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THE IMPACT OF INTELLECTUAL PROPERTY ENFORCEMENT ON OPEN SOURCE SOFTWARE ADOPTION

Completed Research Paper

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Abstract

We investigate how intellectual property (IP) enforcement against open source software (OSS) projects affects OSS adoption. We hypothesize that adoption of OSS sharing similar technological features with the litigated OSS technology and OSS typically used within organizations and complementary with the litigated OSS would be disproportionately affected by IP enforcement. We examine two widely publicized lawsuits – SCO v. IBM and FireStar/DataTern v. Red Hat – using data from SourceForge.net. Our difference-in-difference estimates show OSS projects similar to the litigated OSS had a 14% greater decline than projects in the control group in the months following the filing of SCO v. IBM and had an 11% greater decline following the filing of FireStar/DataTern v. Red Hat; OSS projects for organizations and complementary with the litigated OSS had a 37% greater decline following the filing of SCO v. IBM and a 16% greater decline following the filing of FireStar/DataTern v. Red Hat.

Keywords: Open source software (OSS), intellectual property enforcement, OSS adoption, litigation risk

Introduction

Open source software (OSS) innovation has seen increasing adoption by both organizations and individuals in recent years, and in some markets provides the infrastructure for a significant share of overall economic activity. For example, based on the survey by Netcraft, Apache and its derivatives had been adopted by 2.6 million newly established websites in October 2009 (Netcraft 2009). An increasing body of literature (see Feller et al.(2005), Lerner and Tirole (2005a), Maurer and Scotchmer (2006), and von Hippel (2006) for recent reviews of the literature) has emerged in information systems and other fields studying, among many other things, the incentives for user contributions (e.g., Hann et al. (2004); Lakhani and von Hippel (2003); Roberts et al. (2006)), firm strategies in open source (e.g., Henkel (2006); West (2003)), and the impact of licensing and legal regimes (e.g., Lerner and Tirole (2005b); Stewart et al. (2006)).

One area of active research has been on the determinants of OSS success (Stewart et al. 2006). An important issue in this area is how intellectual property (IP) rights affect the OSS movement. Prior work has empirically examined the impact of OSS licenses on project success (e.g., Stewart et al. (2006)). Moreover, there is a widespread belief that software patents and their enforcement against OSS projects have had an impact on the diffusion of OSS (e.g., Lerner and Tirole (2005a)). A large body of anecdotal evidence has supported these claims (e.g., Mims (2005); Parekh (2005)). For instance, when the first major intellectual property (IP) enforcement action (*SCO v. IBM*) against Linux was filed, many observers voiced concerns that open source may confront an increasing number of IP threats. For example, one such concern was expressed by Gordon Haff, an analyst at Illuminata in Nashua, N.H. who said that “some issues around patents, copyrights, and licenses will, to some degree, perhaps make Linux a victim of its own success” (McMillan and Scannell 2003).

While this anecdotal evidence is informative, there exists (to our knowledge) little systematic empirical evidence on the quantitative impact of such suits (and their risks) on OSS success. This is a surprising gap in understanding. To the extent that there exists continued uncertainty whether holders of software patents and copyrights will exert their IP rights on the open source community (Babcock 2007), empirical evidence in this area will help to inform projections of OSS diffusion. Further, evidence on this question will also help to inform the risks of using OSS software code for end users and software firms. Last, it will inform the continuing debate about the social costs of the patent system, particularly in software and business method patents (e.g., Bessen and Meurer (2008); Cockburn and MacGarvie (2009); Hall and MacGarvie (2010); Jaffe and Lerner (2006)).

Motivated by these observations, we take a first step toward addressing this issue by examining the impact of IP enforcement on OSS adoption. Specifically, we examine how the filing of two widely publicized lawsuits – *SCO v. IBM* and *FireStar/DataTern v. Red Hat* – affected the rate of downloads in OSS projects. Our method of causal inference is difference in difference estimation—that is, we compare the rate of downloads before and after the lawsuit for a set of projects that are affected by these cases (a treatment group) to the rate of downloads before and after the lawsuit for a set of projects that are unaffected by these cases (a control group) (Angrist and Pischke 2009).

Our core argument is that these lawsuits will increase the expected costs of using OSS. As a result, potential adopters will either delay their adoption decision or decide against adopting altogether. We hypothesize two mechanisms through which the costs of OSS adoption would increase: through raising potential litigation costs from enforcement actions by IP rights holders if the user itself gets sued; through raising costs of switching from a piece of OSS if the value of the OSS substantially declines in face of termination of the litigated OSS. We believe these costs will be particularly salient for two groups of users. First, we hypothesize that IP enforcement would have a stronger negative impact on the adoption of OSS that shares similar technological features with the focal litigated OSS technology. Second, we hypothesize that adoption of OSS typically used within organizations and that is complementary (used in conjunction) with the focal litigated OSS would be disproportionately affected.

We test the above two hypotheses based on the largest repository of OSS projects – SourceForge.net (SourceForge). Our empirical results strongly support our hypotheses. In the months following the filing of *SCO v. IBM*, adoption of OSS projects that share similar technological features with the focal litigated OSS had a 14% greater decline relative to the control group; in the months following the filing of *FireStar/DataTern v. Red Hat*, projects similar to the focal litigated OSS were also faced with a 11% greater decline of adoption relative to the control group. Second, in the months following the filing of *SCO v. IBM*, OSS projects used within organizations and complementary to the focal litigated OSS were associated with a 37% greater decline of adoption relative to the control group. Similarly, in the months following the filing of *FireStar/DataTern v. Red Hat*, organization-intended projects that are complementary

to the focal litigated OSS also had a 16% greater decline of adoption relative to the control group. To address concerns about time-varying omitted variables, we further examine robustness of these results using a series of falsification exercises and subsample analyses.

Our study contributes to the following four related fields. First, our study contributes to research on OSS; researchers have identified a variety of project-level characteristics that influence success, including software type, programming language, number of developers, license type, and organizational sponsorship (e.g., Chengalur-Smith and Sidorova (2003); Crowston and Scozzi (2002); Lerner and Tirole (2005b); Stewart et al. (2006)). The social network within which the project is embedded is also important (Grewal et al. (2006); Singh (2010); Singh et al. (2008)). One issue that has not been studied is how changes in the external environment influence OSS success. Thus, we contribute to the literature by suggesting how external IP environment – particularly IP enforcement – affects OSS project success. Meanwhile, it is worth noting that IP rights substantially shape the way organizations interact with the OSS community. Researchers have investigated strategies that organizations employ to profit from OSS innovation (Dahlander and Magnusson 2005; von Krogh and von Hippel 2003). For example, Henkel (2006) shows that organizations can protect their IP rights by selectively revealing code to the OSS community, while Fosfuri et al. (2008) suggest that variations in firms' endowments of IP rights help to determine how they commercialize open source products. To our knowledge, few studies have examined how organizations benefiting from OSS adoption would react to IP enforcement actions taken by proprietary software firms.

In addition to contributing to the research on OSS project success, our findings contribute to several other areas of research. For one, our research contributes to a further understanding of IT adoption by examining how the adoption decision is influenced by environmental factors as proposed by the technology-organization-environment (TOE) framework (Chau and Tam 1997; Tornatzky and Fleischer 1990). In particular, we add to recent work on how changes to legal regimes (Miller and Tucker 2009) influence technology adoption. We highlight the role of the IP environment and seek to establish a set of boundary conditions that will influence OSS adoption and diffusion. More broadly, we add to recent efforts among Information Systems researchers to evaluate the economic impact of changes to legal regimes (e.g., Hu and Png (2009); Png and Wang (2009); Romanosky et al. (2008)).

Third, it has been observed that the view of the courts toward the validity of software patents has changed radically since 1980, and individual and firm behavior has changed accordingly (Graham and Mowery 2003). The increasing use of software patents has contributed to a broader concern about the eroding quality of patents (Hall 2003). Our study provides further empirical evidence about the social costs of IP protection made possible by the patentability of software and provides support for a body of literature that questions the extension of patent protection to the software industry (Cohen and Lemley 2001; Graham and Mowery 2005).

Last, we contribute to the large literature that examines the relationship between IP strategies and innovation (Arora et al. 2001; Benkler 2002; Heller and Eisenberg 1998; Murray and Stern 2007). In particular, technological innovation may be undermined by the enforcement of IP rights. This detrimental impact from IP enforcement is especially salient to technology that needs cumulative or sequential innovation, since it mutes incentives for follow-on inventors to adopt the innovation and improve it (Bessen et al. 2006; Scotchmer 1991). However, there is less understanding about how IP strategies – particularly IP enforcement – affect OSS innovation. We seek to provide the first large scale empirical evidence about the detrimental effect of IP enforcement on OSS innovation adoption.

Theoretical Motivation and Hypotheses

Our research follows in the line of work that has investigated the reasons and determinants of OSS success (e.g., Chengalur-Smith and Sidorova (2003); Crowston and Scozzi (2002); Grewal et al. (2006); Parker and Van Alstyne (2005); Singh (2010); Singh et al. (2008)). The dominant framework in this literature has focused on the role of project characteristics such as project sponsorship and type of license (e.g., Stewart et al. (2006)) or the social network of developers (e.g., Grewal et al. (2006)). Our goal is to extend this existing body of research by examining a factor not considered in the dominant model: the impact of external IP environment. In particular, our focus is to examine how changes in the external IP environment influence software use or adoption, one key metric of OSS project success (Crowston et al. 2003; Crowston et al. 2006).

While our research design is well suited to identifying the causal mechanism we seek to explore (the implications of external IP environment for OSS diffusion and project success), because our data are at the project level we are unable to examine how organizational/individual features influence OSS adoption, as is commonly done in the IS literature for IT adoption (see Fichman (2000) for a summary). This challenge has been well-recognized in the OSS

literature (e.g., Stewart et al. 2006). Rather, we follow the approach taken in IT diffusion studies to examine what factors influence the penetration of new technology within a community (e.g., Dewan et al. (2009)). However, in contrast to much of this literature that examines how external factors like network externalities (Augereau et al. 2006; Goolsbee and Klenow 2002; Gowrisankaran and Stavins 2004), competition (Robertson and Gatignon 1986) or cross-sectional demographic characteristics (Kiiski and Pohjola 2002) influence the rate of IT diffusion, we emphasize IP enforcement as one important environmental factor.

The Probit or Rank Approach described by Stoneman (2002) provides a useful theoretical framework for us to achieve our goals. This approach suggests that an individual or organization considering technology adoption would compare gross adoption benefits against adoption costs and adopt only if the gross benefits are greater than the costs. If there is uncertainty involved, adoption and diffusion are influenced by expected return from use of the technology and variance attached to the return (Hall and Khan 2003; Mansfield 1968; Stoneman 1980; Stoneman 2002). Further, a potential adopter would compare net benefits of acquiring today with net benefits of acquiring one period ahead. If net adoption benefits are higher in some future period, potential adopters will delay their investment decision. Such a wait-and-see strategy may help adopter gather more information and reduce uncertainty (Jensen 1982). We use this framework to motivate our basic approach below. While we are mindful of other approaches within the IS literature that suggests that adoption may not only be influenced by a comparison of costs and benefits but also by other factors such as managerial influences (e.g., Leonard-Barton and Deschamps (1988)) or group norms (e.g., Webster and Travino (1995)), we do not believe our approach is inconsistent with this other work. Rather, our approach simply suggests that a change in expected costs of use will shift the returns to adoption, other things equal. We employ the Rank Approach because it provides a natural framework within which to motivate our hypotheses: our primary interest is in how IP enforcement actions will influence OSS use.

As noted above, our primary interest is to understand whether and how changes in the external IP environment increase expected adoption costs and thus affect the adoption decision *ex ante*. We focus on one particular change: the impact of IP enforcement actions (specifically, litigation) taken against OSS projects. We believe there are two mechanisms for how such actions can influence OSS adoption. The first mechanism is through raising expected litigation costs, which are a function of probability of being sued (i.e. perceived risk of litigation) and the potential litigation costs if the user itself is sued. OSS is particularly vulnerable toward IP litigation, because the existence of many developers makes it difficult to identify the provenance of the code. As noted by Lerner and Tirole (2005a), even developers may “lack the incentives and skills needed to check whether their contribution infringes awards.” To placate some organizational adopters’ concern after the filing of *SCO v. IBM*, Linus Torvalds proposed that Linux kernel developers need to acknowledge their rights to contribute so it is easier to respond to questions of source-code ownership (McMillan 2004). Therefore, we believe that because adopters may be even further from the technology space than developers, adopters, on average, are less certain about the ownership of source code. The potential legal risks to OSS adoption have been cited in the trade press. This was particularly evident after the filing of *SCO v. IBM*, a case that asserted IBM’s violation of its UNIX licenses in its development of Linux code at IBM. For example, Stuart Cohen, chief executive of Open Source Development Labs, noted that “nobody wants to talk about what they’re doing (with Linux) because they don’t want to become a target ...”(Kirby 2004). In some cases commercial OSS vendors such as IBM and Red Hat may provide more attractive targets for the IP rights holder. In some other cases, OSS users may be directly sued as well. In fact, the risks of users being litigated came to fruition in lawsuits like *SCO v. DaimlerChrysler* and *SCO v. AutoZone*. If the adopters are sued, litigation costs were high for both large and small business users¹, and even for non-profit organizations in the sense that the penalties claimed by the plaintiff are usually proportionate to defendant’s revenue (Greenhalgh and Rogers 2007). For example, in *SCO v. IBM*, the initial amount of alleged damages claimed by SCO reached \$1 billion (Lohr 2004).

The second mechanism is through raising the expected costs of switching from OSS if the value of the OSS substantially declines in the face of termination of the litigated OSS. Such expected switching costs are a function of the probability of switching (i.e. perceived risk of switching) and the potential switching costs. Following the definition from Chen and Hitt (2006), we define switching costs to be “the perceived disutility a user would experience from changing product or service providers.” In our setting, there are two scenarios through which legal

¹ Regarding the incentives for IP rights holder to go after small adopters, because small adopters lack enough resources to fight a suit, they tend to settle. Owing to the settlements by a lot of small adopters, the amount of money the IP rights holder can collect will also be substantial. For large adopters, because of their large financial resources, they are even more inviting targets to the IP rights holder.

enforcement actions against OSS will increase the likelihood of switching. First, if the target of the legal action is infringing then the adopter may have to switch software. Second, if the OSS is complementary to and specific to the litigated technology (e.g., OSS that ran only on Linux) then the likelihood of switching will also be increased. The suspension of the litigated technology would decrease the value of all complementary technologies (Nicholson and Snyder 1992), resulting in a high probability of switching.

Below we develop hypotheses about how different types of OSS projects and different types of adopters may be disproportionately affected by IP enforcement actions through these mechanisms. While we do not deny that other types of projects may also be affected by enforcement actions, this possibility will in fact make identification of the core relationships of interest more difficult (by lowering average adoption rates in the comparison groups in our regressions).

Hypotheses

We first examine the context where the probability of being sued (i.e. perceived risk of litigation) will most increase in response to an IP enforcement action. One of the most attractive features of OSS innovation is the public availability of source code. This repository of reusable code significantly reduces the total software development costs, since developers do not need to build reusable components from the scratch. Further, because such knowledge reuse helps mitigate the cost of innovation (Langlois 1999), OSS code reuse enhances knowledge spillovers. As empirically shown by Haefliger et al. (2008), OSS developers reuse code extensively in order to efficiently integrate functionalities and reduce development costs.

As a result of this code reuse, in the wake of IP enforcement actions OSS projects that are technologically similar to the infringing project may assume significant litigation risk. Prior literature in the area of IP strategy has demonstrated that firms engaged in similar lines of research are more likely to cite each other's patents as prior art. However, corporate patentees are more likely to prosecute firms in similar fields for the infringement of patented innovation (Lanjouw and Schankerman 1998; Lanjouw and Schankerman 2004). In our setting, code reuse in OSS development is analogous to patent forward citations. Among OSS projects in a similar field, increases in the extent of code reuse may indicate greater competition against the proprietary IP rights holder. The IP rights holder may wish to signal to competitors his interest in defending his property rights so as to build a reputation for aggressive IP protection (Lanjouw and Schankerman 2001). Therefore, we argue an IP rights holder is more likely to first target OSS projects in fields that display technological similarity.

As a result, because of the greater risks of being sued, OSS projects that share similar technological features with the litigated project will exhibit greater declines in adoption than other types of OSS projects. Further, as we discuss in further detail below, even if the potential adopter is not sued directly, it will bear costs if in the future an adopted OSS project that shares similar technological feature is found infringing and is terminated. In this case, the adopter may be forced to switch to a new (non-infringing) project, further increasing its costs. Thus, we expect that enforcement of IP will decrease the adoption of projects technologically similar to the focal project, relative to other projects.

H1: IP enforcement has a stronger negative impact on the adoption of OSS projects that share similar technological features with the focal litigated OSS than on OSS projects without such features.

For the previous hypothesis we noted the litigation-related risks of OSS adoption arose not only from direct litigation costs but also from the risks that the adopter might have to bear the costs of switching software. Here we describe a related but distinct hypothesis: that switching costs might also influence the adoption of OSS projects complementary (but technologically distinct) to the focal project.

Such switching costs are often particularly high for organizations. Organizational adoption of software often involves adoption of a set of complementary technologies. As shown by researchers, investments in complementary products and services are several times higher than the investment in the actual technology (Brynjolfsson et al. 2004). Prior literature has demonstrated that the embedded nature of enterprise software suggests potentially high switching costs for organization adopters once they invest in these complementary technologies (Forman 2005). In our setting, OSS technologies are commonly used as infrastructures/platforms for organizations. In such a platform environment, changes in the platform will often engender a need to change complementary software applications (Bresnahan and Greenstein 1999). Organizations that are forced to switch will also see a decline in organizational productivity when usage of existing open source systems is interrupted. For instance, such costs will be particularly

large if the organization is doing e-business that uses Apache web servers as a mission-critical part of its infrastructure; the costs of switching such mission-critical and real-time systems have historically been high (Bresnahan et al. 1996). To be clear, we do not argue that switching costs are higher for OSS than other types of software and use of OSS is particularly susceptible to “lock-in.” Indeed, evidence suggests that switching costs may be lower for OSS than for traditional proprietary software products (e.g., Varian and Shapiro (2003)). Our point is simply that such costs are nonzero, and are particularly high for organizations.

If the focal (disputed) OSS is a platform or infrastructure technology, then litigation of the focal technology will decrease the value of complementary OSS technologies (Nicholson and Snyder 1992). If an organization adopts both the focal litigated OSS technology and a set of complementary OSS technologies specific to the litigated OSS, the organization will expect substantial switching costs if they have to change the whole set of systems in the future because of the suspension of the focal litigated OSS. If a potential organizational adopter believes this could happen in the future, it may delay or avoid adopting complementary OSS technologies specific to the litigated one *ex ante*. Thus, we expect that enforcement of IP will decrease the adoption of enterprise OSS complementary to the focal project, relative to other projects.

To clarify this point, consider the adoption decisions of two types of potential OSS adopters. The first type of adopter is an enterprise who has adopted Linux and is considering whether to adopt open source ERP/CRM systems that can only run on Linux. The second adopter is an individual who has adopted Linux and is considering whether to adopt a small open source game that can only run on Linux. We argue that the enterprise in scenario 1 will be likely to delay its adoption decision for its Linux-based ERP/CRM system when there is an infringement lawsuit against Linux, simply because if the Linux cannot be used in the future then the enterprise may incur significant costs to switch to a new system. In contrast, the individual simply loses the enjoyment of using that small game.

H2: IP enforcement has a stronger negative impact on the adoption of Organization/Business OSS projects that are complementary with the focal litigated OSS than on OSS projects without such features.

Econometric Approach

The method of causal inference we use is difference-in-difference estimation (e.g., Angrist and Pischke 2008). The basic idea of difference-in-difference estimation is to examine a set of treated units before and after the treatment (in this case, an IP enforcement action). In our setting, the treated units are those OSS projects technologically similar to the litigated OSS or business-intended OSS projects that are likely to be complementary to the litigated OSS. While we are aware of other approaches to test our two hypotheses, difference-in-difference approach provides better causal inference since it introduces a control group to address any confounding unobserved factors that equally affect treatment group and control group. The regression approach to difference-in-difference also allows for regression controls. Because of these advantages, difference-in-difference estimation has been used frequently in the information systems literature as a method of causal inference, particularly in circumstances where we wish to examine how changes in the external environment influence economic agent’s behavior (see Forman et al. (2009) and Smith and Telang (2009) for examples of recent studies employing difference-in-difference). Indexing units by i and time by t , we adopt the basic form:

$$Outcome_{it} = \alpha + \delta TreatmentGroup_i + \beta_0 AfterTreatment_t + \beta TreatmentGroup_i * AfterTreatment_t + \gamma RegressionControls_{it} + \varepsilon_{it} \quad (1)$$

By plugging in zeros and ones for the binary variables in equation (1), the difference across groups in the before and after treatment is β . If β is negative, the treatment can be interpreted as having a negative effect on the outcome. Just as in a true experiment, this approach means that we can see whether behavior in the treatment group changes differently from that in the control group. $TreatmentGroup_i$ could be a vector of covariates with n dimensions suggesting we are interested in n treated groups. Correspondingly, δ and β could also be vectors with n dimensions. In our setting, we examine the before and after performance of two treatment groups – OSS that is technologically similar to the litigated technology and business OSS that is complementary to the litigated technology (i.e. $n=2$ for the vector $TreatmentGroup_i$).

We note that the parameter β_0 may also be of interest. That is, β_0 captures changes in outcomes across all subjects after the treatment. For example, in our setting, we may be interested in studying if the adoption of unrelated projects is influenced by the IP enforcement actions we study. However, β_0 may also reflect general time trends in adoption (for example, if there is seasonality in software adoption) and so in the absence of a control group it is

difficult to identify the effects of the treatment from the effects of general time trends on projects outside of our treatment groups. So we do not focus on them. In keeping with the difference-in-difference approach, our focus is on examining the implications of IP enforcement actions (the treatment) on the groups most likely to be affected by this treatment.

In the next several sections we describe the treatment, how we identify the treatment groups, our regression controls, and several additional details about our experiment.

Cases of IP Enforcement – the Treatment

In this study, we choose large, well-publicized lawsuits as cases of IP enforcement. Based on a search of major news outlets, we found six lawsuits in total and summarize them in table 1. While many papers implementing difference-in-difference estimation examine the implications of one treatment only, we choose to examine the implications of two cases of treatment to improve the internal validity of our study (i.e., by showing our results hold in multiple contexts, this provides further confidence that our results do not reflect unobserved factors influencing the outcome of the treatment group) and its external validity (to suggest that our results reflect more than the outcomes around a particular IP enforcement case). We further focus on two such cases: *SCO v. IBM* and *FireStar/DataTern v. Red Hat*. Our choice of lawsuits is guided by several factors. First, we hope to choose lawsuits viewed as economically important. These two cases have had wide news coverage and also the defendants in both cases are large commercial players investing in OSS innovation. Second, our approach requires that the open source community not be aware of the risks of litigation *ex ante* (otherwise they will have made the behavioral adjustments that we posit in advance of the IP enforcement announcement). As a result of this requirement, we do not examine any of the numerous follow-on announcements and lawsuits that followed the *SCO v. IBM* case. Last, we exclude cases for which the time between the filing of the IP enforcement action and the settlement of the case was too short to observe any significant behavioral changes. As a result of applying this set of conditions, we focus on the two cases.

Plaintiff	Defendant	Filing Date	Settlement Date	Litigated IP	Technologies in dispute
SCO	IBM	3/7/2003	N/A ²	Copyright	Linux operating system
FireStar and DataTern	Red Hat	6/26/2006	6/11/2008	Patent	A method of interfacing an object-oriented software application with a relational database
NetApp	Sun	9/5/2007	N/A	Patent	7 patents related to NetApp's WAFL and RAID technology
IP innovation	Red Hat and Novell	10/15/2007	N/A	Patent	3 US patents covering the user interface in multiple workspaces sharing display system objects
Microsoft	TomTom	2/25/2009	3/30/2009	Patent	Five patents related to car navigation technology and three for file management systems
Software Tree	Red Hat, HP, Genuitec, and Dell	3/3/2009	N/A	Patent	A System and Method for Exchanging Data and Commands Between an Object Oriented System and Relational System.

Case 1: *SCO v. IBM* (March 7, 2003)

On March 7, 2003, SCO filed a \$1 billion lawsuit against IBM. The SCO Group asserted that SCO has the ownership of Unix and all of its derivative works and some of its copyrighted Unix software was wrongly copied

² N/A means that the case has not been settled yet.

into Linux by IBM (SCO 2003). Prior to this lawsuit, both hobbyists and companies including IBM, Sun, Hewlett-Packard had been continually improving and distributing Linux. It is the dispute between SCO and IBM that brought out a broader issue about how to manage the conflicts between the traditional way of producing proprietary software guarded by strict IP laws of copyright and patent and the OSS movement that is thrived by freely sharing code and shunning the constraints of IP rights” (Lohr 2003). Therefore, the lawsuit attracted much public attention since it was the first major IP, particularly copyright, enforcement targeting OSS usage and development. Based on a Lexis-Nexis search we found that many major news outlets such as the Wall Street Journal, the San Jose Mercury News (Silicon Valley, California), the Boston Globe, the Los Angeles Times, the Daily Telegraph (Sidney, Australia), the Business Times (Singapore) all reported on this lawsuit around the filing date.

Case 2: *FireStar/DataTern v. Red Hat* (June 26, 2006)

The second major case is related to the JBoss suite of software: *FireStar/DataTern v. Red Hat*. On June 26, 2006, FireStar/DataTern filed a lawsuit asserting that Red Hat’s JBoss suite - particularly Hibernate 3.0 - infringes FireStar’s 2000 U.S. Patent No. 6,101,502. This patent details a method of interfacing an object-oriented software application with a relational database (Heubner et al. 2000). As many OSS observers noted, this lawsuit “is expected to take center stage on the legal front as SCO’s copyright claims against IBM fade” and “is potentially more significant than the SCO case because it’s about a patent that covers a basic concept or idea, not an expression of an idea, which copyright covers” (Rooney 2006).

Measures

Sample

Our primary data source is SourceForge Research Data Archive (SRDA) (Gao et al. 2007; Van Antwerp and Madey 2008), located at <http://zerlot.cse.nd.edu>, which receives monthly database snapshots from SourceForge. SourceForge is the largest repository of OSS - over 230,000 projects and over 3 million users and developers were registered at the time of our data collection (SourceForge 2009). Therefore, we believe that our empirical tests based on this large OSS website will provide strong evidence about how IP enforcement influences the OSS community. The SRDA provides more complete data sets for time-varying variables on monthly basis than on weekly basis. Therefore, in our empirical test, the unit of analysis for all time-varying variables is project-month. Also, we believe that estimation based on monthly observations can capture effects from IP enforcement actions in a more precise way than on quarterly or yearly observations.

SRDA contains information about each project’s main functionality and its intended adopters. This information includes fields such as topics, descriptions, and operating systems. All topics in SRDA are organized in a hierarchical structure. An OSS “topic” in SRDA is defined to be the domain for the set of problems addressed in the OSS. There are 18 top-level topics in total and examples include “Internet”, “Communications”, and “System.” For each top-level topic, there are several levels of sub-topics; for example, under the top-level topic “System,” there are second-level topics such as “Operating System Kernels” and “Distributed Computing” and there are some third-level topics under a given second-level topic. An OSS “description” in SRDA details the OSS project’s more specific features; for example, HomePlayer, one of the most popular projects on SourceForge, has a description that reads “HomePlayer is an extension of the FreePlayer software provided by the French Internet provider Free (www.free.fr). It adds a lot of functionality like hard-disk browsing, meteo, tv program, etc.” Therefore, we expect that the combination of “topic” and “description” will provide us with enough information to determine the treatment groups for our difference-in-difference estimation. As we mention in greater detail below, we search both the “topic” and “description” fields for the key words used to determine each treatment group. Last, we also use SRDA’s information on “operating system” for projects. An OSS “operating system” describes which platform the software can run on.

The sampling period for *SCO v. IBM* is from January 2002 to July 2003, with 14 months before *SCO v. IBM* and 5 months after. Our choice of time window was influenced by several considerations. First, the extended period helps us to control for yearly and monthly time effects, in particular seasonality that may occur in OSS adoption and use. Second, we choose 5 months after the lawsuit because there was another case filed in August 2003, *Red Hat v. SCO*, that may shift potential adopters’ priors about the potential costs of OSS use and so will shape how the treatment

group responds to the treatment. (On August 4 2003, Red Hat, a major Linux distributor, filed a lawsuit against SCO, asserting that it was making “unfair, untrue and deceptive claims that Red Hat’s version of the open-source system contains code stolen from SCO” (Takahashi 2003).) The sampling period for *FireStar/DataTern v. Red Hat* is from July 2005 to November 2006, with 12 months before *FireStar/DataTern v. Red Hat* and 5 months after. Because of constraints associated with our data source, we are not able to get data before July 2005. Also, we believe the window size of 5 months for *SCO v. IBM* and *FireStar/DataTern v. Red Hat* is long enough for us to capture the after-IP-enforcement reactions from the OSS community.

However, as noted by Hahn et al. (2008) and Rainer and Gale (2005), many registered OSS projects on SourceForge are “impulse” projects in the sense that they are established just for, say, students’ final projects or developers’ experimentation. The quality of these projects is relatively low and they are rarely adopted under the mechanisms we are interested in. Adoption of such projects is unlikely to be affected by IP enforcement actions and they are likely to simply add noise to our data. To mitigate this problem and only focus on active projects, we construct a baseline sample composed of projects that have positive downloads for each month during the sampling period. This rule results in a panel of 3,928 OSS projects over 19 months for *SCO v. IBM* and a panel of 24,301 projects over 17 months for *FireStar/DataTern v. Red Hat*.

Even retaining projects with positive downloads in each month, there exists substantial variation in the installed base of OSS projects on SourceForge. Adopters may have fundamentally different reactions toward OSS projects depending upon the size of the installed base. For example, OSS projects with a large installed base will generate greater monopoly returns to the IP rights holder if it wins at trial (Somaya 2003). Thus, OSS projects with a large installed base may provide a more inviting target to IP rights holders and subsequently exhibit greater litigation risks to adopters. Therefore, it is worth investigating whether our empirical results are driven by the change in adoption for all OSS projects or just driven by the change in adoption for OSS projects with the largest installed base. For this purpose, we construct an alternative sample which excludes OSS projects with the top 5% preexisting installed base³ from the baseline sample. This alternative sampling strategy leads to a panel of 3,730 OSS projects over 19 months for *SCO v. IBM* and a panel of 23,089 projects over 17 months for *FireStar/DataTern v. Red Hat*.⁴

Variables

Dependent Variable

As noted above, our interest is in identifying the effects of IP enforcement actions on the costs of OSS adoption. We follow prior literature in using downloads as a market-based measure of popularity and use (e.g. Crowston et al. (2003); Grewal et al. (2006)). As Grewal et al. (2006) note, when software projects are freely available, researchers have in the past used downloads as proxy for sales (e.g., Chandrashekar et al. (1999)). Monthly downloads may deviate from adoption, however. Some potential users may download OSS without using it. Further, downloads are sometime created by OSS hobbyists who are interested in looking at the source code instead of by adopters. While we acknowledge these concerns, we note there are several reasons why they may be less important to inference in our setting. First, in contrast to some prior work on open source project success that focuses on cross-project variance in project success due to things like license choice, our focus is on within-project variance over time due to IP enforcement actions. As we describe in further detail below, we include a complete set of project fixed effects to address average differences in the number of downloads across projects. We treat deviance of downloads from adoption as an error in our dependent variable that can be addressed through our use of robust standard errors (Wooldridge 2002), and will affect consistency of our parameter estimates only if this deviance changes systematically over time in a way that is correlated with our treatment. We further note that these alternative motives for downloads also reflect user perceptions of the costs and benefits of OSS use. So, even if these alternative

³ We will describe in details about how we measure preexisting installed base in the section of “control variables.”

⁴ To mitigate any concern about the way we construct the baseline sample (i.e. projects that have positive downloads for every month), we have constructed another alternative sample based on projects that have positive downloads for at least one month in the sampling period. However, this set includes many inactive projects. We keep only projects with top 50% preexisting installed base from this set of projects. The results from this alternative sample are qualitatively similar.

motivations influence the relationship between IP enforcement and downloads in our treatment group their influence would not be inconsistent with our underlying hypotheses: that IP enforcement influences the costs of OSS use. (For example, if the expected costs of OSS use increase, then we might expect fewer developers would be interested in downloading it as well.)⁵

Independent Variables

IP enforcement. We operationalize it to be a dummy variable labeled *lawsuit* indicating whether an IP infringement lawsuit has been filed. For *SCO v. IBM*, it is equal to 0 if the observations are from January 2002 to February 2003 and is equal to 1 if the observations are from March 2003 to July 2003. For *FireStar/DataTern v. Red Hat*, it is equal to 0 if the observations are from July 2005 to June 2006 and equal to 1 if the observations are from July 2006 to November 2006. As we described in details below, we also create a dummy *false_lawsuit* for use in our falsification tests: we set it to be 1 if the observation is from three months before the actual filing date of lawsuit and 0 otherwise.

Similarity between OSS and the Focal Litigated Technology. This variable indicates whether the OSS project is similar to the focal litigated technology.

For *SCO v. IBM*, SCO asserted that IBM was misappropriating and wrongly incorporating its copyrighted Unix code into Linux (SCO 2003). Therefore, the focal litigated technology in *SCO v. IBM* is the Linux operating system. The central part of the Linux operating system is called the Linux kernel, whose role is to give the programs access to resources such as hard disk storage and random access memory. (Hertel et al. 2003). Although a variety of distributors such as IBM and Red Hat integrate the Linux kernel into their own products to provide enhanced functions, the Linux kernel is an essential part for any type of Linux distribution and contains the infringing code targeted by SCO. As noted by Al Gillen, vice president of system software research at IDC in Framingham, Mass, “SCO feels that the offending code is now so interspersed with the 2.4 and 2.5 [Linux] kernels, that it will be impossible to effectively remove it. They believe the only way for it to be rectified is to go back to the 2.2 kernel and start all over again from there, and that is never going to happen” (McMillan and Scannell 2003). Thus, we believe Linux kernel projects available on SourceForge will have the highest likelihood of sharing similar technological features with the litigated technology (i.e. Linux distributed by IBM). To identify Linux kernel projects, we search “topic” field in SRDA for the key word “Linux” and “kernel.” One set that largely satisfies this criterion consists of projects with the topic called “Linux” under a higher level topic called “Operating System Kernels” (i.e. “Linux” projects within the set of “Operating System Kernels” projects). We create a dummy variable “*Linux_kernel*” that is equal to 1 if the project’s topic is in this set and 0 otherwise. Examples of projects for which “*Linux_kernel*” is equal to 1 include the project titled “TinyLinux” with the description “TinyLinux is a small Linux Distribution for i386 derived from SuSE 6.4...”

For *FireStar/DataTern v. Red Hat*, FireStar had filed a claim against Red Hat for an alleged patent infringement and the disputed patent (No. 6,101,502) describes a method of interfacing an object-oriented software application with a relational database. More specifically, in this lawsuit, the focal litigated technology is Red Hat’s JBoss suite – particularly Hibernate 3.0’s object-relational mapping technology, which concerns a model for “employing a relational database with object oriented software” (Sanders 2006). As a result, our goal is to find OSS projects from SRDA that also provide object-relational mapping technology. So we search the “description” field of all OSS projects from SRDA for key words “object relational mapping.” Then we create a dummy variable “*object_relational*”: if the project’s “description” field includes these key words, we set the dummy variable “*object_relational*” to be 1; otherwise we set it to be 0. Examples of projects for which “*object_relational*” is equal to 1 include “JGrinder Object/Relational Mapping” whose description field notes that “JGrinder is largely an Object to Relational mapping solution for providing Java persistence. It has been used for high volume, high availability solutions.”

To summarize, we operationalize *Similarity between OSS and the Focal Litigated Technology* to be a dummy variable called “*Linux_kernel*” for *SCO v. IBM* and operationalize it to be a dummy variable called “*object_relational*” for *FireStar/DataTern v. Red Hat*.

⁵ We note that we do not distinguish between adopters who are first-time adopters of OSS and those who are existing users who are adopting a new version that may be available. We believe that the mechanism we describe will influence adoption by both of these groups.

Complementarity between Organization/Business OSS and the Focal Litigated Technology. This variable indicates whether the focal OSS project is complementary to the litigated technology and whether it is used primarily by firms.

For *SCO v. IBM*, the technology in dispute (e.g. Linux) is essential to applications running exclusively on the Linux operating system. That is to say, since the unavailability of the Linux operating system would significantly decrease the value of organizational applications running on Linux, we expect a strong complementarity between the Linux operating system and organizational applications that run exclusively on Linux. We utilize a two-step method to identify the treatment group. The first step is to identify the set of all types of OSS projects primarily intended for use by firms⁶: we search “description” field of all OSS projects and identify projects including the key words “enterprise”, “business”, “company”, “ERP”, and “CRM.” We also searched the “topic” field of OSS and use this to identify topics with the key word “point-of-sale” as enterprise applications. Second, each OSS project from SRDA also provides a field called “operating system” that details the platforms on which a project can run. We identify the set of projects can only run on Linux based on this field. Our treated group called “*business_app_on_Linux*” is composed of projects that lie at the intersection of the sets created by these two steps. That is, for projects that lie within this intersection, we set the value of a dummy variable “*business_app_on_Linux*” to be 1; otherwise we set it to be 0. One example with “*business_app_on_Linux*” equal to 1 is “gShop” which can only run on Linux and has description field that states “gShop is a complete point of sale application that can be customized to suit most types of businesses.”

For *FireStar/DataTern v. Red Hat*, we use the litigated technology’s existence as part of Red Hat’s JBoss suite to identify the treatment group. We expect a strong complementarity between the JBoss suite and applications developed especially for running on JBoss to enhance JBoss’s functionality. Therefore, to identify the set of projects complementary to JBoss, we search the “description” field of all OSS projects from SRDA for keyword “JBoss.” After reading each project’s description carefully we believe the intended audience for all these projects are business adopters. Accordingly, we create a dummy variable “*JBoss_related*”: for projects from the set of JBoss-related projects, we set the variable “*JBoss_related*” to be 1; otherwise we set it to be 0. One example with “*JBoss_related*” equal to 1 is “Redpos” which has description field showing “A simple and rock solid Point Of Sale (POS) application. The POS is based on the JBoss MicroKernel, has a flexible graphical interface and can easily be connected to different backoffice/ERP systems. Its functionality can be extended during runtime.”

In short, we operationalize *Complementarity between Organization/Business OSS and the Focal Litigated Technology* to be a dummy variable called “*business_app_on_Linux*” for *SCO v. IBM* and operationalize it to be a dummy variable called “*JBoss_related*” for *FireStar/DataTern v. Red Hat*.

Control Variables

Preexisting Installed Base. As noted above, adopters’ reaction to IP enforcement may differ with the installed base of the project. To control for these effects, we measure each project’s preexisting installed base using the log transformation of its accumulated downloads on SourceForge two months before the start of the sample period.⁷ We create a dummy variable *large base*. According to the distribution of the preexisting installed base, we set the value of *large base* to be 1 if a project’s preexisting installed base is above the median and set it to be 0 otherwise.

Time-varying controls. As we note below, we employ project fixed effects to control for cross-sectional differences in the average number of downloads across projects. However, we are aware that treated projects that are receiving the treatment may be correlated with some other omitted factors that may be associated with changes in downloads over time. One such omitted variable could be the time-varying improvements in the quality of the software. For example, the newly released versions for a project in each month may be an important factor affecting that project’s monthly downloads. To address this concern, we add the number of new versions released every month (denoted as *new_files*) as a time-varying control for *FireStar/DataTern v. Red Hat* case. Unfortunately, the data on number of *new_files* for the sample period defined by the *SCO v. IBM* case is unavailable to us. Therefore, we follow Grewal et

⁶ We have tried different searches based on some other related definitions for the set of OSS projects used within firms, and all these approaches have yielded qualitatively similar results.

⁷ The reason for us to use log transformation is that the accumulative downloads two months before the sampling period are highly skewed.

al. (2006) in using an alternative measure – monthly concurrent versions systems commits (denoted as *cvs_commits*) – as an indicator of successful technical refinements in each month, since a “commit occurs when a developer uploads the altered source code file, which reflects meaningful contributions to the source code” (Grewal et al. 2006). The summary statistics for both samples are shown as below.

Table 2. Summary Statistics (Baseline Samples)					
	Mean	Std Dev.	Min	Max	Observations
<i>SCO v. IBM – Project-month-level variables</i>					
<i>downloads</i> ⁸	1927.211	16776.250	1	1120505	74632
$\log(\text{downloads})$	4.916	2.045	0	13.929	74632
<i>cvs_commits</i>	25.811	118.478	0	5169	74632
<i>SCO v. IBM – Project-level variables</i>					
<i>Linux_kernel</i>	.017	.128	0	1	3928
<i>business_app_on_Linux</i>	.004	.066	0	1	3928
<i>preexisting installed base</i>	6.762	2.786	0	15.140	3928
<i>FireStar/DataTern v. Red Hat – Project-month-level variables</i>					
<i>downloads</i>	1672.329	45668	1	8447172	413117
$\log(\text{downloads})$	4.100	1.924	0	15.949	413117
<i>new_files</i>	.304	3.720	0	775	413117
<i>FireStar/DataTern v. Red Hat – Project-level variables</i>					
<i>object_relational</i>	.002	.042	0	1	24301
<i>JBoss_related</i>	.001	.037	0	1	24301
<i>preexisting installed base</i>	7.099	2.108	.690	18.420	24301

Empirical Models and Results

Full Sample Analyses and Results

To test our two hypotheses, we update equation (1) using the treatment, treatment groups, and regression controls defined above.⁹ We tested the impacts of the two cases of IP enforcement (*SCO v. IBM* and *FireStar/DataTern v. Red Hat*) in separate analyses for two reasons. First, because of data constraints, we have missing observations for several months between 2003 (when the *SCO v. IBM* case was filed) and 2006 (when the *FireStar/DataTern v. Red Hat* case was filed). Thus, it is difficult to combine the two samples and jointly test the impacts of the two cases using one empirical model. Further, modeling the tests of the implications of the IP enforcement actions separately allows for additional flexibility in how each of our independent variables influence downloads. That is, our estimation strategy does not impose constraints on how variables like *large_base*, *new_files*, and *cvs_commits* influence downloads. As mentioned earlier, our purpose in investigating impacts of the two cases is to show that our results are robust to different contexts (internal validity) and that the proposed hypotheses are generalizable across different settings (external validity). The main specifications are as follows.

$$\text{SCO v. IBM: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{lawsuit}_t + \beta_1 \text{lawsuit}_t * \text{Linux_kernel}_i + \beta_2 \text{lawsuit}_t * \text{business_app_on_Linux}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{cvs_commits}_{it} + \gamma_3 \text{year2003}_t + \gamma_4 \text{month-of-year}_t + v_i + \varepsilon_{it} \quad (2)$$

⁸ As shown in this table, downloads are highly skewed, so we use $\log(\text{downloads})$ as dependent variable in the following empirical models.

⁹ We also tried to test each hypothesis separately (i.e. impacts on each treated group) and the results are qualitatively similar. Because of the limited space, we only present the empirical specifications testing H1 and H2 together.

$$\text{FireStar/DataTern v. Red Hat: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{ lawsuit}_t + \beta_1 \text{ lawsuit}_t * \text{object_relational}_i + \beta_2 \text{ lawsuit}_t * \text{JBoss_related}_i + \gamma_1 \text{ large_base}_{it} + \gamma_2 \text{ new_files}_{it} + v_i + \varepsilon_{it} \quad (3)$$

There are several things to note about equations (2) and (3). First, to control for differences in adoption propensities across OSS projects, we employ fixed effects models in all of our analyses (e.g., Wooldridge (2002)); these fixed effects will control for time-invariant differences (i.e. v_i) in the average number of downloads across projects. Second, for *SCO v. IBM*, we include a year dummy (i.e. *year2003*) and month-of-year dummies (i.e., February, ..., December) to control for time and seasonality trends in adoption. For *FireStar/DataTern v. Red Hat*, we do not include these time effects because of constraints associated with our data source.¹⁰ However, in robustness checks for both equations (2) and (3), we employ month dummies that incorporate both year and month (e.g., February 2002, March 2002, ..., July 2003 for *SCO v. IBM*; August 2005, September 2005, ..., November 2006 for *FireStar/DataTern v. Red Hat*); these models will allow us to better control for unobserved time-varying factors in both models but in them we are unable to identify the parameter β_0 as it is perfectly collinear with these month dummies. Third, we use the log transformation of downloads as the dependent variable, because the distribution of downloads is highly skewed. Fourth, *large_base_{it}* is a control for project's preexisting installed base that may affect changes in downloads over time. We set it to zero before the IP enforcement lawsuits so that it is not differenced out of the regression (Forman et al. 2010). Fifth, we do not include the direct effects of the variables *Linux_kernel_i*, *business_app_on_Linux_i*, *object_relational_i*, and *JBoss_related_i* as they will be absorbed in our fixed effects.

Our interest is examining whether $\beta_1 < 0$ (H1) and $\beta_2 < 0$ (H2) for both specification (2) and (3). As mentioned before, the parameter β_0 may also be of interest: to the extent that lawsuits may potentially shift all OSS users expectations about the risks of OSS use (not only the treatment groups we have identified), this parameter captures changes in the average number of downloads across all projects after a lawsuit. We do not focus on it, however, as it may also reflect general time trends in the attractiveness of OSS.

The estimated coefficients for specification (2) and (3) are shown in column (1) in table 4 and column (1) in table 5. First, the estimated β_1 is significantly negative for both cases, together confirming H1. More specifically, in the months following the filing of *SCO v. IBM*, Linux kernel projects had a 14% greater decline than projects in the control group; in the same manner, in the months following the filing of *FireStar/DataTern v. Red Hat*, projects about the mapping method between an object model and a relational database were faced with an 11% greater decline relative to projects in the control group. Second, the estimated β_2 is also significantly negative for both cases, together confirming H2. In the months following the filing of *SCO v. IBM*, OSS projects that were intended primarily for business organizations and that run exclusively on Linux were associated with a 37% greater decline relative to projects in the control group; also, in the months following the filing of *FireStar/DataTern v. Red Hat*, OSS projects complementary to JBoss suite were faced with a 16% greater decline than the control group.

To further mitigate any concerns about time-varying omitted variables bias, we conduct a series of robustness tests. First, as noted above, we use another (larger) set of month dummies to control for any time-varying factors that may influence downloads (i.e. we use such 18 month dummies as February 2002, March 2002, ..., July 2003 for *SCO v. IBM*; we use such 16 month dummies as August 2005, September 2005, ..., November 2006 for *FireStar/DataTern v. Red Hat*), as shown in the following specification (4) and (5). As noted above, the drawback of this strategy is that the direct effect of lawsuit is absorbed into these dummies and thus β_0 in specification (4) and (5) is dropped. The results are shown in column (2) in table 4 and table 5. We can see all the estimated coefficients (and implied marginal effects) are similar to those from the main specification.

$$\text{SCO v. IBM: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{ lawsuit}_t + \beta_1 \text{ lawsuit}_t * \text{Linux_kernel}_i + \beta_2 \text{ lawsuit}_t * \text{business_app_on_Linux}_i + \gamma_1 \text{ large_base}_{it} + \gamma_2 \text{ cvs_commits}_{it} + \gamma_3 \text{ month}_t + v_i + \varepsilon_{it} \quad (4)$$

$$\text{FireStar/DataTern v. Red Hat: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{ lawsuit}_t + \beta_1 \text{ lawsuit}_t * \text{object_relational}_i + \beta_2 \text{ lawsuit}_t * \text{JBoss_related}_i + \gamma_1 \text{ large_base}_{it} + \gamma_2 \text{ new_files}_{it} + \gamma_3 \text{ month}_t + v_i + \varepsilon_{it} \quad (5)$$

Our second robustness check is implementing a falsification test to provide further evidence that our results do not reflect the presence of unobserved factors that may be correlated with lawsuit and the treated groups. We create a dummy *false_lawsuit*; we set it to be 1 if the observation is from three months before the actual filing date of lawsuit and set it to be 0 otherwise. More specific forms for this falsification test are shown as follows.

¹⁰ Specifically, our sample is from July 2005 to November 2006. Year dummies and month-of-year dummies are collinear with *lawsuit*.

SCO v. IBM: $\log(\text{downloads})_{it} = \alpha + \beta_0 \text{lawsuit}_t + \beta_1 \text{lawsuit}_t * \text{Linux_kernel}_i + \beta_2 \text{lawsuit}_t * \text{business_app_on_Linux}_i + \rho \text{false_lawsuit}_t * \text{Linux_kernel}_i + \phi \text{false_lawsuit}_t * \text{business_app_on_Linux}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{cvs_commits}_{it} + \gamma_3 \text{year2003}_t + \gamma_4 \text{month-of-year}_t + v_i + \varepsilon_{it}$ (6)

FireStar/DataTern v. Red Hat: $\log(\text{downloads})_{it} = \alpha + \beta_0 \text{lawsuit}_t + \beta_1 \text{lawsuit}_t * \text{object_relational}_i + \beta_2 \text{lawsuit}_t * \text{JBoss_related}_i + \rho \text{false_lawsuit}_t * \text{object_relational}_i + \phi \text{false_lawsuit}_t * \text{JBoss_related}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{new_files}_{it} + v_i + \varepsilon_{it}$ (7)

Dependent variable:	Baseline Sample			Alternative Sample		
	Main Specification	Robustness Check	Falsification Test	Main Specification	Robustness Check	Falsification Test
log (downloads)	(1)	(2)	(3)	(4)	(5)	(6)
lawsuit	-.593 (.017)***		-.592 (.017)***	-.595 (.017)***		-.594 (.017)***
lawsuit · Linux kernel	-.152 (.064)*	-.152 (.055)**	-.120 (.065)+	-.165 (.066)*	-.166 (.060)**	-.133 (.067)*
lawsuit · business_app_on_Linux	-.457 (.102)***	-.457 (.099)***	-.500 (.103)***	-.454 (.102)***	-.454 (.097)***	-.496 (.103)***
false_lawsuit · Linux kernel			.150 (.044)***			.152 (.046)***
false_lawsuit · business_app_on_Linux			-.198 (.096)*			-.197 (.096)*
Controls	Project, Month, Year	Project, Month	Project, Month, Year	Project, Month, Year	Project, Month	Project, Month, Year
Time-varying controls	cvs commits	cvs commits	cvs commits	cvs commits	cvs commits	cvs commits
Other controls	large base	large base	large base	large base	large base	large base
Number of groups	3928	3928	3928	3730	3730	3730
Number of observations	74632	74632	74632	70870	70870	70870
R square	.872	.878	.872	.843	.852	.843

Notes: 1) +: significant at 10%; *: significant at 5%; **: significant at 1%; ***: significant at 0.1%; 2) Robust standard errors are in parentheses; 3) alternative sample is the baseline sample excluding projects with top 5% preexisting installed base; 4) R-squared includes fixed effects in R-squared computation.

Falsification tests of this nature are commonly employed in difference-in-difference estimation (e.g. Bertrand et al. (2004)). The logic for this falsification test is that if the estimates are reflecting changes in the time-trend of downloads instead of reflecting the influence of the effects of the lawsuit, then adding the interaction of *false lawsuit* and the treatment group would also pick up some of this time trend. Our interest here is examining whether $\beta_1 < 0$ and $\beta_2 < 0$ as well as the estimates of ρ and ϕ .

The results are presented in the column (3) in table 4 and table 5. The estimated β_1 and β_2 again confirm our hypotheses. The estimates of ρ and ϕ are largely consistent with our assertion that our results reflect a causal relationship between IP enforcement actions and downloads for the treated projects, rather than omitted time-varying factors. The estimated ρ is insignificant for *FireStar/DataTern v. Red Hat* and even becomes positively significant for *SCO v. IBM* which suggests Linux kernel projects are even associated with an increase in downloads over the months preceding the lawsuit. Further, the estimated ϕ is significantly positive at the 10% level for the

FireStar/DataTern v. Red Hat case. While the estimated ϕ is significantly negative at the 5% level for the *SCO v. IBM* case, a comparison of their magnitudes still shows the decline of downloads following the lawsuit is much greater than that preceding the lawsuit. These results suggest organization-intended projects that need to run exclusively on Linux had experienced a decline in downloads preceding the lawsuit, but their declines become 21% greater following the *SCO v. IBM* case. We implement the same testing procedures for H1 and H2 by the alternative sample which excludes OSS projects with the top 5% preexisting installed base from the baseline sample. As shown in the column (4), column (5), and column (6) in both table 4 and table 5, the results remain consistent with the baseline sample, suggesting that our results are driven by the change in downloads for all OSS projects rather than driven by the change in downloads for OSS projects with the largest installed base.

Dependent variable:	Baseline Sample			Alternative Sample		
	Main Specification	Robustness Check	Falsification Test	Main Specification	Robustness Check	Falsification Test
log (downloads)	(1)	(2)	(3)	(4)	(5)	(6)
lawsuit	.213 (.003)***		.213 (.003)***	.221 (.003)***		.221 (.003)***
lawsuit · Object-Relational	-.119 (.047)**	-.119 (.047)**	-.101 (.050)*	-.109 (.049)*	-.109 (.048)*	-.090 (.051)+
lawsuit · JBoss	-.178 (.056)***	-.178 (.055)***	-.150 (.058)**	-.187 (.059)***	-.189 (.058)***	-.155 (.061)**
false_lawsuit · Object-Relational			.072 (.065)			.077 (.066)
false_lawsuit · JBoss			.113 (.062)+			.128 (.065)*
Controls	Project	Project, Month	Project	Project	Project, Month	Project
Time-varying controls	new files	new files	new files	new files	new files	new files
Other controls	large base	large base	large base	large base	large base	large base
Number of groups	24301	24301	24301	23089	23089	23089
Number of observations	413117	413117	413117	392513	392513	392513
R square	.902	.910	.902	.867	.878	.877

Notes: 1) +: significant at 10%; *: significant at 5%; **: significant at 1%; ***: significant at 0.1%; 2) Robust standard errors are in parentheses; 3) alternative sample is the baseline sample excluding projects with top 5% preexisting installed base; 4) R-squared includes fixed effects in R-squared computation.

Subsample Analyses and Results

A key requirement in our difference in difference approach is that unmeasured factors affect the treatment group and control group equally in our regressions. In our analyses above, we attempt to improve confidence that our results do not reflect the impact of time-varying unmeasured factors through the addition of time-varying controls and through our falsification tests. In this section we attempt to further improve confidence in our results through a set of

subsample analyses in which we provide a more precisely matched control group for the treatment group used to test H2.¹¹

A particular concern in our test of H2 is that since organization adopters are a special group of adopters, as suggested by the TOE framework (e.g. Tornatzky and Fleischer (1990)), a variety of factors such as technological context and organizational context, together with other environmental factors, may influence an organization's decision to adopt OSS. Consequently, a potential concern with our baseline strategy of testing H2 is that the estimate of β_2 is actually reflecting a negative time trend for downloads by organizational adopters instead of reflecting the impact of the infringement lawsuits. Further, one potentially alternative hypothesis is that IP enforcement may actually have stronger impact on organization adoption of all types of OSS instead of only on organization adoption of OSS that is complementary to the infringing technology. More broadly, the small fraction of treated groups in some of our analyses raise questions about the appropriateness of our control groups. If the time trend of downloads for our control group differs significantly from that of treatment group, this may create problems for our inference.

To address these concerns, we compile new set of narrower control groups in our tests of H2 for both our cases. For *SCO v. IBM*, we identify the new control group as the set of projects that are intended for organization users and can run on operating systems other than Linux whereas the corresponding treatment group is composed of projects that are intended for organization users but can only run on Linux operating systems. For *FireStar/DataTern v. Red Hat*, we construct another control group composed of projects having "J2EE" but not having "JBoss" in their description fields. That is, this control group is composed of projects that are related to Java Platform, Enterprise Edition (i.e. J2EE), but not related to JBoss whereas the corresponding treatment group is composed of projects that are related to J2EE and are directly related to JBoss. We believe that these control groups are more closely matched to the treatment groups, so that without any infringement lawsuit, the treatment group should exhibit the same pattern of change in downloads over time as this matched control group. The main specifications (8) and (9) are shown as follows. As in the full sample analyses, we have also tried robustness tests based on specifications using the set of month dummies to control for any time-varying factors (i.e. specifications (10) and (11) as shown below).

$$\text{SCO v. IBM: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{lawsuit}_t + \theta \text{lawsuit}_t^* \text{business_app_on_Linux}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{cvs_commits}_{it} + \gamma_3 \text{year2003}_t + \gamma_4 \text{month-of-year}_t + v_i + \varepsilon_{it} \quad (8)$$

$$\text{FireStar/DataTern v. Red Hat: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{lawsuit}_t + \theta \text{lawsuit}_t^* \text{JBoss_related}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{new_files}_{it} + v_i + \varepsilon_{it} \quad (9)$$

$$\text{SCO v. IBM: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{lawsuit}_t + \theta \text{lawsuit}_t^* \text{business_app_on_Linux}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{cvs_commits}_{it} + \gamma_3 \text{month}_t + v_i + \varepsilon_{it} \quad (10)$$

$$\text{FireStar/DataTern v. Red Hat: } \log(\text{downloads}_{it}) = \alpha + \beta_0 \text{lawsuit}_t + \theta \text{lawsuit}_t^* \text{JBoss_related}_i + \gamma_1 \text{large_base}_{it} + \gamma_2 \text{new_files}_{it} + \gamma_3 \text{month}_t + v_i + \varepsilon_{it} \quad (11)$$

Our interest is examining whether $\theta < 0$. The results for specification (8) are shown in column (1) in table 6 and the results for specification (9) are shown in column (3). The estimated θ for both cases is significantly negative, together confirming H2. More specifically, in the months following the filing of *SCO v. IBM*, projects that are intended for organization users but can only run on Linux operating systems were associated with a 30% greater decline than organization-intended projects that can run on other operating systems. Also, in the months following the filing of *FireStar/DataTern v. Red Hat*, projects directly related to JBoss had 12% greater decline than other J2EE-related projects. Meanwhile, as shown in column (2) and column (4) in table 6, all of the estimated coefficients (and implied marginal effects) based on the specifications (10) and (11) are similar to those from the main specifications (8) and (9).

Conclusions

We build on prior studies that have evaluated factors affecting the success of OSS adoption and highlight IP enforcement as one important environmental factor in influencing OSS adoption. The focus of our study is to investigate how IP enforcement actions influence the adoption of related OSS projects based on data extracted from

¹¹ Unfortunately, due to the nature of the treatment group for H1, it is very difficult to similarly find a more precisely matched control group for our treatment of projects with similar technology to the litigated project.

SourceForge. First, we hypothesize that IP enforcement would have a negative impact on the adoption of OSS sharing similar technological features with the litigated technology, arguing that adopters of this group of OSS would face higher expected litigation costs as well as switching costs. Second, we hypothesize that adoption of OSS that caters to firms and that is complementary to the litigated technology would also experience a decline, positing that adopters of this software would face higher expected switching costs. To test these hypotheses, we examine the implications of two widely known IP enforcement actions – *SCO v. IBM* and *FireStar/DataTern v. Red Hat* – on downloads of OSS. Our empirical evidence strongly supports our hypotheses. In the months following *SCO v. IBM*, Linux kernel projects had 14% greater decline and projects intended for business and running exclusively on Linux had 37% greater decline than projects in the control group; also, in the months following *FireStar/DataTern v. Red Hat*, projects related to the object relational mapping technology had a 11% greater decline and projects complementary to JBoss suite had 16% greater decline. To address concerns about time-varying omitted variables, we conduct a series of robustness checks and subsample analyses, all of which have yielded similar results.

This study provides several insights to policy makers and practitioners. First, confirming a large body of anecdotal evidence, we highlight the negative impact of IP enforcement on the diffusion and success of open source. We find that this impact is not only statistically significant, but is also economically large. Moreover, our research confirms the social costs of IP protection and in particular underscores that potential costs of increasing use of patents in the software industry. Third, our results demonstrate potential costs of OSS use for organizations. This suggests the need for organizations to be cautious about the legal aspects of using OSS; it also suggests that warranties or indemnification programs offered by commercial OSS vendors may have significant value for users.

	<i>SCO v. IBM</i>		<i>FireStar/DataTern v. Red Hat</i>	
Dependent variable:	Main Specification	Robustness Check	Main Specification	Robustness Check
log (downloads)	(1)	(2)	(3)	(4)
lawsuit	-.588 (.119)***		.133 (.042)**	
lawsuit · business_app_on_Linux	-.365 (.125)**	-.365 (.121)**		
lawsuit · JBoss			-.127 (.061)*	-.127 (.060)*
Controls	Project, Month, Year	Project, Month	Project	Project, Month
Time-varying controls	cvs commits	cvs commits	new files	new files
Other controls	large base	large base	large base	large base
Number of groups	93	93	168	168
Number of observations	1767	1767	2856	2856
R square (within)	.852	.863	.919	.925

Notes: 1) +: significant at 10%; *: significant at 5%; **: significant at 1%; ***: significant at 0.1%; 2) Robust standard errors are in parentheses 3) R-squared includes fixed effects in R-squared computation.

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