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Patent Assertion in Standard Development: Forking through Cooperation

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ABSTRACT

This paper examines the impact of patent assertion on the direction of standard development. We are particularly interested in the effects of the recent entry of patent assertion entities that only assert their essential intellectual property and abstain from developing new standard specifications within the wireless telecom standard development organization 3GPP. We discuss how licensing negotiations with patent assertion entities differ from those with product companies and test our ideas using data from 3GPP. We show that lawsuits initiated by assertion entities have a larger impact on subsequent cooperative standard development compared with lawsuits by product companies. We also characterize the nature of the shift in standard development activities.

Keywords: Standard development, technological change, interorganizational cooperation, patent assertion, mobile telecommunications

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INTRODUCTION

Patent assertion is a form of competition and negotiation in the development of technological standards such as telecommunication protocols. Electronics is known to be littered with patents (Hall and Ziedonis, 2001), and any consumer product in information and communication technology is likely to be affected by or associated with hundreds of patents (Biddle, 2012). In standard development organizations such as the Third Generation Partnership Project (3GPP), there is a strong incentive for industry participants to attempt to insert patented solutions into the standard specifications or to maneuver to avoid such solutions being imposed on them by rivals (Simcoe and Rysman, 2008). There are thus thousands of patents declared essential for 3G and 4G wireless telecommunication systems, and intense interactions among firms to get one another to pay royalties for licenses to build products for the standard (Bekkers et al., 2017). However, we know little about the influence of dedicated Patent Assertion Entities (PAEs) in standard development organizations. In this paper we attempt to shed light on PAEs impact on the direction of specification development in 3GPP.

We are interested in how patent licensing negotiations influence standard development activities in 3GPP working groups. We use data about 3GPP member firms' ownership of standard-essential patents that we connect with the standard specifications and the working groups within 3GPP where those patents are implicated. We then connect the patents with the associated litigation activity and examine how patent litigation influences the development of standard specifications. We particularly focus on the role of PAE ownership of the 3GPP essential patents. We ask how the nature of the PAE business model influences the licensing negotiation for SEPs, and, consequently, how PAEs' litigation of SEPs impacts specification development. To our knowledge, our paper is among the first to explore the impact of PAEs on

standard development. Our preliminary analyses suggest that PAEs do have a substantial impact on standard development through the process of change requests on ongoing specifications. We also find that 3GPP contributors who are sued by PAEs subsequently initiate new cooperative specification development activities within the relevant working groups. PAEs thus have a tangible effect on the direction of standard development.

CONCEPTUAL BACKGROUND

Patent Assertion Entities (PAEs) are dedicated patent licensing firms that do not manufacture and sell communication products but focus on licensing intellectual property and providing related services (Leiponen and Delcamp, 2018). As such, they are "non-practicing entities" (NPEs) because they do not "practice" their patents. However, in this paper we distinguish PAEs as a subgroup of NPEs as we have both in our dataset. We define companies that are focused only on the creation or acquisition of patents and their monetization through licensing as PAEs. Meanwhile, we also have a few NPEs in the dataset that invent new technologies and attempt to monetize the associated patents, but that are also long-standing participants in the development of standard specifications. In other words, PAEs are a subset of NPEs solely focused on the monetization of a set of patents rather than in long-term innovation in a field of technology.

From existing studies such as Fischer and Henkel (2012) and Leiponen and Delcamp (2018) we know that PAEs tend to focus on high-quality patents that are broad (have many claims) and general (apply to many technology classes) because such patents tend to be more valuable in licensing. Standard-essential patents (SEPs) are particularly valuable because they are necessary in order to build products for a communication standard. If the standard is successful, there may be a very large market for the licensed technologies. However, most Standard Development Organizations (SDOs) such as 3GPP require that essential patents are

licensed under terms that are Fair, Reasonable, and Non-Discriminatory (FRAND). While SDOs rarely explicitly state what FRAND means, the FRAND-compliance of licensing arrangements is defined through negotiation and litigation among patent holders and potential licensees. Nevertheless, SEPs are very desirable and valuable patent assets for licensing entities to monetize.

However, there is not a particularly liquid market for SEPs. Most SEPs are so valuable that the original inventors themselves hold and commercialize them. Nevertheless, there are PAEs that themselves make original inventions and attempt to license those as essential to a standard. Development of such essential patents and holding them until the technologies are adopted in a standard requires a consistent long-term effort in the field of technology. Indeed, in this paper we assess the implications of patent litigation that took place between 2007 and 2012, whereas some of the original patented inventions were made in the early 1990s. This is thus not any kind of "fly-by-night" patent assertion.

Contrary to popular beliefs, most PAEs are rather sophisticated businesses with significant capabilities in technology development, patenting, and/or litigation (Leiponen and Delcamp, 2018). Technology-oriented PAEs tend to focus on a narrow field of technology where they have deep expertise, often originating from academic or major technology company spinoffs. They also often build larger portfolios of related patents and pursue complex cooperative arrangements with innovating companies, such as when Mosaid formed an alliance with Nokia and Microsoft to monetize a portfolio of Nokia inventions and share the revenue with Nokia and Microsoft[1].

[1] https://www.zdnet.com/article/microsoft-weighs-in-on-mosaid-nokia-patent-deal/

While PAEs have certainly made a big impact on patent litigation (in some technology fields, the majority of patent litigation is initiated by PAEs), it is not clear if they truly matter for technological change. Cohen et al. (2016) argued that they reduce R&D effort by infringing firms. This seems natural, because R&D budgets tend to be financed internally and large damage awards can reduce the amount available for internally-financed activities. In particular, firms found to be infringing may need to shut down certain R&D projects to avoid treble damages[2]. However, it is not known to what degree the damage amounts encourages R&D by other, particularly smaller and independent inventors. Abrams et al. (2019) explore this issue and suggest that while PAE litigation reduces downstream citations to a patent, it may also encourage invention because of a more liquid market for patents. Indeed, Xue (2019) presents large-scale evidence that when a PAE initiates litigation in a patent class, there tends to be more patenting within that class subsequently. The effect may in part be driven by PAEs selecting into technology fields that are highly dynamic and growing, but there is little evidence in her data that PAE entry into litigation *reduces* patenting in the affected technology field. Abrams et al. suggest that the net effect depends on the share of infringers who are innovators vs. non-innovators. In other words, if PAEs primarily sue infringing firms that are not very innovative, the downstream innovation-dampening effect could be less than the upstream invention-encouraging effect. However, if PAEs primarily sue highly innovative firms and thereby reduce their R&D investment, downstream innovation could decline in the economy.

The insights from Abrams et al. are based on a model simulation and they do not empirically examine in which fields or contexts PAEs actually harm vs. incentivize innovation. Our goal in this paper is to empirically examine the effects of PAE litigation on standard

[2] https://www.ip-watch.org/2016/07/26/us-high-court-restores-treble-damages-for-patent-infringement/

development. We are interested in isolating the effect of PAE litigation on the effort and direction of standard development. This is important because it informs us about whether PAEs are simply a "tax" in the economy and transfer R&D effort from infringing firms to usually smaller inventors, or whether PAE litigation induces other strategic changes in the direction of innovation effort, too. In other words, we seek to assess whether PAEs have real effects on innovation in the economy through the direction of standard development.

We build on an earlier study of litigation and standard development (Jones et al., 2019) that highlights the connections between patent litigation and subsequent standard development. That paper theorized about the impact of litigation conflict on cooperation using evolutionary game theory. Much of the management literature on cooperation highlights that conflict can lead to a loss of trust and disruption of cooperative relationships (e.g., Greve et al., 2010; Malhotra and Lumineau, 2011; Sytch and Tatarynowicz, 2014). However, when firms are connected with and dependent on each other for the long term through the communication system, a litigation event that attempts to shift appropriation of value from one party to another may lead to increased cooperation between the litigants. A long-term perspective on cooperation allows the parties to focus on future benefits of cooperation and develop valuable features based on technological complementarities between the parties. However, Jones et al. (2019) also find that the litigation challenge also induces the defendant in a lawsuit to significantly enhance exploration of alternative avenues with a new set of cooperative partners. Complementarities and outside options are thus important drivers of cooperation in standard development.

This paper focuses on the response of product companies to litigation challenges by PAEs. Licensing negotiations with PAEs differ from those with product companies in that there is not an aspect of joint technological development or the shadow of the future that enhance the

value of cooperation. For example, when Apple and Qualcomm settled their patent disputes in 2019, the settlement involved (undisclosed) royalty payments, a multiyear licensing agreement, and a long-term supply agreement[3]. When PAEs such as WiLAN license patents, the agreement usually only concerns access to patented technologies[4]. Access to a PAE's patented technologies thus does not create an equally promising opportunity for complementary innovation compared with access to a product company's patented technologies. This argument is corroborated the observation by Abrams et al. (2019) that PAE acquisition of patents tends to reduce subsequent citations to them. As a result, a patent litigation initiated by a PAE is likely to result in an attempt to move away from the patented technologies and seek to deploy other solutions to the technical needs. We thus hypothesize that *a PAE filing of a patent lawsuit will induce an effort to mitigate the licensing commitment by creating alternative solutions through standard development contributions.*

DATA AND METHOD

Empirical Context

INCOMPLETE!

In this paper we explore how a patent licensing dispute impacts standard development when the plaintiff is a Patent Assertion Entity (PAE). We can distinguish three types of patent holders in the 3GPP dataset: product companies, technology companies, and PAEs. Product companies include all firms that sell products and services to either final consumers or to other firms. Most product companies in our dataset sell user equipment to consumers, network equipment to telecom operators, or telecom services to consumers. We also observe technology companies

[3] https://investor.qualcomm.com/static-files/fb14de14-186a-4ae6-a4e0-ee208764672f
[4] https://www.innovation-asset.com/blog/cisco-and-wi-lan-sign-multi-year-license-agreement

such as InterDigital and Qualcomm, who in the context of wireless telecommunication are largely Non-Practicing Entities. For example, Qualcomm is a major provider of patented technologies for the Radio Access Network (RAN) specifications but does not sell related user equipment or network equipment. Within 3GPP, it primarily provides licenses to its sizable patent portfolio, although it also sells chipsets that are a component to mobile phones (particularly the widely adopted Snapdragon products)[5]. InterDigital is also a major inventor and patent licensor within 3GPP. Both these companies also actively participate in specification development.

Our dataset of Standard Essential Patents and their litigation among 3GPP members also includes PAEs that we define as companies who do not offer products or services beyond patent licensing and who do not contribute to specification development. Our current dataset includes six such PAEs: Core Wireless, Optis (or Panoptis), Innovative Sonic, SPH America, VirnetX and WiLAN. These firms own about 400 patents essential for wireless telecom standards, and they have pursued nine cases of litigation within our period of study. In total, 47 3GPP member companies were defendants in these lawsuits. Table 2 below shows some of the most frequent plaintiffs and defendants in our dataset. Three of the PAEs are among the most frequent litigators of SEPs: SPH America, Core Wireless (now a subsidiary of Conversant), and VirnetX. We also see that the technology companies Qualcomm and InterDigital vigorously enforce their patents. Companies most often targeted by patent lawsuits include telecom operators and major equipment vendors.

[5] Patent licensing represents about 20% of Qualcomm's revenues and over half of its profits: https://investor.qualcomm.com/static-files/e3f006cd-77d9-46e2-bb3d-013065906ecb

Table 2 Frequent 3GPP plaintiffs and defendants

Most active plaintiffs	# lawsuits	Most frequent defendants	# lawsuits
SPH AMERICA	11	AT&T	22
MOTOROLA	10	APPLE	21
ERICSSON	8	MOTOROLA	18
INTERDIGITAL	7	SPRINT NEXTEL	16
APPLE	9	T-MOBILE	16
QUALCOMM	6	SAMSUNG ELECTRONICS	15
CORE WIRELESS	5	VERIZON	14
NOKIA	4	ZTE	10
NORTEL NETWORKS	3	NOKIA	9
SAMSUNG ELECTRONICS	3	RESEARCH IN MOTION	8
VIRNETX	3		

Notes: Green firms are PAEs, blue firms are equipment vendors, purple firms are primarily technology licensors, and red firms are telecom operators.

Table 3 provides descriptive details about each PAE and their SEP portfolios and litigation. Innovative Sonic and WiLAN are commercializing their own patented inventions. Both companies have been in the wireless technology field for years. WiLAN has an interesting history in the field of radio technology. It was founded in 1992 by two scientists at the University of Calgary and invented several fundamental technologies that were subsequently incorporated in the IEEE 802.11 set of WiFi standards. Those technologies were based on OFDM inventions originally made by Bell Labs in the 1960s and further developed by other companies including WiLAN. OFDM technologies were later adopted in the WiMAX standard and WiLAN licensed its relevant patent portfolio to that part of the communication industry. Finally, the WiMAX technologies found their way into the 4G or "Long-Term Evolution" technologies that are by 2019 implemented in the wireless telecom networks worldwide. Thus, somewhat fortuitously, WiLAN's inventions from the 1990s were adopted—and licensed—worldwide in telecommunication networks.

Core Wireless and Optis/Panoptis obtained their patents from wireless innovators Nokia and Unwired Planet, respectively. Panoptis acquired Unwired Planet and other patents from

Panasonic and Ericsson. Core Wireless made an arrangement with Nokia in 2011 to acquire and monetize 2000 patents and share the revenue with Nokia and Microsoft. Core Wireless was subsequently acquired by Mosaid (renamed Conversant).

Table 3 PAE patents and their litigation 2001-2016

PAE firm	Number of SEPs	Source of SEPs	Number of lawsuits	Main defendants
Core Wireless	7	Nokia	5	Apple
Innovative Sonic	133	Own inventions	1	Research In Motion
Optis	195	Unwired Planet	?	?
SPH America	3 (or 6)	ETRI	11	Acer, Apple, Fujitsu, HP, HTC, Huawei, Kyocera, Lenovo, Motorola, Nokia, Panasonic, Sierra Wireless, Sony, Sony Ericsson, UT Starcom, ZTE,
VirnetX	7	SAIC/Leidos	3	Apple, NEC
Wi-LAN	36	Own inventions	2	Acer, Apple, Atheros, Broadcom, D-Link, HP, Infineon, Intel, Lenovo, Marvell Tech, Sony, Toshiba, Texas Instruments

Sample

Our sample combines data from the Searle Center on Law, Regulation, and Economic Growth at Northwestern University (3GPP technical contributions), ETSI.org (Standard Essential Patents), Lex Machina (patent litigation), and Thompson Reuters (patent citation data). To estimate the impact of PAE litigation on cooperative standard development, we created a panel of WG-quarter-firm dyads (pairs of firms) from 2005 through 2012.

Estimation variables and inference

Our dependent variable is the number of contribution documents coauthored by a dyad. We focus on the cooperative creation of specifications because it indicates both activity and direction of development. When firms cooperate in R&D activities, they tend to seek cooperation with others who have complementary inputs into the technological challenge. This was highlighted in

the standard development setting by Bar and Leiponen (2014): when firms make new cooperative specification proposals, they are likely to include partners that are complementary to themselves in terms of technological portfolios. Thus, when firms initiate cooperative arrangements with new partners, that is an indication that they are pursuing a new direction of technological change. Co-authored contributions are a simple count of discussion documents and technical reports by a dyad in a given WG at a given quarter.

Our main independent variable is the litigation filing treatment. We include a host of control variables as explained in Jones et al. (2019).

We use a difference-in-differences approach to test our research question and estimate a negative binomial model.

We examine the impact of a PAE filing on subsequent cooperative specification development by the defendant and other 3GPP members. Arguably, the lawsuit is exogenous to the cooperative activities of product companies in standard development. While the community, as a whole, has made decisions to adopt specifications that depend on essential patents by the PAEs, we argue that individual companies did not intentionally deploy strategies that made them particularly vulnerable to those lawsuits (beyond adopting the standard). Nevertheless, we acknowledge that the PAE lawsuits are not randomly targeted. Therefore there may be selection into specific working groups relevant to the patented technologies, and specific types of companies that are more likely to become targets of litigation. We addressed the problem of sample selection by using a matching procedure, because we have many informative covariates but lack an appropriate instrument.

RESULTS

We first describe the PAE litigation impact in working groups through analysis of working group contributions over time and for four quarters before and after the filing. In figure 1 we show the evolution of average contributions (change requests, discussion papers, and technical reports) per working group and overlay the lawsuits initiated by PAEs. We observe little overall correlation between PAE filings and specification development.

Figure 1 Impact of PAE filings on technical contributions within the working group

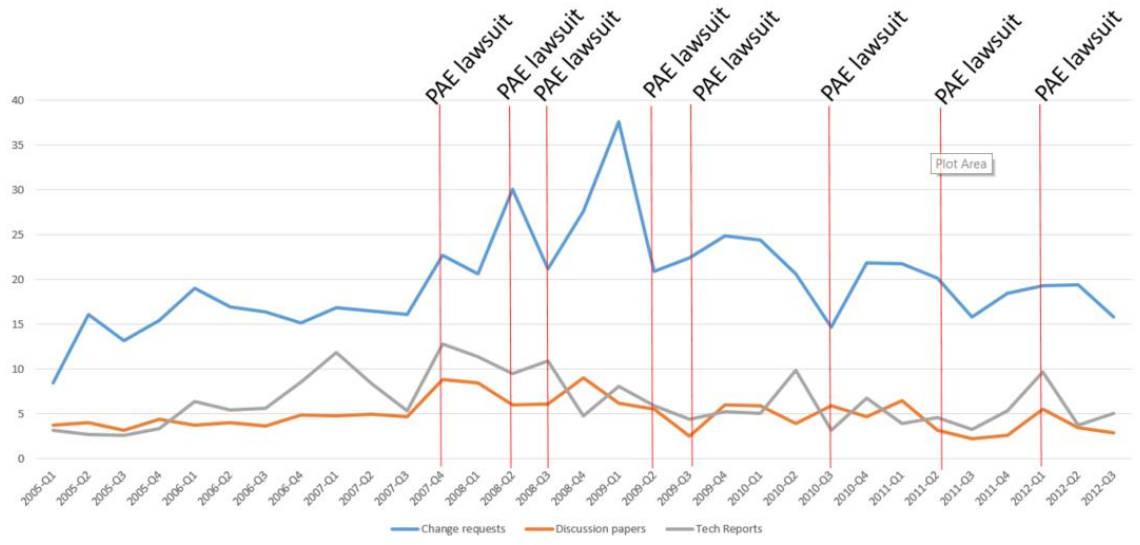


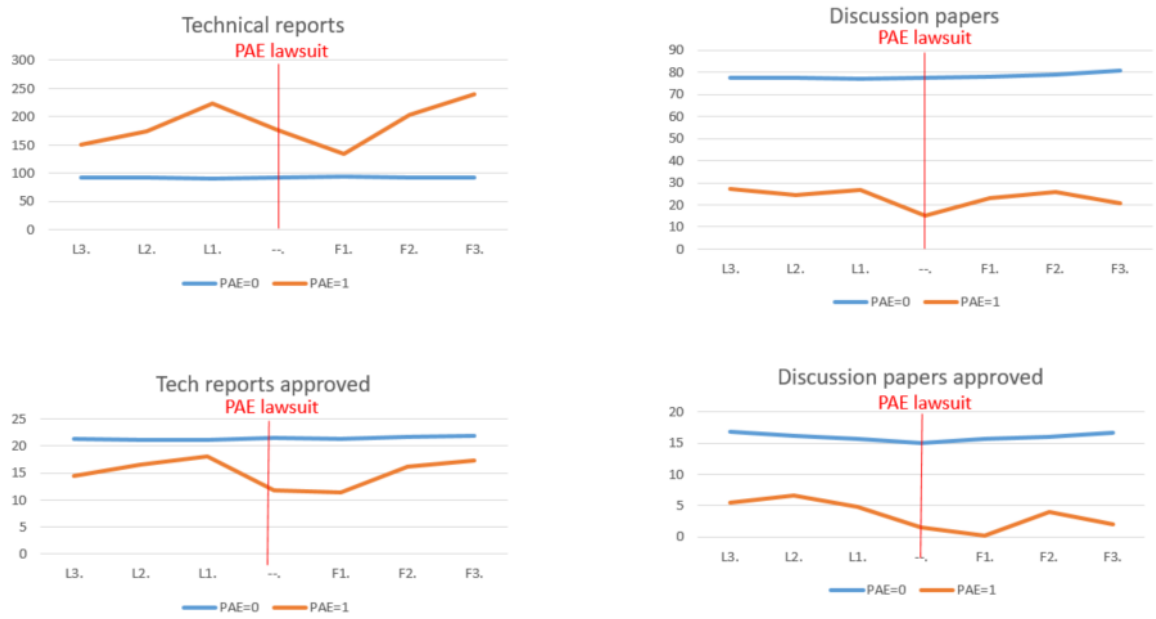
Figure 2 illustrates what happens within the relevant working group after a PAE initiates litigation. It appears that PAE litigation tends to happen within working groups that have been very active in terms of making changes to the specifications under development, but the rate of changes is in decline at the time of the filing. This suggests the working group is winding down a flurry of development activity. However, the PAE filing appears to reverse the decline in change requests. The declining rate of approvals of submitted change requests is also reversed around the time of PAE filing, and so is the number of firms involved in change requests. However, the

rate of rejections of change requests is not affected or even further declines. Overall, more changes to the relevant specifications appear to be made right after a PAE files a patent lawsuit related to the SEPs of the working group.

Figure 2 Impact of PAE filings on change requests within the working group

Figure 3 illustrates the evolution of other types of technical contributions around the time a PAE initiates a lawsuit. Technical reports and discussion papers tend to be more oriented toward future specifications rather than toward changing existing specifications. Interestingly, technical reports and discussion papers do not appear to be affected by the PAE filing.

Figure 3 Impact of PAE filings on other contributions within the working group



Regression analyses

Table 4 presents our preliminary estimation results using a matched sample of dyads where treated dyads contained a defendant sued by a PAE and the control dyads were otherwise similar but did not contain a defendant sued by a PAE. Aligned with Jones et al. (2019), we find that after a lawsuit, plaintiffs and defendants tend to increase their cooperative activities (post filing * litigant dyad). However, PAEs almost never participate in specification development so the PAE plaintiff * litigant dyad coefficient is very large and negative. In model 2 we drop these dummies from the model.

Similarly, in defendant-defendant dyads, after a patent lawsuit, the dyad members tend to significantly increase their cooperative standard development. However, when the lawsuit is filed by a PAE, co-defendants do not significantly change their cooperation pattern after the filing (PAE plaintiff * post filing * litigant dyad), beyond the changes experienced by other co-defendant dyads.

The interesting result appears in the defendant-other dyads. As before, these dyads tend to increase cooperative development after a patent lawsuit is filed (post filing * litigant dyad). However, when the plaintiff is a PAE, there is an additional and quite large and significant effect of new cooperative activity within the dyad (PAE plaintiff * post filing * litigant dyad). Table 5 illustrates the magnitudes of these effects. Whereas there is no additional PAE treatment effect in plaintiff-defendant dyads, the estimated effect on defendant-defendant dyads is 3.3 for non-PAE plaintiffs and 4.4 for PAE plaintiffs. However, the difference between the two is statistically insignificant. In contrast, the treatment rate for defendant-other dyads when the plaintiff is a PAE is more than double that when the plaintiff is not a PAE (4.7 vs. 1.9). This effect is both statistically and economically significant.

We thus find that when a PAE files a lawsuit concerning the SEPs of the affected working group, defendants in the lawsuit tend to change their standard-development activities significantly more than in the case of other types of plaintiffs. They particularly increase specification contributions developed with other firms. The descriptive evidence above suggests that much of the change in the standard development activity originates from newly submitted change requests which attempt to revise some of the already developed (but not released) technical specifications related to those SEPs. In our ongoing work we plan to specifically investigate the volume and nature of the impact in submitted change requests.

Table 4. Negative Binomial Difference-In-Differences Model

Dependent variable: dyad co-authoring	Model 1		Model 2	
	Est.	S.E.	Est.	S.E.
Plaintiff-defendant dyad				
Post-filing	0.04	(0.27)	0.04	(0.27)
Litigant dyad	-0.57	(0.35)	-0.65	(0.37)
Post-filing * Litigant dyad	1.36**	(0.45)	1.26**	(0.46)
PAE plaintiff * Litigant dyad	-32.48***	(0.71)		
PAE plaintiff * Post-filing * Litigant dyad	-1.33***	(0.20)		
Defendant-defendant dyad				
Baseline	0.54**	(0.21)	0.54**	(0.21)
Post-filing	-0.44	(0.28)	-0.44	(0.28)
Litigant dyad	-0.46	(0.31)	-0.53	(0.33)
Post-filing * Litigant dyad	1.18***	(0.34)	1.32***	(0.36)
PAE plaintiff * Litigant dyad	-1.53***	(0.37)	-1.36***	(0.36)
PAE plaintiff * Post-filing * Litigant dyad	0.31	(0.26)	-0.13	(0.37)
Defendant-other dyad				
Baseline	-0.16	(0.27)	-0.16	(0.27)
Post-filing	0.06	(0.13)	0.06	(0.13)
Litigant dyad	-0.32*	(0.15)	-0.32*	(0.15)
Post-filing * Litigant dyad	0.65***	(0.16)	0.65***	(0.16)
PAE plaintiff * Litigant dyad	0.01	(0.32)	0.03	(0.31)
PAE plaintiff * Post-filing * Litigant dyad	0.89*	(0.38)	0.87*	(0.38)
Controls				
Technological distance	-0.09	(0.11)	-0.10	(0.11)
No authoring by dyad member	-1.88***	(0.15)	-1.89***	(0.15)
Combined citation-weighted patents	0.08**	(0.03)	0.08**	(0.03)
Std. dev. Of citation-weighted patents	-0.10*	(0.04)	-0.10*	(0.04)
Third-party closure	0.01***	(0.00)	0.01***	(0.00)
Litigants in open cases	-0.01	(0.02)	-0.01	(0.02)
SEPs in open cases	-0.04	(0.03)	-0.04	(0.03)
Off-quarter filing	0.16	(0.11)	0.16	(0.11)
Suit-countersuit	0.01	(0.34)	0.01	(0.34)
Working group dummies	Included		Included	
Quarter dummies	Included		Included	
Dispersion parameter	6.67		6.68	
AIC	107,598.2		107,601.7	
Observations	207,180		207,180	

Table 5. Point Estimates of Average Treatment Rate for PAE and Non-PAE Litigation

Average treatment rate	Non-PAE	PAE
Plaintiff-defendant	3.9	1.0
Co-defendant	3.3	4.4
Defendant-other	1.9	4.7

Note. An average treatment rate of 1.0 indicates no effect. Values above 1.0 indicate a positive effect, and values below 1.0 indicate a negative effect of litigation.

PRELIMINARY CONCLUSIONS

Our preliminary results suggest that PAEs do influence innovation strategies of firms via standard development. When a PAE initiates litigation, we observe changes in the level of technical contributions to the affected 3GPP working group. We also find that after a 3GPP member company is sued by a PAE, the member tends to initiate a substantial number of new standard development activities with other firms.

Our results are consistent with the idea of "forking" in open-source software communities. While there are few studies about forking, it is a significant event in the evolution of the OSS system. Forked OSS projects generate multiple incompatible versions of the product. While each version may generate some private benefits to the parties who initiated the fork, there may be significant social costs to having incompatible versions in the marketplace and a fragmented developer community that needs to duplicate efforts. For example, Ernst, Easterbrook and Mylopoulos (2010) find that forking may ensue from a new and different set of requirements. They study a case where an OSS program was forked to provide alignment with academic needs as opposed to business needs. Indeed, many OSS licenses explicitly define a right to fork so as to make it available for participants to develop software that addresses their needs. In a related study, Wen, Forman and Graham (2013) explored the impact of PAE-driven software patent disputes on OSS project activity and find that litigation cases such as the SCO v. IBM case reduced OSS development activity in projects that were highly affected by this dispute. Strategic disputes can thus influence subsequent development activity in technical communities. To our knowledge, our study is the first one to test the impact of strategic conflict on the direction of development effort.

Qualitatively understanding the drivers of the observed behavior is particularly important in complex settings such as standard development and patent licensing. We illustrated some of the dynamics at work through the case of WiLAN's OFDM patent licensing. WiLAN had invented Wideband-OFDM technologies in the 1990s. They were initially adopted in other wireless systems such as WiFi and WiMAX. While originally based on a different set of radio technologies, 3GPP adopted OFDM-based specifications in the cellular telecommunications standards underpinning 4G/LTE. 3GPP released the 8th version of the standard that contained the OFDM specifications in late 2008. WiLAN pursued licensing agreements concerning three SEPs[6] with a large part of the industry (19 companies in total) in three lawsuits between 2007 and 2008, that is, during the specification development for Release 8. These lawsuits were settled out of court. This case illustrates how the timing of specification development and adoption within 3GPP coincided with the PAE patent litigation. Subsequently, our statistical analyses suggest that 3GPP members responded to the litigation by attempting to change some of the specifications through cooperative development of alternative approaches. This response to patent litigation by PAEs is significantly stronger than to that by other types of plaintiffs. We believe it is because the nature of the PAE business model is geared toward monetization rather than long-term collaborative development of technology. As a result, patent litigation with PAE plaintiffs does not offer opportunities to exploit technological complementarities between the litigants (cf. Jones et al. 2019) and thus presents no potential long-term benefits from innovation, only additional licensing costs.

[6] US 5282222: Method and apparatus for multiple access between transceivers in wireless communications using OFDM spread spectrum (WiLAN 1992 priority)
US 5555268: Multicode direct sequence spread spectrum (WiLAN 1994)
US6549759: Asymmetric adaptive modulation in a wireless communication system (Ensemble Communications 2001, assigned to WiLAN 2004)

REFERENCES (incomplete)

3GPP.org. Release 15. Accessed January 2018, http://www.3gpp.org/release-15.

Bar T, Leiponen A (2014) Committee composition and networking in standard setting: The case of wireless telecommunications. *Journal of Economics & Management Strategy*. 23(1):1-23.

Baron J, Gupta K, Roberts B (2015) Unpacking 3GPP standards. Working Paper. *Searle Center on Law, Regulation, and Economic Growth.* Northwestern University, Chicago, IL

Baron J, Spulber DF (2015) Technology standards and standards organizations: Introduction to the Searle Center Database. Working Paper. *Searle Center on Law, Regulation, and Economic Growth.* Northwestern University, Chicago, IL.

Clarkson G, Toh PK (2010) 'Keep out' signs: The role of deterrence in the competition for resources. *Strategic Management Journal*. 31(11):1202-1225.

Cohen WM, Levinthal DA (1989) Innovation and learning: The two faces of R&D. *Economic Journal*. 99(397):569-596.

Delcamp H, Leiponen A (2014) Innovating standards through informal consortia: The case of wireless telecommunications. *International Journal of Industrial Organization*. 36:36-47.

The Economist (2010) The great patent battle. (October), http://www.economist.com/node/17309237.

Elmer-Dewitt P (2012) Apple v. Samsung: The patent trial of the century starts today. *Fortune.* (July 30), http://fortune.com/2012/07/30/apple-v-samsung-the-patent-trial-of-the-century-starts-today/.

Farrell J, Saloner G (1988) Coordination through committees and markets. *RAND Journal of Economics*. 19(2):235-252.

Fershtman C & Gandal N (2011) Direct and indirect knowledge spillovers: the "social network" of open-source projects. *RAND Journal of Economics.* 42(1), 70-91.

Gandal N, Kende M & Rob R (2000). The dynamics of technological adoption in hardward/software systems: the case of compact disc players. *RAND Journal of Economics.* 31(1): 43-61.

Graham S, Vishnubhakat S (2013) Of smart phone wars and software patents. *Journal of Economic Perspectives.* 27(1): 67-85.

Gulati R (1995) Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances. *Academy of Management Journal*. 38(1), 85-112.

Helfat CE (1994) Evolutionary trajectories in petroleum firm R&D. *Management Science*, 40(12):1720-1747.

Helfat, C. E., & Raubitschek, R. S. (2018). Dynamic and integrative capabilities for profiting from innovation in digital platform-based ecosystems. Research Policy, 47(8), 1391-1399.

Heller MA, Eisenberg RS (1998) Can patents deter innovation? The anticommons in biomedical research. *Science*. 280: 698-701.

Iacus SM, King G, Porro G (2012) Causal inference without balance checking: Coarsened exact matching. *Political Analysis*. 20(1):1-24.

Jacobides MG, Cennamo C, Gawer A (2018) Towards a theory of ecosystems. *Strategic Management Journal*. Forthcoming.

Johnston JS, Waldfogel J (2002) Does repeat play elicit cooperation? Evidence from federal civil litigation. *The Journal of Legal Studies*. 31(1):39-60.

Jones S, Leiponen A, Vasudeva G (2019). Dear Enemy in innovation ecosystems: Conflict and cooperation in mobile telecom standards development. Unpublished manuscript.

Khanna T, Gulati R, Nohria N (1998) The dynamics of learning alliances: Competition, cooperation, and relative scope. *Strategic Management Journal*. 19(3): 193-210.

Kramer RM, Lewicki RJ (2010) Repairing and enhancing trust: Approaches to reducing organizational trust deficits. *Academy of Management Annals*. 4(1): 245-277.

Lanjouw J, Schankerman M (2001) Characteristics of patent litigation: A window on competition. *RAND Journal of Economics*. 32(1): 129-151.

Layne-Farrar A, Padilla AJ, Schmalensee R (2007) Pricing patents for licensing in standard-setting organizations: Making sense of FRAND commitments. *Antitrust Law Journal*. 74(3), 671-706.

Polidoro F, Toh PK (2011) Letting rivals come close or warding them off? The effects of substitution threat on imitation deterrence. *Academy of Management Journal*. 54(2):369-392.
Ranganathan R, Rosenkopf L (2014) Do ties really bind? The effect of knowledge and commercialization networks on opposition to standards. *Academy of Management Journal*. 57(2), 515-540.
Ranganathan R, Ghosh A, Rosenkopf L (2018) Competition–cooperation interplay during multifirm technology coordination: The effect of firm heterogeneity on conflict and consensus in a technology standards organization. *Strategic Management Journal*. Forthcoming.
Rosenkopf L, Metiu A, George VP (2001) From the bottom up? Technical committee activity and alliance formation. *Administrative Science Quarterly*. 46(4):748-772.
Schelling TC (1960) *The Strategy of Conflict*. (Harvard College).
Shapiro, C. (2000). Navigating the patent thicket: Cross licenses, patent pools, and standard setting. *Innovation Policy and the Economy*. 1: 119-150.
Simcoe TS, Graham SJH, Feldman MP (2009) Competing on standards? Entrepreneurship, intellectual property, and platform technologies. *Journal of Economics and Management Strategy*. 18(3): 775-816.
Simcoe T (2012) Standard setting committees: Consensus governance for shared technology platforms, *American Economic Review*. 102(1): 305-336.
Somaya D (2003) Strategic determinants of decisions not to settle patent litigation. *Strategic Management Journal* 24(1): 17-38.
Stuart EA (2010) Matching methods for causal inference: A review and a look forward. *Statistical Science* 25(1):1-21.
Stuart TE, Podolny JM (1996) Local search and the evolution of technological capabilities. *Strategic Management Journal*. 17(S1):21-38.
Teece DJ (1986) Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*. 15(6): 285-305.
Teece DJ (2009) *Dynamic capabilities and strategic management: Organizing for innovation and growth*. (Oxford University Press).
Teece DJ (2018) Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. *Research Policy*. Forthcoming.
Vasudeva G, Alexander EA, Jones SL (2014) Institutional logics and interorganizational learning in technological arenas: Evidence from standard-setting organizations in the mobile handset industry. *Organization Science*. 26(3):830-846.
Vasudeva G, Teegen H (2011) Why do private firms invest in public goods?. Marcus A, Shrivastava P, Sharma S, Pogutz S, eds. *Cross-Sector Leadership for the Green Economy* (Palgrave Macmillan, New York): 263-276.
Ziedonis RH 2003 *Patent litigation in the US semiconductor industry* (Vol. 138). (The National Academies Press, Washington, DC).
Ziedonis RH (2004) Don't fence me in: Fragmented markets for technology and the patent acquisition strategies of firms. *Management Science.* 50(6), 804-820.