis to standards in core components areas where there were IP litigation during the sample period. Second, this procedure

the classes identified as being complementary via this procedure are similar to those identified via other methods used in prior research (see Miller and Toh 2020).[11] Our final sample contains 74 ICT standards and 71 different complementary areas.

We construct the descriptive figures below depicting standards-based ecosystem evolution as follows. For each standard, we calculate the statistics in question across the complementary areas identified from the procedure above, and then take the average across all standards at each time period *t*, where *t* corresponds to year relative to the beginning of the standard (denoted *t*0). We define *t*0 as the first year IP related to the standard was disclosed to the relevant SSO. We further restrict the sample to 57 standards for which we have data up to *t*+7 so that we can more systematically assess the evolution over a longer timeframe.[12] Each standard has on average six complementary areas. We include details on figure calculations in the notes under each figure.

Descriptive Figures

First, we document the growth in *complements* over time by tracing patent filings (that were eventually granted) in complementary areas. Figure 1 displays the average (across standards) number of patents in all of the standard's complementary areas per year. This figure shows that patenting in complementary areas experiences significant growth, beginning a few years prior to, and continuing several years after, standardization.[13] In these areas, number of patents filed increased 148 percent between *t*-5 and *t*+5. Thus, per expectation, complements appear to experience growth alongside standardization. Contrast this growth with patenting in the corresponding core (SEP) areas – Figure 1 shows an 8 percent decline over the same period in patenting in the standard's core (SEP) area. This decline in the core areas is arguably not surprisingly – the need to invest in the core areas may decline once standards have been set.

may leave out other complementary technology classes that did not experience a joint lawsuit with the SEPs during the sample period. On the flip side, we believe that as litigations tend to occur in complementary areas that are valuable, this procedure allow us to focus on the more important areas that are complementary to standards.

[11] Miller and Toh (2020) uses patent co-citation across technology classes to identify classes complementary to core (SEP) classes. We replicate their method on our sample and compare the outputs to classes identified using our procedure. We find an 89-percent overlap in technology classes identified as complementary across these two methods.

[12] Alternatively, we plotted all figures using (i) all 74 standards, and (ii) only standards for which we have information at t+10. We found no notable difference in the figures or the conclusion we draw from them in either case.

[13] Note that the observed growth in complements prior to the beginning of standardization (t0) is in line with findings from Toh and Miller (2017) showing that firms build up their ownership of complements prior to standardization.

[Insert Figure 1 about here]

Second, we document the growth in *complementors* over time by tracing entities filing patents in complementary areas.[14] Figure 2 displays the average (across standards) number of entities in all areas complementary to a standard, broken down by the entity' 'size', i.e. number of patents the entity filed across all complementary areas in the year. This figure shows that the overall number of complementors grew 103 percent from *t*-5 to *t*+5. On its own, this would almost suggest a "generative" growth pattern of ICT ecosystems. However, a closer look suggests otherwise. Figure 2 reveals that a large portion of this growth comes from 'smaller' complementors (filing fewer than 5 patents in the year, and to a lesser extent, complementors filing 5-50 patents in the year). We supplement with Figure 3 to see more clearly the change in corresponding share of patents in the complementary areas by complementor type. While the number of complementors with fewer than 5 patents per year grew 103 percent between *t*-5 and *t*+5 (Figure 2), their share of the total patents declined from 34 percent to 28 percent (Figure 3). Meanwhile, the number of complementors with 50 or more patents per year grew from an average of 8 to 23 per year between *t*-5 and *t*+5 (Figure 2) and their share of patenting increased from 24 percent to 40 percent in the same time frame. Further examination shows that these complementors tend to be significantly larger than ones in the other two categories in terms of revenues, patent portfolios, and R&D spending.[15] Moreover, entities patenting in complementary areas post-standardization often own SEPs as well. At *t*+5, 20 percent of entities with 50 or more patents in the complementary area are also SEP owners, and they are 110 times more likely than non-SEP owners to reach that level of yearly patent filing.

[Insert Figure 2 and Figure 3 about here]

Third, we document changes in market structure, using the eight-firm concentration ratio of patenting, in the complementary areas. Figure 4 shows that at the beginning of a standard (*t*0), a complementary area has a similar concentration ratio (~23 percent) as another area (technology class) unrelated to the standard. However, this concentration ratio in the complementary area on average increases

[14] Entities include assignee firms as well as others such as universities or individual assignee-inventors.
[15] For instance, at *t*+5, the average firm with less than five patents had mean and median revenue levels of $13.6 billion and $1.6 billion respectively, while firms with more than 50 patents had mean and median revenue levels of $39 billion and $36 billion respectively.

sharply from about 21 percent prior to the standardization to 33 percent by t+10, while concentration in unrelated areas remain relatively stable.

[Insert Figure 4 about here]

Fourth, we document the relative dominance of SEP-owners and non-SEP-owners in the complementary areas, before and after standardization. Figure 5 reports the average (across entities) number of patents in all areas complementary to a standard filed by an SEP-owners and a non-SEP-owners, in the five years pre- and post-standardization (t-4:to and t+1:t+5 respectively). This figure shows that a typical SEP-owner has significantly more patents relative to a non-SEP-owner in both the pre-standardization (195 relative to 2) and post-standardization (279 relative to 3) periods. Notably, the SEP-owner experiences a meaningful, non-trivial spike in patenting in the complementary areas between the two periods (from 195 to 279). To check if the stark contrast between SEP-owner and non-SEP-owner arises because there are many more non-SEP owners with very few patents, we restrict the 'non-SEP-owners' to include only the 10 largest entities in patenting. As Figure 5 shows, even these 10 largest non-SEP-owners have on average only 10 patents each in the pre-standardization period, with this number dipping to 9 post-standardization.

[Insert Figure 5 about here]

In sum, the above documentations indicate that, post-standardization, an ecosystem experiences substantial growth in *complements*, but *complementors*, while growing in number, mostly remain small and continue to account for substantially fewer complements. The concentration ratio rises, with few large developers of complements accounting for greater overall share of patenting over time. Further, an owner of the core components produces substantially more complements than a non-owner, especially after standardization. These documentations do not seem to align with the notion of "generative" growth touted in existing research, but instead suggest that ecosystems are evolving in "exclusionary' ways.

CENTRAL TENET IN "EXCLUSIONARY" ECOSYSTEM EVOLUTION

With the above descriptive traces of "exclusionary" ecosystem evolution, we can now go further to illustrate its central tenet – how standardization, besides facilitating coordination, also enables the core component owners to crowd out other complementors over time. In the standard setting context, we show that, upon standardization of core components (SEPs) in the ecosystem, core component owners use standards-based litigation (involving SEPs) as a tool to crowd out other complementors from complementary areas within the ecosystem over time.

Below, we illustrate the central tenet as follows. First, we lay out the theoretical mechanisms underlying this central tenet. Second, we extend the earlier dataset and construct variables to conduct our analyses. Third, we document a pronounced spike in the litigation rate of an SEP owner's patents in the complementary areas post-standardization, relative to equivalent changes in a non-SEP owner's patents over standardization. This aligns with our claim that standardization of SEPs enables core component owners to increase their use of litigation in complementary areas. Fourth, we use regression analyses to illustrate that, post-standardization, core component owners' use of standards-based litigation in a complementary area is followed by a subsequent increase (reduction) in complements created by SEP owners (non-SEP-owners) in the area, and also a reduction in entry and an increase in exit in the complementary area.

Theoretical Mechanisms

Standardization of core components within an ecosystem renders the complements developed by the core component owner more central within the ecosystem as well. Both core components and complements owned by the same firm are usually designed as part of an integrated 'blue print' (Baldwin and Woodard 2009, Rosenkopf et al. 2001), resulting in greater alignment and interdependence between them (Ethiraj and Levinthal 2004, Adner 2017). When IPs over the core components are disclosed as SEPs during standard setting, not only these SEPs increase in value (Rysman and Simcoe 2008), IP over the corresponding complements also becomes more valuable (Miller and Toh 2020).[16]

Upon standardization, when other complementors develop complements to connect with the SEPs, they often end up coming close in their designs to the core component owner's complements in the same

[16] An example of a core component is Qualcomm's 'high rate packet data transmission channels' technology (patent #6173007), which is part of a core data transmission technology disclosed as an SEP during standard setting. Used on its own, this technology enables high-speed transmission for the highest data-rate user in the system but causes delay for other users. Meanwhile, Qualcomm has a complementary technology, 'method for assigning optimal packet lengths' (patent #6064678), which resolves the aforementioned problem by finding optimal packet lengths and ensuring all users in network gets 'fair' share of system throughputs. The IP over this complement that Qualcomm owns is not part of disclosed SEPs. When the former core component becomes the industry standard, other participants in the ecosystem have to license and build off this core components. When doing so, they would also need to use the latter complement, which increases its value as well.

area. This is not surprising, given that the core component owner who has in-depth knowledge of the functioning of core components has likely designed its complements in optimal ways that others would follow. When the core component owner owns IPs over these complements, the other complementors end up infringing on these IPs, and the core component owner sues them using IP lawsuits.

We illustrate the above with the following real-life example. Qualcomm owns the SEP over a core component within the WCDMA transmission standard – the Transmitter Power Control System (patent #5,267,262). It also developed a complementary RFIC chip, built into handsets, which allows the receiver to receive the signal with less interference. This complement is compatible with its core component, and is protected by two complementary patents on 'Method and Apparatus for Increasing Receiver Immunity to Interference' (patent #5,722,063 and #5,732,341). When another complementor, Maxim Integrated, developed a competing chip for wireless handsets that is compatible with Qualcomm's SEP (Transmitter Power Control System), its design was inadvertently similar enough to Qualcomm's RFIC chip to induce Qualcomm to allege and sue Maxim for infringing on the aforementioned complementary patents.

These IP litigations deter not only the defendant involve in the suits but also other complementors operating within the same complementary areas (Lerner 1995, Clarkson and Toh 2010). They signal to observers the core component owner's existing stakes in the complementary areas (Lanjouw and Schankerman 2001, Somaya 2003), and given the typical high cost of litigation, their importance and hence the extensive efforts it is willing to invest in defending its IP in these areas (Bhagat et al. 1994, Somaya 2012, Kersetter 2012). They convey the core component owner's reputation for and ability at litigiousness (Agarwal et al. 2009, Ganco et al. 2020), affecting other complementors' mental calculus of the attractiveness of continuing to invest and operate within the complementary area. Thus, we expect that litigations initiated by the core component owners over infringement of its complementary IP, made valuable by standardization, will have a deterrence effect on other complementors' inventive effort in the complementary areas.

Sample Construction for Analysis

Next, to examine how core component (SEP) owners' standards-based litigation in a complementary area deters other complementors, we extend the data described earlier to create a firm-area-year sample based on the 74 standards and 71 complementary areas. To capture firms involved in ecosystems around these standards, we initially gather firms from all four-digit SIC industries where at least one firm has disclosed an SEP to one of the standards during our sample period (33 four-digit SIC industries total).[17] We then restrict the sample to firms active in developing technology in the 71 complementary areas as follows. Standards-related litigation in complementary areas first showed up in our data in 1996. To incorporate some time period leading into the first standards-related litigation, we begin sampling in 1993. The sample starts with all firms that have patented in the 71 complementary areas five years prior and up to 1993, and adds other firms that subsequently patented in the areas through the sampling period 1993-2009.[18] The eventual sample consists of 98,272 observations in an unbalanced panel comprised of 1,429 firms.

Variables

We use two independent variables to capture standards-based litigations in complementary areas. A standards-based litigation in a complementary area *k* is a lawsuit that includes patents from area *k* and at least one SEP from a different core-component area (not area *k*). Focusing on these lawsuits in complementary area *k* that includes SEPs from other core-component (non-*k*) areas allows us to isolate complementary components (in *k*) that were related to and made more central because of standardization of SEPs, per our earlier theorizing. *Firm's Standards-based Litigation*$_{ik,t-1}$ is the count of the number of standards-based lawsuits that firm *i* files in complementary area *k* in year *t-1*. *Rivals' Standards-based*

[17] These include the following SIC classifications: 1389 (oil and gas field services), 3357 (drawing and insulating of nonferrous wire), 3570 (computer and office equipment), 3571 (electronic computers), 3572 (computer storage devices), 3576 (computer communications equipment), 3577 (computer peripheral equipment), 3578 (calculating and accounting machines), 3600 (electronic and other electrical equipment),3613 (switchgear and switchboard apparatus), 3620 (electrical industrial apparatus), 3640 (electric lighting and wiring equipment), 3651 (household audio and video equipment), 3651 (household audio and video equipment), 3661 (telephone and telegraph apparatus), 3663 (radio and tv broadcasting and communications equipment), 3669 (communications equipment), 3674 (semiconductors and related devices), 3679 (electronic components), 3711 (motor vehicles and passenger car bodies), 3760 (guided missile and space vehicles and parts), 3822 (auto controls for regulating residential and commercial environments), 3825 (instruments for measuring and testing of electricity and electrical signals), 3826 (laboratory analytical equipment and supplies), 4812 (radiotelephone communications), 4813 (telephone communications), 4822 (telegraph and other message communications), 4899 (communications services), 6794 (patent owners and lessors), 7370 (services-computer programming, data processing, etc.), 7372 (services-prepackaged software), 7374 (computer processing, data preparation, and processing services), 9997 (unclassified). Dropping non-ICT industries that enter the sample because they include firms diversified into the ICT industry yields similar results.

[18] Note that if a firm, initially included in the sample, did not patent in the area for 5 years following, it would be coded as an 'exit' (one of the dependent variables, explained in a later section) and then dropped from the sample.

Litigation$_{ik,t-1}$ is the total number of standards-based lawsuits that all other (non-*i*) firms file in the complementary area *k* in year *t-1*.

To control for the general effect of litigation in the complementary area, we add a count of firm *i*'s non-standards-based lawsuits involving at least one patent from area *k* (*Firm's Non-standard-based Lawsuits*$_{ik,t-1}$), and similarly, a count of rivals' non-standards-based lawsuits in area *k* (*Rivals' Non-standard-based Lawsuits*$_{ik,t-1}$). We also control for several firm factors. We add the firm's R&D spending (in millions of dollars), and firm size using natural log of the firm's revenues (*ln(Revenues)*). As firms with greater financial resources may file more lawsuits, we account for the firm's short-term reserves (*Cash & Short-Term Investments*). Firms with wider technological scope may avoid litigious areas as they have more outside options. We trace technology classes in which the firm files for patents during the year, calculate the Herfindahl-Hirschman Index (HHI) of these filed patents across classes so as to factor in relative weights per class, and measure *Patent Scope* as one minus the HHI, so that higher values indicate wider scope. Firms with SEPs may expand into the complementary areas to capture value-created by the SEPS (Miller and Toh, 2020). We control for the firm's cumulative number of SEPs disclosed to SSOs (*Cumulative SEPs*$_{,it}$).

We further control for several area and industry-level factors. To capture technological opportunities in a complementary area, we add a count of patent applications in the prior three years that were subsequently granted (*Area Patents*$_{k,t-1}$). To account for technological competition in the area, we include a Herfindahl-Hirschman Index of patents across firms (*HHI Area Patents*$_{k,t-1}$). Patenting in complementary areas may have grown along with increased standard setting activities over time. We control for the number of standards that have experienced disclosures up to time *t* (*Active Standards*$_t$). To capture unobserved industry, area, and year-specific factors, we include dummies for the firm's four-digit SIC code, area *k* (three-digit technology class), and year.

Descriptive Statistics and Graphs

Table 1 contains descriptive statistics and correlations for the firm-area-year sample. On average, a firm invested in about $1 billion on R&D per year and applied for over four patents per complementary area (technological class) per year. *R&D* has a high correlation with *ln(Revenue)* (0.65) and *Cash & Short-*

term Investment (0.77). However, collinearity does not appear to be a concern as both the condition index (18) and variance inflation factors (mean = 1.55; max = 3.2) fall below thresholds that warrant concern.

[Insert Table 1 about here]

Recall that our objective is to show how, post-standardization, core component (SEP) owners use standards-related litigation to crowd out other complementors from the complementary areas. Before analyzing the effect of such litigations, we first show, using descriptive graphs, that litigation in the complementary areas by SEPs owners increases post-standardization, relative to those by non-SEP owners. For each standard, we trace all patents that an SEP owner has in the corresponding complementary areas, calculate their mean yearly litigation rates, and take the average across all SEP owners separately for pre- and post-standardization. We then do the same for all non-SEP owners in our sample. Figure 6 reports the average of these litigation rates across standards, separate for SEP-owners and non-SEP owners, and for pre- and post-standardization. This figure clearly shows that litigation rates for SEP owners' patents spike substantially upon standardization, relative to the (smaller) increase experienced by non-SEP owners.[19]

[Insert Figure 6 and Figure 7 about here]

Dependent Variable: Number of Complements

Here, we examine the relationship that standards-based litigations have with the dependent variable – the firm's complements. As a proxy for the number of complements a firm creates in a complementary area, we count patent applications filed in the area k in year t that were subsequently granted. Table 2-Models 1 and 2 are pooled negative binomial models using only the control variables and only the litigation variables respectively. We then use firm-level random effects (Model 3) and fixed effects (Model 4), and firm-area level random effects (Model 5) estimations. Model 6 uses a firm-area level fixed effect Poisson

[19] To further demonstrate that, post-standardization, the SEP owner's patents in the complementary areas become more central and valuable in the ecosystem and thus experience greater hazard of being infringed upon, we alternatively trace citations that patents receive, following a similar approach as the one in Figure 6. We restrict the set of patents to those applied for in the t-5 to t-1 period, so as to eliminate patents that were only filed post-standardization and thus may not have enough time to receive citations, and document the change in citations received in Figure 7. Again, this figure clearly shows that, post-standardization, the SEP owners' patents in the complementary areas received more citations than they did pre-standardization, and this increase appears to be greater in magnitude the equivalent change in non-SEP owners' patents.

model. Note that our variables appear to exhibit enough within firm-area variation to produce reliable estimates.[20] Main findings are largely consistent across models. Below, we focus our interpretation of findings in Model 6.

In Model 6, per our expectation, we find a positive effect for *Firm's Standards-based Litigation*$_{ik,t-1}$ (0.136, p=0.046) and a negative effect for *Rivals' Standards-based Litigation*$_{ik,t-1}$ (-0.021, p=0.039). An additional standards-based lawsuit filed by the firm corresponds with about a 14 percent increase in its patent filings in the area in the following year. The mean patents in an area in a year for firms that file a standards-based lawsuit is about 25, so the estimate amounts to about a 3.5 unit increase. An additional standards-based lawsuit filed by rivals corresponds with a 2.1 percent reduction in the focal firm's patenting in the complementary area following year. Note that on average, a standards-based lawsuit includes complementary patents in three different complementary areas. Thus, it appears that one additional standards-based lawsuit has an economically meaningful effect on the evolution of the ecosystem, with the filing firm expanding its production of complementary patents while deterring others from doing so.

Notably, these effects of standards-based litigations exist over and above the presence of non-standards-based ones, suggesting that they are not merely reflecting the typical deterrence effects of generic litigations within the complementary area.[21] In fact, the non-standards-based litigations appear to have no significant effect once we control for firm-area effects (Model 6: *Firm's Non-standard-based Litigation* (0.006, p=0.832) and *Rivas' Non-standard-based Litigation* (-0.003, p=0.169)).

[Insert Table 2 about here]

Dependent Variable: Entry

Here, we examine the relationship that standards-based litigations have with the dependent variable – entry into the complementary area. Given our objective of tracing growth in the number of *complementors*

[20] We observe a within firm-area coefficient of variation above 30 percent for all variables except Patent Scope (7 percent) and Active Standards (19 percent). We continue to include Patent Scope because small changes could signal meaningful changes in the firm's IP strategy (though results are not sensitive to its exclusion). We also note that the litigation variables exhibit greater within variation than between variation.

[21] We further test for differences in effects between the respective pairs of standards-based and non-standard-based litigations using Wald tests, separately for firm's and rivals' litigations, and find significant differences across models, suggesting that the standards-based litigations' effects exist over and above that of the non-standards-based litigations.

in each complementary area, an area-year unit of analysis for tracing entry is likely more informative. We measure $Entry_{kt}$ into a complementary area with a count of firms that filed for patents in the area *k* in year *t* and have not done so in the prior five years. $Total\ Standards\text{-}Based\ Litigation_{k,t-1}$ is the number of standards-based litigation in area *k* in year *t*-1. Descriptive statistics for these variables can be found in the notes under Table 3.

We begin by considering all entities, including individual inventors, nonprofits, universities, and for-profit firms that lack financial data. Model 1, with a pooled Negative Binomial model, shows that one additional standards-based lawsuit is associated with a 3.1 percent decline in entry (p=0.038). With an average of 106 entries per area-year, this approximately translates into a 3.3 unit reduction in entry. Accounting for unobservable area factors using area-level fixed effect Poisson model, we find a similar result (Model 2: -0.012, p=0.004). In Models 3 (Negative Binomial) and 4 (area-level fixed effect Poisson), we restrict the sample to only firms (excluding other entities) with financial information and who belong to industries where firms are actively disclosing to standards. We observe a strong effect of standards-based litigation, with one additional lawsuit reducing entry by roughly 4 percent.

We note that, across models, other non-standards-based litigations in the area are negatively associated with entry as well, reflecting the generic deterrence effect of litigations. However, these effects tend to be smaller, in the -0.3 percent to -1 percent range. We further test for difference between standards-based and non-standards-based litigations using the Wald test, and find that the former effect is more negative and significantly different at 5 percent level in all models. Overall, we find that standards-based litigation within a complementary area appears to deter entry into the area, and more so than typical non-standards-based litigation.

[Insert Table 3 about here]

Dependent Variable: Exit

Here, we examine the relationship that standards-based litigations have with the dependent variable – exit from the complementary area. As with entry, we focus on an area-year unit of analysis. We measure $Exit_{kt}$ from a complementary area with a count of firms in year *t* that had patented in area *k* but failed to patent in the complementary area for five years (*t*-4:*t*). We use the same independent variables as we do in the Entry analysis.

We begin by considering all exits, including individual inventors, nonprofits, universities, and for-profit firms that lack financial data (Table 4). Model 1, with a pooled Negative Binomial model, shows that one additional standards-based lawsuit is associated with a 1.7 percent increase in exit (p=0.09). With an average of 203 exits per area-year, this approximately translates into a 3.5 unit increase in exit. Accounting for unobservable area factors using area-level fixed effect Poisson model, we find a similar result (Model 2: 0.01, p=0.000). In Model 3 (Negative Binomial) and Model 4 (area-level fixed effect Poisson), we restrict the sample to only firms (excluding other entities) with financial information and who belong to industries where firms are actively disclosing to standards. We observe a strong effect of standards-based litigation, with one additional lawsuit increasing exit by roughly 2.6 percent (p=0.002).

We note that, across models, other non-standards-based litigations in the area are positively associated with exit as well, reflecting the generic deterrence effect of litigations. However, these effects tend to be smaller, in the 0.4 – 0.8 percent range. We further test for difference between standards-based and non-standards-based litigations using the Wald test, and find that the former effect is larger in magnitude and significantly different at the 10 percent level in all models except Model 1. Overall, we find that standards-based litigation within a complementary area appears to increase exit from the area, and more so than typical non-standards-based litigation.

[Insert Table 4 about here]

Additional Analyses

In this section, we conduct additional robustness checks to examine potential issues related to simultaneity bias, patenting dynamics, sample construction and measurement.

In Table 2, we estimate a firm's patenting in complementary area *k* at time *t* as a function of its standards-based litigation in *k* at *t*-1. To litigate patents at *t-1*, though, it must have owned patents in *k*. If the firm persistently patents in *k*, estimations in Table 2 may be prone to simultaneity bias.[22] We address

[22] While there may be unobserved factors such as the firm's overall IP strategy that could influence both litigation and patenting and bias our estimates, their presence does not necessarily negate what we attempt to demonstrate here – the

this issue in two ways. First, using the firm-area fixed effect Poisson model, we add a control for the firm's total patent stock in area *k* up to time *t*-1 and a control for the firm's propensity to litigate (measured as the five-year total of the firm's IP lawsuits filed up until *t*-2). We find a similar estimate for *Firm's Standards-based Litigation* (semi-elasticity = 0.14, p=0.05).

Second, we account for the firm's patenting dynamics using a linear dynamic panel regression model to (Arellano and Bond, 1991; Blundell and Bond, 1998) with $ln(Patents_{ikt})$ as the dependent variable, a two-period lag structure and all firm and area-structure variables estimate as predetermined variables with a one-period lag.[23] Our findings remain consistent (*Firm's Standards-based Litigation*: 0.18, p=0.08; *Rivals' Standards-based Litigation*: -0.02, p=0.00).

Thus far, we have identified areas (technology classes) as being complementary to SEPs based on past IP lawsuits that involve patents in these areas jointly with SEPs. A problem may arise in this approach if a firm adds, to a standards-related lawsuit, nonessential patents that are not actually complementary to the SEP, i.e. patents that do not function with or provide complementary value to the SEPs. This could reduce the precision of our estimates. As a further check, we constrain the 3-digit technology classes to those that most likely contain implementation (complementary) patents for communication standards (SEPs) by including only the technology classes with communications in the description. We find robust results (*Firm's Standards-based Litigation*: 0.19, p=0.05; *Rivals' Standards-based Litigation*: -0.03, p=0.03).

The dependent variable in Table 2 measures the firm's patenting in the complementary area *k*. A potential critique could be that even if the area *k* contains complements to the firm's SEP, not all of the firm's patents in *k* are complements or even related to the standards or ecosystem in question. First, we note that earlier results are likely conservative in the face of such potential false positives – standards-based litigation should not affect the firm's filing of patents in *k* unrelated to the SEP or ecosystem.[24] Nonetheless,

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firm uses litigation to push others out of the complementary area before increasing its patenting in the area. Our robustness checks here are meant to show that they have not biased our estimates, rather than to prove their absence.

[23] We instrument for the lagged dependent variables using three-period lags in levels and four-period lags in differences. We instrument for the predetermined independent variables using two-period lags in levels and three-period lag in differences.

[24] Going further, it is possible that if the area *k* is highly litigious, the firm may file for more patents here even if they are not complementary to its SEPs or related to the ecosystem. However, this possibility does not align with our

we address this issue by using a more conservative measurement of the firm's patenting in area *k* – we only include and count patents when there are more explicit signs of complementarity with SEPs, i.e. when they cite SEPs or when some other patent cites both the SEP and the focal patent together. This reduces the total number of patents in the complementary areas by 92 percent. Rerunning the firm-area random effects negative binomial (*Firm's Standards-based Litigation* = 0.43, p=0.00; *Rivals' Standards-based Litigation* = -0.04, 0.02) and firm-area fixed effect Poisson model (*Firm's Standards-based Litigation* = 0.05, p=0.01; *Rivals' Standards-based Litigation* = -0.03, 0.00), we find similar results.

The above additional analyses notwithstanding, we caution against interpretation of strict causal relationships in our regression analyses thus far. As we mentioned at the beginning, our objective in this paper is to document evolution patterns and associational relationships, using approaches that are largely descriptive in nature, as starting points for future further examinations of exclusionary ecosystem evolution.

CONCLUSION

In this paper, we propose that an ecosystem does not always evolve in a "generative" way as typically depicted in the literature, but rather, could evolve in an "exclusionary" fashion where complements increase but complementors do not grow meaningfully and instead core components owners dominate the complementary areas with their own complements. Using data on ICT ecosystems that use standard setting as coordination mechanism, we provide what we believe is the first systematic trace in the literature of how ecosystems evolve alongside standardization.

Our documentation of ecosystem evolutions indicates signs of "exclusionary" growth. Main findings constituting these signs include: post-standardization, complements grow in number but complementors mostly remain small and account for few complements. Concentration ratio in complementary areas rises, and a core component owner on average accounts for substantially more complements than a non-owner. We also go further to demonstrate a mechanism through which "exclusionary" evolution occurs – core component owners exploit standardization and litigation to crowd

findings on *Rivals' Standard-based Litigation*, i.e. high litigiousness of the area should correspond with more *Rivals' Standard-based Litigation* and more patenting by the firm in this area, which is contrary to our findings.

out other complementors over time. On average, litigation rate of a core component owner's patents in the complementary areas spikes post-standardization. Regression analyses show that, post-standardization, standards-based litigation (involving core components) in a complementary area is followed by a subsequent increase (reduction) in complements created by core component owners (non-core component-owners) in the area, and also a reduction (increase) in entry in (exit from) the complementary area.

We believe these documentation and findings on "exclusionary" ecosystem evolution have important implications for strategy research in the ecosystem space (Baldwin 2012). Much of ecosystem research thus far, either on platform-based (Kapoor and Agarwal 2017) or non-platform-based ones (Toh and Miller 2017), has been attuned towards resolving the coordination problem (Jacobides et.al. 2018). The general sense has been that core component owners (e.g. platform owner) need to find a way to overcome the challenge of coordinating with other firms developing complementary products, so that the ecosystem can flourish and grow (Dushnitsky et al. 2020). The commonly-depicted successful end-state is one where the ecosystem is "generative", with multiple independent and legally-autonomous firms creating value by producing a myriad of heterogenous complements (Cennamo and Santalo 2019). The core component owners' task is depicted as figuring out how to get to and manage this end-state, using some form of meta-organization or otherwise (Kretschmer et al 2020). What we highlight here is that this is not the only possible path forward for an ecosystem's evolution; coordination *across* firms is not the only option available to the core component owners. Rather, they can, and as we show, often do internalize this coordination *within* their firm boundaries and actively participate or dominate the complementary areas themselves with their own complements. There is hence a duality in strategic decisions early on for the core component owners; the strategy of attracting and coordinating with third-party complementors (Gulati et.al. 2012) is interdependent with the choice to integrate into the complementary areas (Zhu and Liu 2018).

Another notion in the paper that deserves further deliberation is the strategic nature of standardization. Standardization for the purpose of ensuring compatibility, via standard setting, *de jure* manner, or through *de facto* market determination, is certainty not a new concept in strategy research (Shapiro and Varian 1999, Toh and Miller 2017). Yet, the focus of its examination has mostly if not always been on coordination outcomes, about its merits of enabling smooth connections (Baldwin 2012, Teece

2018). By and large, its strategic nature, i.e. the ability of a firm to use it for strategic purposes, has been overlooked. We do not claim to have formally laid out standardization's strategic nature either. But our findings, especially in the latter part demonstrating how exclusionary evolution occurs, hint that such strategic nature exists. In our case, the establishment of certain core components as industry standard allows their owners to subsequently use IP litigation over these core components for deterrence purposes, deterring not just rivals in the core-component space, but importantly, also deter third-party complementors in complementary areas. Our main focus here is not to demonstrate such strategic nature of standardization; further examination of how and when this strategic nature is salient, while important, is unfortunately beyond the scope of this paper. We do however believe it would be fruitful for future research to examine and lay out this strategic side of standardization in greater details and more effectively than we have done.

Though not our intention, we suspect our findings may trigger political or policy thoughts about the 'rightful' role of core component owners in ecosystems. In real life, at least within platform-based ecosystems, there has been increased scrutiny over recent actions of platform owners such as Amazon and Apple in integrating into complementary areas within their platform ecosystems. We cited some of this scrutiny earlier (in footnote 1). Along with this scrutiny comes discussions about social welfare implications, e.g. whether consumers are harmed as a result, and about whether integration is 'fair' to other participants in the ecosystem such as complementors. Indeed, media portrayal of such integration often evokes a sense of malfeasance on the platform owners' part. Even staying within the economic consideration of the platform owners themselves, one could discuss if integration into complementary areas is indeed profit-maximizing for the platform owner over the long run in the 'general equilibrium' sense, or whether it could end up causing more harm to the platform owner itself by discouraging participation by complementors. We want to clarify that we are not making claims about welfare implications, rightfulness or optimality of integration, or malfeasance in any way; this paper simply is not set up to do so. Our focus is merely to objectively describe that exclusionary ecosystem evolution can take place, does take place within our context, and go one step further to demonstrate how it takes place. We intentionally refrain from drawing more normative conclusions about what firms *should* do. In fact, we do not even claim that exclusionary evolution will always or systematically take place across settings; rather, we are just pointing out that it could. We defer these important discussions and normative takeaways to future policy research.

Rather, what this paper is, at its core, fundamentally resonates with issues central in strategy research – value appropriation and firm boundaries. Theories of the firm are abundant in strategy research – transaction cost economics, knowledge-based view of the firm, property rights theory and so on. Yet none so far pertains specifically to boundaries of firms within ecosystems. If existing theories apply to these ecosystem firms, we would not need new ones. But to the extent that much of existing theories explain vertical integration, while we know at the same time that vertical value chain and typical buyer-supplier relationships tend not to exist in ecosystems (Kapoor 2018), it does beg the question of whether other causal effects are at work determining where a firm's boundaries end and market begins within ecosystems. Our findings in essence trace changes in core component owner's boundaries over time and their evolution as coordination takes place. At a broad glance, they do not appear to conform with what one would expect based on past theories – enhanced coordination between firms, by reducing transactional frictions, should reduce the need for integration and shrink firm boundaries. We found the opposite – that core component owners integrate more into complementary areas over time as coordination (via standardization) improves. Contrary to typical reasons prescribed in existing theories, we believe they likely do so to appropriate the value they helped create in complementary areas but that is difficult for them to capture otherwise via conventional contractual tools because of the lack of vertical value chain relationships (Miller and Toh 2020). This calls for future research to determine if a different, more formal theory of firm boundaries is needed. We defer to and hope future research will pick up on this important endeavor to further our understanding of firms in ecosystems.

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Table 1. Descriptive statistics

	Mean	**Stadard Deviation**	**Min**	**Max**	**Correlations** (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Investment (Patents)$_{ikt}$	4.13	16.77	0.00	576.00	1												
(2) Firm's Standards-based Litigation$_{ik,t-1}$	0.00	0.05	0.00	3.00	0.04	1											
(3) Rivals' Standards-based Litigation$_{ik,t-1}$	0.38	1.18	0.00	11.00	-0.02	0.03	1										
(4) Firm's Non-standards-based Litigation $_{ik,t-1}$	0.01	0.18	0.00	13.00	0.06	0.01	0.01	1									
(5) Rivals' Non-standards-based Litigation $_{ik,t-1}$	10.57	11.85	0.00	157.00	-0.01	0.01	0.16	0.03	1								
(6) R&D$_{i,t-1}$	997.10	1605.05	0.00	9571.00	0.20	0.01	-0.04	0.03	-0.03	1							
(7) ln(Revenue)$_{i,t-1}$	7.63	2.70	-6.91	12.48	0.18	0.03	-0.06	0.03	-0.06	0.65	1						
(8) Cash & Short-term Investments$_{i,t-1}$	2673.97	5186.39	0.00	60592.00	0.15	0.02	-0.02	0.02	-0.01	0.77	0.56	1					
(9) Patent Scope$_{i,t-1}$	0.62	0.35	0.00	0.97	0.17	0.01	-0.09	0.01	-0.15	0.35	0.57	0.26	1				
(10) Cumulative SEPs$_{i,t-1}$	10.39	53.57	0.00	895.00	0.03	0.08	0.02	0.04	0.05	0.29	0.19	0.21	0.10	1			
(11) Area Patents (3yr)$_{k,t-1}$	3517.11	2910.48	4.00	17072.00	0.13	0.02	0.21	0.03	0.31	-0.11	-0.16	-0.08	-0.10	-0.02	1		
(12) HHI Area Patents$_{k,t-1}$	0.08	0.06	0.01	0.68	0.04	-0.01	-0.08	0.01	-0.07	0.01	0.01	0.02	0.00	0.02	-0.12	1	
(13) Active Standards$_t$	57.65	13.28	21.00	72.00	-0.04	0.02	0.18	0.02	0.32	0.05	0.00	0.08	-0.14	0.11	0.29	-0.04	1
N=98,272																	

Table 2. Investment (Patent) regressions

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Method:	Negative Binomial	Negative Binomial	Firm Level Random Effect Negative Binomial	Firm Level Fixed Effect Poisson	Firm-Area Level Random Effect Negative Binomial	Firm-Area Level Fixed Effect Poisson
Firm's Standards-based Litigation$_{ik,t-1}$		1.195***	0.600***	0.728***	0.170***	0.136**
		(0.000)	(0.000)	(0.000)	(0.002)	(0.046)
Rivals' Standards-based Litigation$_{ik,t-1}$		-0.052**	-0.021***	-0.029**	-0.020***	-0.021**
		(0.015)	(0.000)	(0.025)	(0.001)	(0.039)
Firm's Non-standards-based Litigation$_{ik,t-1}$		0.958***	0.226***	0.355***	0.0168	0.0161
		(0.000)	(0.000)	(0.000)	(0.338)	(0.577)
Rivals' Non-standards-based Litigation$_{ik,t-1}$		-0.009***	-0.004***	-0.002	-0.004***	-0.002
		(0.000)	(0.000)	(0.306)	(0.000)	(0.248)
R&D$_{i,t-1}$ (000)	0.215***		0.114***	0.0726*	0.121***	0.069***
	(0.000)		(0.000)	(0.079)	(0.000)	(0.000)
ln(Revenue)$_{i,t-1}$	0.219***		-0.089***	0.080	0.076***	0.203***
	(0.000)		(0.000)	(0.341)	(0.000)	(0.000)
Cash & Short-term Investments$_{i,t-1}$ (000)	0.005**		0.001	0.014	0.009***	0.014***
	(0.283)		(0.572)	(0.295)	(0.000)	(0.001)
Patent Scope$_{i,t-1}$	1.720***		0.859***	1.344***	1.110***	1.567***
	(0.000)		(0.000)	(0.000)	(0.000)	(0.000)
Cumlative SEPs$_{it}$	-0.000		-0.000	-0.001	-0.001***	-0.001***
	(0.912)		(0.498)	(0.213)	(0.000)	(0.001)
Area Patents (3yr)$_{k,t-1}$ (000)	0.063***		0.0169***	0.052***	0.043***	0.047***
	(0.000)		(0.000)	(0.000)	(0.000)	(0.000)
HHI Area Patents$_{k,t-1}$	-1.564***		-3.229***	1.940**	-4.120***	0.884
	(0.003)		(0.000)	(0.011)	(0.000)	(0.208)
Active Standards$_t$	-0.067***		-0.0460***	-0.062***	-0.054***	-0.060***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Industry Dummies	YES	NO	YES	NO	YES	NO
Area Dummies	YES	NO	YES	YES	YES	NO
Year Dummies	YES	NO	YES	YES	YES	YES
Observations	79,344	79,344	79,344	78,963	79,344	77,140
Firms	1,125	1,125	1,125	1,033	1,125	1,032
Areas	71	71	71	71	71	71
Log Pseudolikelihood	-139820	-158838	-139598	-339545	-122892	-132213
Pseudo R-Square	0.12	0.02	0.12			
Wald Test P-values:						
Firm's Standards-based Litigation = Firm's Non-standards-based Litigation		0.09	0.00	0.01	0.01	0.01
Rivals' Standards-based Litigation = Rivals' Non-standards-based Litigation		0.05	0.10	0.03	0.01	0.01

In parentheses we include p-values calculated from robust standard errors clustered at the firm-area level in Model 1, Model 2, and Model 6. Robust standard errors are clustered at the firm-level in Model 4. *** p<0.01, ** p<0.05, * p<0.1

Table 3. Entry into the complementary area

	Model 1	Model 2	Model 3	Model 4
DV	Entry (All patent assignees)	Entry (All patent assignees)	Entry (Firms with financial information & industry has firms active in standards)	Entry (Firms with financial information & industry has firms active in standards)
Method:	Negative Binomial	Area-Level Fixed Effect Poisson	Negative Binomial	Area-Level Fixed Effect Poisson
Total Standards-based Litigation$_{k,t-1}$	-0.031**	-0.012***	-0.040***	-0.036***
	(0.038)	(0.004)	(0.001)	(0.003)
Total Non-standards-based Litigation$_{k,t-1}$	-0.003*	-0.003***	-0.010***	-0.010***
	(0.099)	(0.000)	(0.000)	(0.001)
Area Patents (3yr)$_{k,t-1}$ (000)	0.096***	0.073***	0.0180	0.0159
	(0.000)	(0.000)	(0.192)	(0.288)
HHI Area Patents$_{k,t-1}$	-6.559***	-7.108***	-6.880***	-6.899***
	(0.000)	(0.000)	(0.000)	(0.000)
Active Standards$_t$	-0.036***	-0.036***	-0.075***	-0.075***
	(0.000)	(0.000)	(0.000)	(0.000)
Area Dummies	YES	NO	YES	NO
Year Dummies	YES	YES	YES	YES
Observations	1,203	1,203	1,203	1,203
Areas	71	71	71	71
Pseudo R-Square	0.24		0.33	
Log Pseudolikelihood or Log Likelihood	-5142	-6145	-2304	-2092
Wald Test P-value: Total Standards-based Litigation = Total Non-standards-based Litigation	0.05	0.03	0.02	0.03

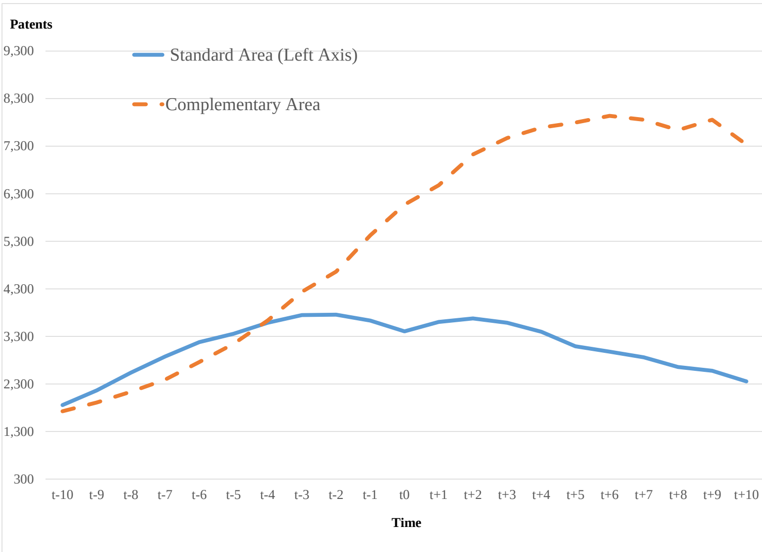
We use an area-year sample. Entry in Model 1 and 2 has a mean of 103 and standard deviation of 96. Total Standards-based Litigation has a mean of 0.2 and standard deviation 0.9, Total Non-standards-based Litigation has a mean of 8.6 and standard deviation of 13.5. In parentheses we include p-values calculated from robust standard errors clustered at the area level. *** p<0.01, ** p<0.05, * p<0.1

Table 4. Exit from the complementary area

	Model 1	Model 2	Model 3	Model 4
DV	Exit (All patent assignees)	Exit (All patent assignees)	Exit (Firms with financial information & industry has firms active in standards)	Exit (Firms with financial information & industry has firms active in standards)
Method:	Negative Binomial	Area-Level Fixed Effect Poisson	Negative Binomial	Area-Level Fixed Effect Poisson
Total Standards-based Litigation$_{k,t-1}$	0.017*	0.010***	0.026***	0.019**
	(0.090)	(0.000)	(0.002)	(0.018)
Total Non-standards-based Litigation	0.008***	0.004***	0.005**	0.004*
	(0.002)	(0.000)	(0.028)	(0.058)
Area Patents (3yr)$_{k,t-1}$ (000)	0.083***	0.046***	0.0387	0.033
	(0.000)	(0.000)	(0.192)	(0.262)
HHI Area Patents$_{k,t-1}$	-0.483	-0.626***	-0.651*	-0.647*
	(0.334)	(0.000)	(0.065)	(0.065)
Active Standards$_t$	0.015***	0.016***	0.035***	0.035***
	(0.000)	(0.000)	(0.000)	(0.000)
Area Dummies	YES	NO	YES	NO
Year Dummies	YES	YES	YES	YES
Observations	1,203	1,203	1,203	1,203
Areas	71	71	71	71
Pseudo R-Square	0.2		0.22	
Log Pseudolikelihood or Log Likelihood	-6071	-10319	-2891	-2679
Wald Test P-value: Total Standards-based Litigation = Total Non-standards-based Litigation	0.39	0.03	0.02	0.07

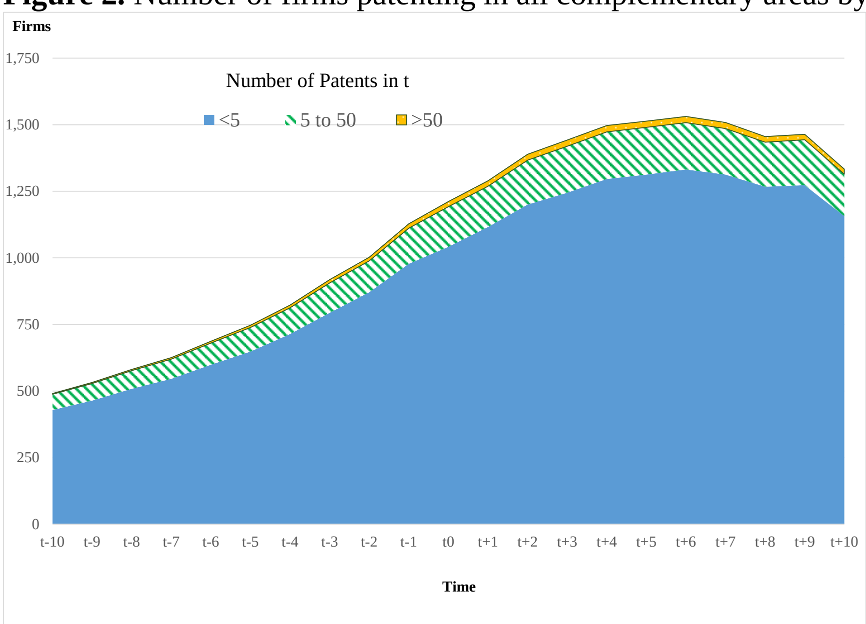
We use an area-year sample. Exit in Model 1 and 2 has a mean of 203 and standard deviation of 190. Total Standards-based Litigation has a mean of 0.2 and standard deviation 0.9, Total Non-standards-based Litigation has a mean of 8.6 and standard deviation of 13.5. In parentheses we include p-values calculated from robust standard errors clustered at the area level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 1. Patents by area



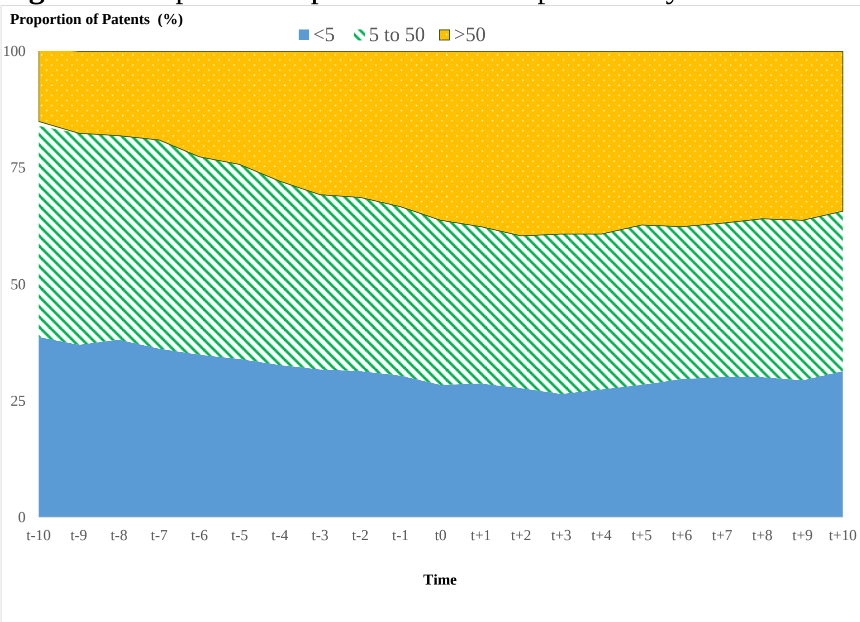
To calculate each data point, for each standard, we sum the patents across all complementary areas (or SEP areas), then average this number across all standards at *t*. Standardization begins at t0.

Figure 2. Number of firms patenting in all complementary areas by patent level



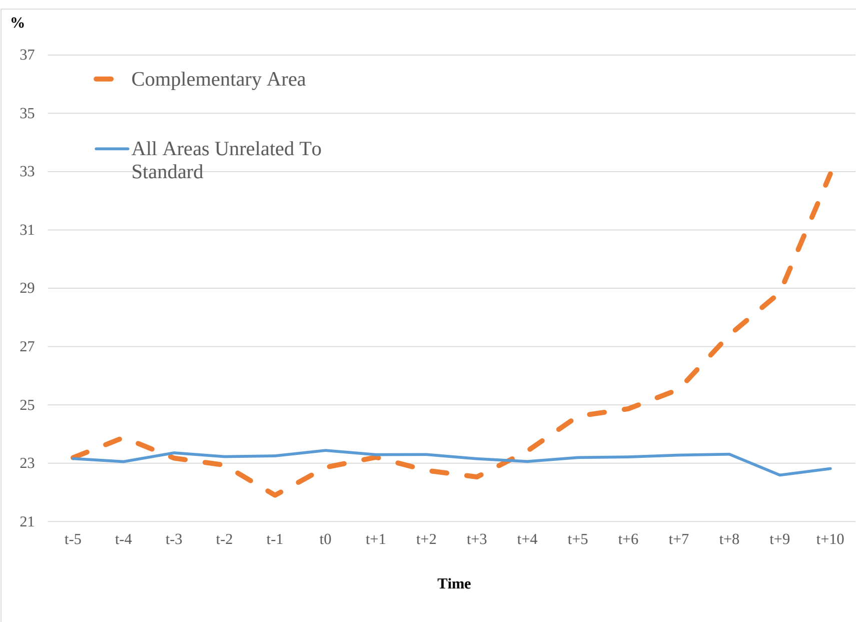
To calculate each data point, we sum the total number of firm's patents across all complementary areas within each standard. We then count how many firms fall into each patent bucket in period *t* for each standard. We then take the average across standards. Standardization begins at t0.

Figure 3. Proportion of patents in all complementary areas



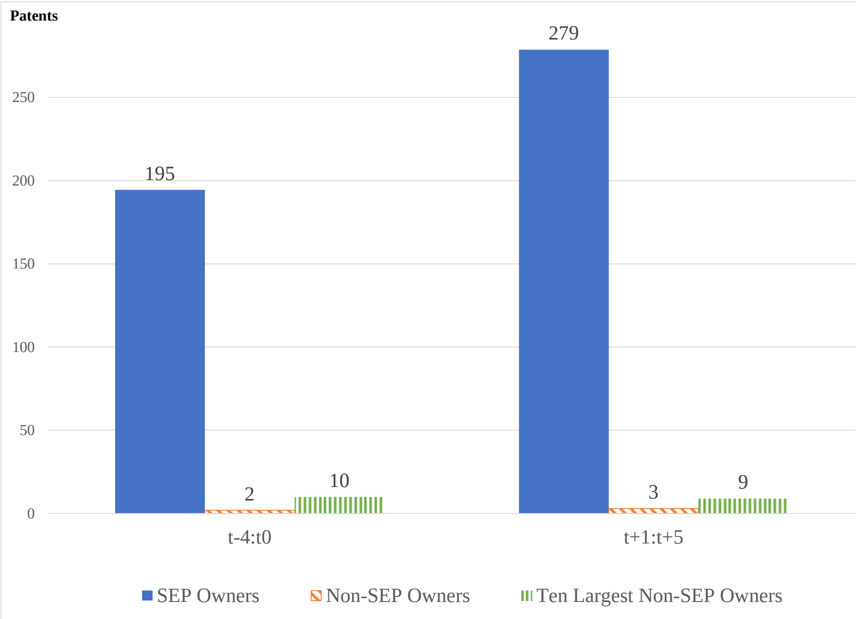
To calculate each data point, we sum the total number of firm's patents across all complementary areas within each standard. We then calculate the proportion of total patents in *t* that belong to firms in each bucket. We then take the average across standards. Standardization begins at t0.

Figure 4. Eight-firm patent concentration ratio



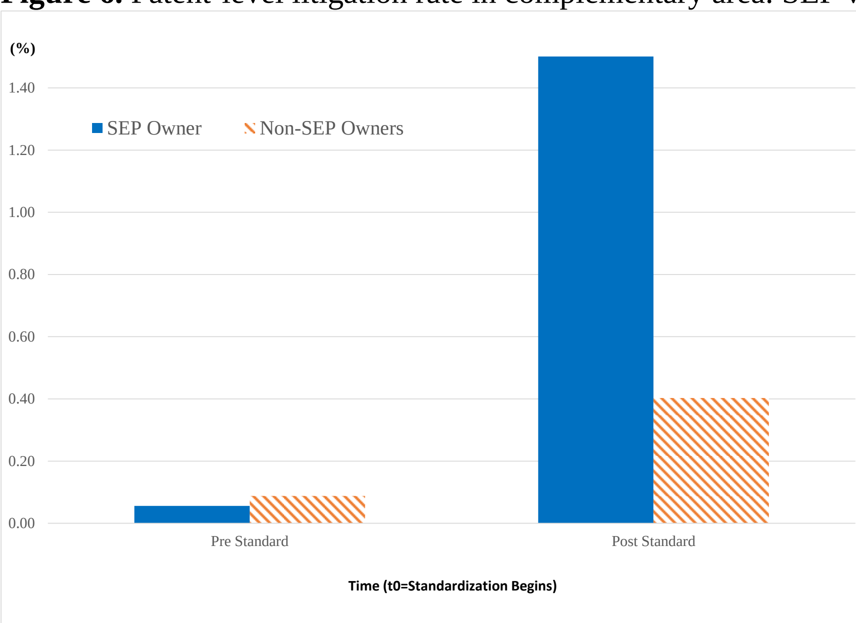
To calculate the eight-firm patent concentration ratio for the complementary area, for each standard, we take the average eight-firm patent concentration ratio across all the complementary areas then take the average across standards.

Figure 5. Average patents in complementary area: SEP vs. Non-SEP owners



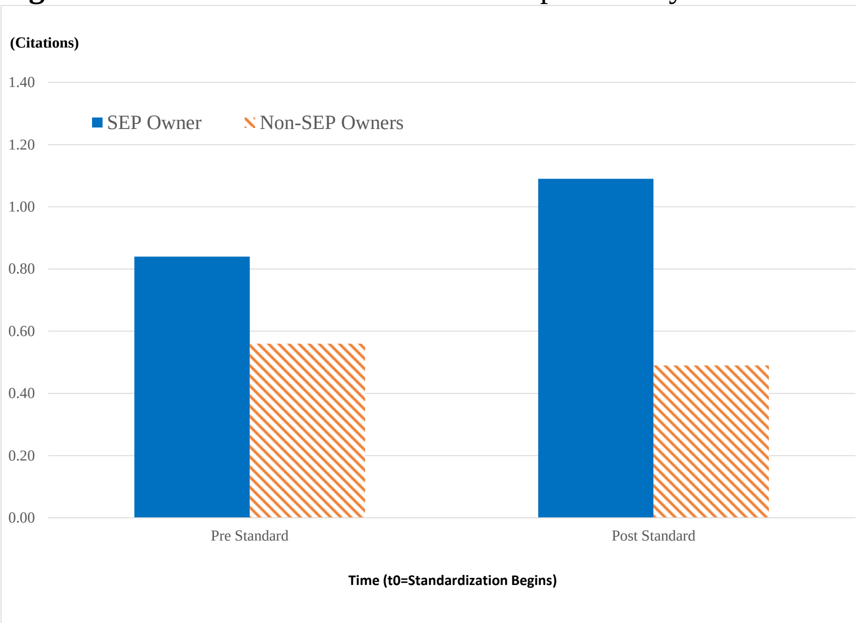
To calculate each data point, for each standard, we tally each firm's total patents in the complementary area then average (within standard) across SEP owners and non-SEP owners, then take the average of these values across standards. Standardization begins at t0.

Figure 6. Patent-level litigation rate in complementary area: SEP vs. Non-SEP owners



To calculate each data point, for each standard, we take all patents in the complementary areas that exist prior to standardization and compute their average yearly litigation rates pre- and post-standardization. Then for each standard, we take the average across these litigation rates for the patents belonging to SEP owners and for patents belonging to non-SEP owners. To summarize to the standards-level, we average across all standards. Standardization begins at t0.

Figure 7. Patent-level citation rate in complementary area: SEP vs. Non-SEP owners



To calculate each data point, for each standard, we take all patents in the complementary areas that exist in the t-5 to t-1 period and compute their average yearly citation rates pre- and post-standardization. Then for each standard, we take the average across these rates for the patents belonging to SEP owners and for patents belonging to non-SEP owners. To summarize to the standards-level, we average across all standards. Standardization begins at t0.