Research Policy 42 (2013) 895–913

Contents lists available at SciVerse ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Private–collective innovation, competition, and firms' counterintuitive appropriation strategies

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ARTICLE INFO

Article history:
Received 20 September 2011
Received in revised form 7 January 2013
Accepted 7 January 2013
Available online 8 February 2013

Keywords:
Private–collective innovation
Exclusion rights
Competition
Interfirm coordination
Industry self-regulation
Open source software

ABSTRACT

We extend theory on private–collective innovation by studying the role of exclusion rights for technology in the competition between private–collective and other innovators. We argue that private–collective innovators both pledge their own and invest in orphan exclusion rights for technology as a subtle coordination mechanism to compete against firms proposing alternative proprietary solutions. We discuss implications of our findings for theories of innovation, particularly appropriation strategy, ownership and control, and coordination and industry self-regulation.

Prologue:

> *On August 2, 2004, the independent insurance company Open Source Risk Management (OSRM) published a report suggesting that Linux was infringing on as many as 283 different patents, dozens of which belonged to the Microsoft corporation. On October 12, 2004, U.S. software giant Novell announced that it would not enforce any of its patents against Linux or the Open Source Software (OSS) community more broadly. On November 12, 2004, the firm acquired 39 patents crucial to Internet commerce and Web services in an auction for $15.5 m (an acquisition that was conducted in disguise through a subsidiary called JGR Acquisition). Shortly thereafter, Novell officially donated these newly acquired patents to the open source community.*

1. Introduction

Established management theory suggests that a firm's performance increases as the firm creates and captures more value, all else being equal (from Penrose, 1959 to MacDonald and Ryall, 2004). Another fundamental conjecture is that private property rights over resources are a means for firms to capture value through appropriation (Demsetz, 1967; Grossman and Hart, 1986; Pfeffer and Salancik, 1978). Finally, in high-technology industries, patents are important property rights firms can possess that allow the excluding of competitors from gaining access to rare resources and guarantee freedom to operate (Hall and Ziedonis, 2001). So, why would a profit-maximizing firm waive (parts of) the exclusion rights it owns—particularly if those rights protect a rare and valuable resource from imitation? (Dierickx and Cool, 1989). And, even more puzzling, why would a firm continue to purchase further exclusion rights protecting such resources, only to waive them again after acquisition, as in the introductory example? Basic management theory fails to explain the logic behind the public pledges of certain firms—among them IBM, Novell, and Nokia—not to assert their exclusion rights against anyone who infringes on them while developing or adopting open source software (OSS). More advanced theory on the use of exclusion rights could rationalize the pledges if the patent waivers created positive externalities for the right-holders that outweigh the opportunity costs of not excluding third parties (Peitz, 2004; Varian and Shapiro, 1999). Known examples of such instances include DuPont's waiver on the onco mouse patent (Murray et al., 2009) to stimulate upstream research and development (R&D) for related product applications, and Intel's way of resolving constraints for other firms to develop technologies that are complementary to its own (Ethiraj, 2007). However, neither basic nor advanced theory can easily explain the above behavior *in the absence of such externalities*. Moreover,

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http://dx.doi.org/10.1016/j.respol.2013.01.004

extant theory cannot reconcile such pledges, on the one hand, with the continued purchasing behavior, on the other.

In this paper, we suggest an explanation for why firms may both pledge and invest in exclusion rights for technology. Our argument extends the theory on private–collective (hereafter also abbreviated 'p–c') innovation more broadly (von Hippel and von Krogh, 2003). The p–c innovation model theorizes about why firms have incentives to contribute privately to the production of public goods that exceed the firms' benefits of free-riding; examples of such p–c innovation include OSS (Fosfuri et al., 2008), pharmaceuticals (Perkmann, 2009), biotechnology (Henkel and Maurer, 2009), and agriculture (Kloppenburg, 2010). Moreover, science in itself shares traits of p–c innovation (see Dasgupta and David, 1987; Stephan, 1996; von Hippel and von Krogh, 2003). Within this theory we focus on the role that exclusion rights play in the hitherto unexplored *competition* (as noted, e.g., by Lerner and Tirole, 2005) between p–c innovators—firms participating in p–c innovation and implementing it in their products—and innovators that draw on proprietary resources but compete in the same product markets as the aforementioned firms (hereafter called similar proprietary innovators). We propose, somewhat counterintuitively, that private–collectively innovating firms facing competition from proprietary innovators are willing to give up control over exclusion rights, just to capture more value from innovation eventually.[2] This rather unorthodox approach becomes the rational strategic choice for these innovators exactly when residual exclusion rights held by competitive proprietary innovators cover part of the good and threaten to foreclose p–c innovators from accessing it. In this situation, well known from other domains of cumulative and overlapping innovation (Green and Scotchmer, 1995), the public pledging of exclusion rights serves two purposes for p–c innovators. First, just like forming R&D consortia (e.g., Sakakibara, 2002) or patent pools (e.g., Joshi and Nerkar, 2011), pledging not to assert patents can trigger corporate collective reciprocal action (Barnett and King, 2008; Ingram and Inman, 1996) among all p–c innovators that is aimed at mitigating mutual hold-up when implementing p–c innovation in commercial products. Second, the public and highly visible non-assertion pledges additionally establish norms of non-exclusion (North, 1990) at a broader industry level, thereby preventing competing proprietary innovators from exercising their exclusion rights, which also could forestall all p–c innovation. Finally, the p–c innovators' continued purchasing of exclusion rights (and their non-assertion of those rights) complements these efforts by forearming against those competitors who may not be susceptible to the normative changes of non-exclusion in the industry, most notably patent trolls.

We empirically test our rationale within the infrastructure software industry, a setting in which we can clearly identify groups of p–c innovators (e.g., IBM) and proprietary innovators (e.g., Microsoft) from 2000 onwards, and in which the competition between the two types of players comes to bear. In this industry, the publication of the OSRM report in 2004 (see prologue) came as a largely unexpected shock to market participants, affecting the (treatment) group of p–c innovators but not the (control) group of proprietary ones, thus allowing us to observe differential pledging behavior between the two groups and estimate differences-in-differences (d-i-d) in their patent-purchasing activity pre and post shock. Not only are our results consistent with our theoretical rationale; drawing on additional quantitative and qualitative data we are also able to demonstrate that our *ex-post* findings are indeed likely the consequences of *ex-ante* strategies chosen by private–collectively innovating firms triggered by the exogenous shock. Finally, we provide empirical evidence that is consistent with viewing p–c innovators' pledges as a *successful* attempt at coordinating on exploiting joint p–c innovation efforts using complementary assets.

Our findings allow us to make several contributions to different streams of literature; however, three appear most important. First, our paper fills part of a gap in the theory of innovation strategy identified by scholars before us. Namely, whereas literature on the topic of p–c innovation has greatly advanced our understanding of how firms create value by engaging in such innovation (e.g., Henkel, 2006; Murray et al., 2009) and of how their individual business models should allow them to capture some of this value (e.g., von Krogh and von Hippel, 2006; West, 2003), the challenges arising from the interplay with competing proprietary innovators have so far largely been ignored (as noted, e.g., by Lerner and Tirole, 2005). We enrich the theory of p–c innovation by introducing competition between p–c innovators and proprietary competitors more explicitly than has been done before. Here, we show that both groups, p–c and proprietary innovators, use diametrically opposed approaches to capturing value using exclusion rights, despite working in the same industry. Notably, such intra-industry variation in the use of the same appropriation mechanism is different from previous conceptualizations of appropriability regimes (Teece, 1986). We explicate that the waiving of exclusion rights becomes part of the profit-maximizing strategy for p–c innovators to capture value from innovation under the given competitive conditions. Second, and likely interesting to management scholars more broadly, we describe how unilateral actions such as waivers of exclusion rights by p–c innovators serve a coordinative purpose among several actors and enable them to jointly design industry-regulating institutions to facilitate value capturing. In explaining how such moves may lead to the creation of reputational cost barriers for proprietary innovators that prevent them from exercising their exclusion rights, we add to resource dependence theory (e.g., Pfeffer and Salancik, 1978). We show that, counterintuitive as it may seem, gaining (*de facto*) control over a resource may come about by giving (*formal*) control away. This indicates that these two forms of control may be mutually exclusive in certain settings. Third, and finally, we believe that the thoughts and rationales presented in this paper may be of some relevance to the current policy debate on software patenting, in that they suggest shifting the discussion about non-obviousness/inventive step further away from a pure debate about admissible thresholds to one of protectable software categories.

2. Theory and hypotheses

2.1. Private–collective innovation and competition

The "private–collective model of innovation" (von Hippel and von Krogh, 2003) describes a mode of value creation through innovation that lies between the two ends of a spectrum marked by the established models of proprietary innovation at one extreme and collective innovation at the other. In the proprietary model of innovation, society incentivizes inventors by granting them exclusion rights to secure returns from their private investments (Demsetz, 1967; Nordhaus, 1969). Collective innovation, intended to provide public goods (Olson, 1971), relinquishes ownership rights over non-rivalrous resources to make them nonexcludable. In the private–collective, or hybrid (Bonaccorsi et al., 2006), model, firms contribute to the production of a common-pool resource (the 'p–c good'), just as in the case of creating public goods. Yet

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[2] Importantly, we refer to voluntary relinquishments of rights as opposed to licenses that are mandatory for private–collective innovators to grant when engaging with the public (e.g., as in the case of open source software, under the most recent General Public License version 3—GPLv3). We elaborate on this further in the Theory and the Data sections.

here, firms are willing to contribute because they can attain private benefit that exceeds the costs of participation, as well as the benefits that free-riding might convey to them (von Hippel and von Krogh, 2003). These private benefits to firms accrue in various forms, notably through learning from innovative communities outside the firm boundaries. Most importantly, however, p–c innovators will realize gains through their use of complementary assets that allow them to capitalize on the collective good (Teece, 1986). Often, these complementary assets may be production or distribution assets located in other vertical layers of the innovation value chain (Wolter and Veloso, 2008). Naturally, the value of these complementary resources increases with the diffusion of the p–c good (Varian and Shapiro, 1999; von Hippel and von Krogh, 2003).

Successful p–c innovators thus purposefully replace elements of their innovation value chain with a non-proprietary resource, and they try to capture value from their activity in other layers of the chain. A necessary condition for this business model to work is gaining and retaining access to the core p–c innovation (Benkler, 2002; von Krogh and von Hippel, 2006), however. In other words, nobody must forestall or exclude p–c innovators from the use of the partly public good they invest in. Accordingly, in most settings,[3] p–c innovators themselves are required to waive control over the resources they choose to contribute to the public good. Software may serve as an example. In essence, by contributing a piece of code to an OSS project, the contributing party automatically grants a license to use, modify, and redistribute the code to all legitimate users of the code. The scope of this license usually covers free access to all patented technology inherent in this specific contribution. Thus, given the single-sided focus on exactly these firms in the literature so far, it is not surprising that most scholars writing about hybrid business models (e.g., Bonaccorsi et al., 2006; Henkel, 2006; von Hippel and von Krogh, 2003; West, 2003) take the "absence of exclusion" assumption for granted (Benkler, 2002).

What if, however, this assumption is being challenged? An element essential to any theory concerned with strategic firm behavior is missing from extant theory on private–collective invention: competition (a shortcoming pointed out earlier by Lerner and Tirole, 2005). Notably, not all players in a given industry might want to profit from engaging in (joint) p–c innovation.[4] Rather, a significant subgroup in any industry might have invested in competitive proprietary offerings, and then seek to generate returns from them, and design organizational structures and adjust business models accordingly (Amit and Zott, 2001). These firms will deploy mechanisms to protect their private investments and returns (Lerner and Tirole, 2005) in order to render them inimitable by competitors (Dierickx and Cool, 1989), using exclusion rights (Ceccagnoli, 2009), among others. Given their nature, however, these exclusion rights not only might often pertain to the results of the firm's private innovation efforts but can extend beyond these efforts.

2.2. Cumulative innovation, imitation, and overlapping exclusion rights

An important case is the one in which these rights, held by proprietary innovators, extend to the core innovation that p–c innovators draw on. There are several reasons for why this can happen, two of which appear paramount and are interrelated. First, when proprietary and p–c innovators compete in the same markets, it is generally likely that they will be offering solutions that also share technological similarities, among others. Due to the cumulative and overlapping nature of technological innovation (Green and Scotchmer, 1995), particularly in so-called technologically complex industries (Cohen et al., 2000), technological similarities may in fact be accompanied by an overlap in ownership of exclusion rights, too. Specifically in those cases in which p–c innovation efforts are modeled explicitly after an existing private good (e.g., West, 2003), such problems are likely. In such instances, the resulting p–c good might almost inevitably infringe on exclusion rights held by proprietary innovators (Economist, 2003; Lerner and Tirole, 2005), and hence loses its character as a truly public (i.e., non-rivalrous and nonexcludable) good (we therefore also speak of a 'partly' public good hereafter). Second, the aforementioned problems are being aggravated by the fact that much of the p–c innovation effort is carried out without effective legal coordination to avoid infringement of proprietary solutions (e.g., DiBona, 2005). It follows that when proprietary innovators compete with a group of p–c innovators, the proprietary firms may likely own exclusion rights extending to the p–c initiative, offering them the chance to block p–c innovators' access to their core innovation.

Third-party exclusion rights thus pose a major danger to p–c innovators. Equally importantly, p–c innovators themselves do not seem to benefit much from owning exclusion rights pertaining to the p–c good. To the extent that their rights cover *explicit* contributions to the public good, p–c innovators usually have to waive rights control[5]; this means that the p–c innovators could not rightfully enforce their IP against users of the collective good even if they wanted to. To the extent that their rights protect technology that was not explicitly contributed to the p–c innovation effort but that is *related* to it—that is, technology extending beyond the specific scope of the mandatory waiver while staying relevant to the functionality of the p–c good—enforcement may still be legal. However, these related intellectual property rights (IPRs) look like blunt instruments intended to capture more value from p–c innovation.[6] First, they do not aid the firm in appropriating the good; by definition, p–c innovators will never be able to 'own' the p–c good, precisely because it is (partly) public (Gambardella and Hall, 2006; Hart and Cowhey, 1977). Second, on a more subtle level, they cannot even use their ownership of related exclusion rights to control who eventually gets to exploit the p–c good and who does not (Pfeffer and Salancik, 1978). This is because p–c innovators cannot conceivably exploit the p–c good for commercial purposes themselves, but, by enforcing their property rights, exclude third parties from doing the same thing. Such behavior might not be illegal, but it would clearly violate established codes of conduct (North, 1990; Ostrom, 1990; von Hippel and von Krogh, 2003), and, further, also destabilize the entire p–c innovation endeavor (Benkler, 2002). An example that illustrates the discrepancy between formal entitlement that comes with retaining exclusion related to the public good and their de-facto utility of capturing value from the

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[3] Note, however, that there is considerable variance in how different OSS licenses would handle the issue. We elaborate on this crucial point further below. Further examples include content production on Wikipedia and other activities governed by related licenses (see www.creativecommons.org for more examples).

[4] Note that the other extreme, free-riding by private innovators, is not detrimental to private–collective innovators.

[5] Consider contributions to OSS under the GPL as an example: since GPLv2 (enacted in 1991) firms have been required to waive partial control for explicit and direct contributions of software code to OSS, at least when redistributing open software.

[6] Clearly, this was the legal situation before 2007 for almost all open innovation projects in software (and to some extent still is the case today). At that time, GPLv2 was by far the most widely adopted OSS license. Under GPLv2 firms only need to grant access to the core IP pertaining to their actual contributions to OSS, and only when they actually redistribute the open software. Most importantly, IP access is limited to specific geographies, and, in terms of scope, does not extend beyond the specific patents underlying the directly contributed software (i.e., related rights are unaffected). Finally, note that GPLv3 (launched in July 2007) has become more restraining in that it forces firms into automatically granting a license that explicitly permits access to their contribution-related patents as well in order to enable legal use, modification, and redistribution of the OSS.

core innovation is IBM's Watson, famous for being the first computer to win on *Jeopardy!* The Watson program largely builds on the OSS project Apache UIMA (formerly IBM UIMA 2.0), to which IBM itself contributed most of the content. As part of the GPLv2, IBM did waive control over these specific software contributions. In addition, however, the Watson system also contains some core intelligence software on natural language processing which IBM did *not* make available as open source. Formally, IBM retains the right to enforce its related IPRs on this specific proprietary piece of language processing software against anyone. However, it would be inconceivable for the firm to use them against the OSS community.

To summarize, in technological domains characterized by cumulative and overlapping innovation, exclusion rights endanger the functioning of hybrid business models when proprietary innovators, who can turn their rights against p–c innovation, appear on the stage. This is particularly the case when the hybrid business models draw on p–c innovation efforts modeled on a pre-existing proprietary technology. At the same time, p–c innovators cannot control the development, shape, and access to the p–c good using their own intellectual property.

2.3. *Waiving exclusion rights to capture value from innovation*

The competitive dynamics arising from this situation are significant, and they motivate p–c firms to engage in radically reshaping the conditions that determine how much value they can capture from innovation—often referred to as the "appropriability regime" (Pisano and Teece, 2007; Teece, 1986). Following our earlier arguments, the fact that proprietary innovators can acquire and own exclusion rights over a p–c good is undesirable for p–c innovators; a regime that enables the ownership and enforcement of exclusion rights therefore comes at substantial indirect costs to p–c innovators. At the same time, the availability of such exclusion rights does not directly benefit the p–c innovators, either. To the extent that they still control such OSS-related rights, they have no incentives to foreclose third parties from the use of the partly public resource.

In this setting, so we argue, the simultaneous waiving and purchasing of further third-party exclusion rights becomes the optimal strategic choice for p–c innovators to reshape their appropriability regime. The rationale is threefold, and we explicate it below. The first two arguments lead to our first hypothesis; the third argument leads to our second hypothesis.

First, private–collective innovators have an interest in *coordinating with other p–c firms* to not endanger each other's access to the partly public good (i.e., to avoid mutual hold-up). To some extent, this risk is mitigated by the compulsory waivers of exclusion rights with which they may have to comply anyhow (see above). However, additional non-assertion pledges transcending the scope of the compulsory rights waivers may allow p–c innovators to further solidify such a state of interfirm coordination.[7] Here, further related exclusion rights held by p–c innovators lose their characteristics as blocking rights to p–c innovation at large (see above). Notably, unilateral pledges are preferable to multilateral ones, because they require less interfirm coordination but likely reach the same goal. The reason why the unilateral pledges are as suited as multilateral agreements is because a p–c innovator, in credibly signaling to the world of other p–c innovators to not enforce their rights against collective efforts, may reasonably hope for reciprocal behavior on their part (Lincoln et al., 1992; Westphal and Zajac, 1997). Given these circumstances, so we propose, the unilateral non-assertion of formal exclusion rights is thus an easy way to corroborate a coordination equilibrium among p–c innovators. Compared with more formal alternatives (e.g., forming a pool of exclusion rights) it additionally requires almost no formal contracting and incurs no related costs (see, e.g., Joshi and Nerkar, 2011). Furthermore, it may lay the foundations for the formation of mechanisms for industry self-regulation in that increasing levels of coordination of the mutual struggle of p–c firms may give rise to formal or informal organizations aimed at increasing the welfare of their stakeholders (Barnett and King, 2008; Ingram and Inman, 1996; Ostrom, 1990).

Second, p–c innovators have incentives to *disarm the exclusion rights held by competitive proprietary innovators*. In this regard, the non-assertion pledges unfold additional value to p–c innovators, above and beyond their means as coordination devices. Most importantly, they delimit the original legitimacy of proprietary innovators to defend their business models against p–c innovators, even if the latter infringe on the rights of the former; namely, through the almost symbolic waiving of their exclusion rights, p–c innovators establish societal norms of non-possession (or, at least, non-enforcement) of exclusion rights pertaining to the core innovation, and simultaneously foster norms of reciprocity and knowledge-sharing (North, 1990; Westphal and Zajac, 1997). Such action by p–c innovators may shift the perception of industry stakeholders (Hoffman and Ocasio, 2001) on how exclusion rights should be used in general. In more detail, what likely results is an unfavorable view of enforcing exclusion rights against p–c innovation efforts in general—a view that includes proprietary innovators. In particular, those proprietary innovators that are perceived as being similar[8] to p–c innovators should be affected; their reputation may be at stake when being seen as enforcing their exclusion rights against p–c innovators instead of seeking co-operative solutions in the interest of all parties involved—be these trading partners or final customers benefitting from the p–c innovation.[9] Thus, blocking p–c innovators becomes "costly" to proprietary innovators.[10]

Taken together, the mutual non-assertion claims by p–c innovators represent largely *symbolic action* (since the p–c innovators have few incentives to enforce their residual exclusion rights, anyway) aimed at coordinating p–c innovators' actions to establish norms of non-enforcement of exclusion rights. By giving up the ability to control value appropriation through ownership of exclusion rights, p–c innovators can instead use them to coordinate on decreasing their dependence on private innovators and their competitive actions (e.g., Pfeffer and Salancik, 1978). Thus, by voluntarily forfeiting one source of control (ownership), they may attain another (access), and one that is arguably more important in the present context.

The theoretical rationale presented so far substantially extends theory on p–c innovation, and, at first sight, it conflicts with both established management theory and practice, according to which

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[7] Think of voluntary pledges pertaining to adjacent fragments of code that the firm never explicitly contributed to OSS, but which OSS infringes on inadvertently. Referring back to the earlier IBM Watson example, these could be pledges on software patents covering natural language processing which newer versions of Apache UIMA may infringe upon. We will delineate the scope of these voluntary pledges from compulsory ones in the Data and Method sections.

[8] We thank an industry contact for drawing our attention to this point.

[9] Final consumers may find it difficult to understand why two seemingly similar firms—a proprietary and a p–c innovator offering competitive products—act in opposed ways when it comes to the enforcement of their IP. In an attempt to reconcile these different behaviors, consumers likely will tend to appreciate the relative 'generosity' of the p–c innovator and to condemn the 'selfishness' of the proprietary innovator, irrespective of the actual economics underlying the situation. They will do so as it helps them to self-justify (Steele, 1988; Holland et al., 2002) their own preferences of retaining identical access to the p–c innovation, be this judicially legitimate/economically desirable or not.

[10] In addition, private–collective innovators' joint pledging effectively creates a deterrence mechanism against violating norms of non-enforcement by posing a credible counter threat against deviators. Proprietary innovators trying to enforce their exclusion rights against OSS now face a large number of co-ordinated allies who have de-facto patent pooled their OSS-related legal resources. We deem this mechanism less important, however.

private exclusion rights are advantageous to *all* firms that seek to capture rents in competition (Dierickx and Cool, 1989), including p–c innovators (Fosfuri et al., 2008). As such, strong cognitive inertia should deter private–collective innovators from waiving their exclusion rights in the first place, no matter how objectively superior this approach of capturing value from innovation looks (Barnett, 2006). As is well known, it takes an external shock to enable actors to overcome these inertial forces (see Ostrom, 1990). In this case, an external shock that emphasizes the competitive threat that proprietary innovators pose to p–c innovation should trigger the strategic action we laid out above. We therefore posit:

Hypothesis H1. Once the private–collective business model is visibly threatened by the existence of exclusion rights, private–collective innovators will pledge related exclusion rights in the form of non-assertion pledges, whereas similar proprietary innovators will not.

2.4. *Residual exclusion-rights acquisition*

The voluntary waiver of their own exclusion rights enables p–c innovators to corroborate their equilibrium of mutual non-enforcement of exclusion rights. Moreover, it raises the barriers to denying access to the p–c good for all those competitive proprietary innovators who are susceptible to changing norms of non-enforcement. However, there may remain competitors to p–c innovators that are not susceptible to the creation of social norms of non-enforcement, because they are indifferent to industry stakeholders' (most notably, consumers') perceptions and to the associated reputational costs. Namely, these other firms are non-producing entities that base their entire business model on threatening to legally block manufacturing firms and pressing them for ransoms (a.k.a. "trolls" in the domain of technological exclusion rights, such as patents; see Reitzig et al., 2007). And notably, their interest in attacking p–c innovators might increase dramatically once they learn about the vulnerability of the p–c business model (i.e., with the shock). P–c innovators can only arm themselves against the threat these competitors pose by *acquiring residual exclusion rights* in the market that may pertain to the joint innovation efforts, in order to prevent the forestalling of access to the p–c good, even if these newly acquired rights may immediately become subject to the p–c firm's prior non-assertion claim. Thus, at the margin, p–c innovators and trolls will have identical incentives to acquire such exclusion-rights post shock, for the expected troll's ransom will correspond to the p–c innovator's initial willingness to acquire the orphan right. Similar proprietary innovators, however, will have no incentives to acquire such third-party rights. This is because they would have to enforce these rights against p–c innovators or sell their rights to trolls in order to recoup their investment in the first place. Neither action will be feasible once the p–c innovators have pledged their rights, however. With proprietary innovators facing a loss of legitimacy to even enforce their original rights post pledge, purchasing additional armor in the marketplace and using it against the p–c innovators would most likely be perceived as an excess of self-defense. In fact, due to the emerging norms of non-enforcement post shock, their using of third-party rights against p–c innovation would make proprietary innovators' actions look like attempts at rent-seeking at the expense of overall value creation, damaging their reputation with clients and leading to unpredictable losses. Based on this third consideration of our strategic rationale, we posit:

Hypothesis H2. The difference in purchases of residual exclusion-rights post and pre shock will be higher for private–collective innovators than for similar proprietary innovators.

2.5. *Increased reliance on private–collective innovation in times of softened competition*

Support for H1 and H2 would be direct empirical evidence for why p–c firms did what they did—notably, announce not to assert patents and purchase further IP at the same time. Indirect evidence for our strategic rationale being true, however, may be inferred from changes in firms' innovative outputs over time. We argue that unless it became visible shortly after the shock that the pledges would not have the desired effects, p–c innovators would seek to capitalize on their investment in securing access to the public good. Once they have reduced the risk of being forestalled access to their core innovation by pledging their own rights (H1) and disarming orphan rights (H2), the pressure to amortize their investment in securing the IP-free space should manifest itself in their increasing drawing on private–collective innovation for commercial product development—to reduce their cost base relative to their competitors. Proprietary innovators, on the contrary, should not feel the same pressure, and they should also suffer from cannibalization conflicts and organizational inertia preventing them from adopting a strategy similar to the p–c innovators in the short run.[11] We therefore propose:

Hypothesis H3. The difference in reliance on access to the private–collective good post and pre shock will be higher for private–collective innovators than for similar proprietary innovators.

3. Data collection and analytical methods

Our hypotheses require the identification of a setting in which directly competing private and private–collective innovators are exposed to a shock that exposes the vulnerability of p–c firms' strategies to capture value from innovation. We need data for both groups of firms, p–c and proprietary innovators, on their decision to waive exclusion rights (H1), their acquisitions of third-party residual rights pertaining to the p–c good (H2), as well as their exploitation of the p–c good (H3), both before and after the shock.

3.1. *The setting: infrastructure software*

A setting that lends itself to the test of our hypotheses is infrastructure software. It comprises operating systems and back-end applications such as database management systems (e.g., Fitzgerald, 2006). In this domain, as has been well documented, one group of proprietary innovators generates software and captures value from it by excluding competitors through the enforcement of patents and copyrights (e.g., Microsoft). At the same time, a group of p–c innovators (e.g., IBM) has strongly embraced OSS solutions and seeks to deploy complementary assets to capture value from OSS (Henkel, 2006; West, 2003). This second group of firms also invests their own resources in the customization and further development of OSS.

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[11] Eventually, this "regime change" might even lead to the adoption of the p–c innovation by traditional private innovators. This adoption would most likely happen due to cost reasons: private innovators may decide to replace parts of their product market offering with the private–collective resource if (1) joining the private–collective innovation efforts is cheaper than lone innovation or if (2) the private innovator may free-ride on existing efforts (see von Hippel and von Krogh, 2003 for an elaboration of these points). Also note that the private innovator may always choose to free-ride on the private–collective innovation efforts, an option which is risk-free if the specific private innovator is the only party likely to exert its exclusion rights.

3.2. The external shock and its aftermath: the OSRM report

The exogenous shock in this setting came in the form of a report issued by the independent insurance company Open Source Risk Management (OSRM), on August 2, 2004. The report suggested that Linux, one of the flagship projects of the OSS movement and itself an important piece of infrastructure software, was potentially infringing on several hundred private patent rights, thereby threatening the viability of OSS-based (particularly Linux-based) business models. Specifically, OSRM, headed by several individuals well-respected in the OSS community, noted that Linux was potentially infringing on as many as 283 different patents, dozens of which were held by proprietary innovators such as Microsoft. By publishing its report, OSRM spontaneously increased the likelihood that exclusion rights could and would be applied by proprietary innovators against OSS.[12] Immediately, these firms took up OSRM's analyses and issued press releases in which they communicated their strengthened competitive position against the p–c innovators.[13] And prior loose talk by proprietary innovators about OSS potentially infringing on patents was substituted with tangible legal accusations overnight.

3.3. Data

For our tests we first separate proprietary from p–c innovators *before* the exogenous shock in August 2004. For these two types of firms, we then present the data pertaining to H1 through H3.

3.3.1. Identification of private–collective innovators

To single out p–c innovators in infrastructure software, we identified firms that both (a) drew largely on OSS solutions for their products and services before 2004 and (b) promoted the further development of OSS by investing significant amounts of resources. In contrast, proprietary innovators are those firms that invest in R&D, product development, and exclusion rights to offer proprietary software solutions in the same product markets as p–c innovators. As there exists no universally accepted codification of firms into these two categories relevant to our analysis, we devised the following iterative multi-stage procedure to identify p–c and private innovators in infrastructure software.

Starting from two databases, the Forbes Global 2000 and the SoftwareMag Software 500 rankings,[14] in a first step, we pre-selected technology-active firms that rely on infrastructure software for their product market offerings, whose average annual sales exceeded $1bn,[15] and that existed as independent companies for our entire observation period (2000–2008, a sufficiently large window around the shock date). Drawing on archival databases (e.g., Factiva) and Web searches (Google), in a second step, we sought to understand these firms' involvement in OSS before the exogenous shock (2004). We scanned related press releases, expert reports, and software-related news as well as employee and insider weblog posts by firms in an exploratory way in order to gain a more fine-grained understanding of which of the commercial firms had committed to innovation and value capturing around OSS early on.

Notably, the picture emerging from this exploratory analysis showed that until 2004, many of the p–c innovators had co-founded or joined the Open Source Development Laboratory (OSDL), whereas none of the other firms had, either because they were indifferent to OSS or because they were proprietary innovators. Upon closer inspection of the goals of the OSDL, it became apparent that classifying firms into OSDL members and others would be a useful first selection criterion in identifying p–c innovators.[16]

We then examined OSDL member firms' histories in more detail. Not surprisingly, we found that the firms most reliant on OSS, and most active in its promotion and further development, were those that took an active role in designing and promoting the OSDL as an organization (whereas some other members were even free-riding on those firms' efforts). This list includes the founding members (in 2000) or initiators and leaders of working groups (in 2001) within the OSDL. These firms in particular would have faced prohibitively high switching costs of reverting from OSS to proprietary infrastructure software solutions in 2004 because of their early and strong commitment to making OSS an integral part of their product market offerings and given their considerable investment in its further development and diffusion.

We thus define p–c innovators as those that founded the OSDL or one of its working groups. These are IBM, NEC, Computer Associates (founding members[17]) as well as Nokia (the leader in developing the first OSDL working group, "Carrier Grade Linux").

3.3.2. Identification of proprietary competitors

Proprietary innovators, on the other hand, we selected from the OSDL-non-member pool. To this end, we first identified direct competitors (in terms of market offering) of the aforementioned p–c innovators, drawing on information we could obtain from the p–c firms' annual reports, Hoover's, specialist software magazines, product catalogues, and neutral product tests and rankings. Within this pool of competitors, in a second step we searched for information about the companies' stance towards open source and Linux before and after the shock (i.e., pre and post 2004), similar to what we had done for the p–c innovators above (drawing on sources such as Google, LexisNexis, and Factiva). Third, and finally, in order to settle on the actual matched pairs of p–c innovators and proprietary innovators, we narrowed the results of this search process down to

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[12] We conducted several formal and informal interviews with heads of IP departments in software related industries, and we also spoke to other industry experts. All of them confirmed that, while there had been an ongoing conversation about the overlap between OSS and IP, this debate had been rather unspecific and in its infancy stage. Thus, so these experts concurred, the OSRM report published in 2004 not only represented the first publication by *peers affiliated with the OSS camp* specifying the potential of patent infringement, but it also came as a big surprise to anyone but the authors of the report themselves.

[13] See, for example, http://www.zdnet.co.uk/news/application-development/2004/11/23/microsoft-denies-ballmer-linux-warning-39174877/.

[14] For the Forbes Global 2000, we focused on the categories "Software & Services" and "Technology Hardware & Equipment." See for example http://www.forbes.com/lists/2009/18/global-09_The-Global-2000_IndName_17.html, and for the SoftwareMag Software 500: http://www.softwaremag.com/S_FocusAreas.cfm?Doc=The500 (accessed 24 November 2009).

[15] Given the theoretical argument we intend to test, we deliberately restrict our analysis to those players that should have the complementary assets to capture (private) value from their engagement in and investment in OSS. Because our theoretical arguments only invoke such firms, this poses no additional constraint to our theoretical elaborations within the chosen scope of this paper.

[16] According to its archived Web site of August 2003, the OSDL's mission is to "to be the recognized center of gravity for Linux; the central body dedicated to accelerating the use of Linux for enterprise computing" (see http://web.archive.org/web/20030802150846/http://osdl.org/about_osdl/members/). The OSDL, for a long time, also employed Linus Torvalds, founder of Linux. Of the 23 listed members of the OSDL in August 2003, 16 were software or hardware firms that were not mere distributors of Linux. Of these, 14 matched our original search criteria (firm exists in all years during the 2000–2008 period and has average annual sales of more than $1bn).

[17] Despite being founding members of the OSDL, Intel and HP are not included in our tests for H3. We did not include Intel for this test because the Linux operating system, from its outset, was designed to run on Intel platforms. We therefore expect to see no change in Intel's reliance on OSS (H3) over time. HP is not included in our standard specification for H3 because of technical problems regarding the data-gathering for H3. Because HP has not allowed a large share of its Web site to be archived since 2003, it is impossible to rebuild HP's product portfolio over the entire estimation period. We do include both Intel and HP in our extended tests pertaining to H1 and H2, however.

Table 1
Private–collective innovators and their matched private counterparts.

Private–collective innovator	Makes pledge	Type of pledge (also see Table 2)	Matched private innovators	Makes pledge
Computer associates	Yes	Specific patents (14) Join Patent Commons	1. Intuit, 2. Intelex Technologies, 3. BMC Software, 4. Symantec	No
HP	Yes	Join Patent Commons	1. Affiliated Computing Services, 2. First Data, 3. NCR, 4. Eastman Kodak	No
IBM	Yes	Specific patents (500) Specific applications (open standards in healthcare and education) Join Open Invention Network Join Patent Commons	1. Microsoft, 2. TSMC, 3. Accenture, 4. EMC Corporation	No
Intel	Yes	Join Patent Commons	1. LSI, 2. Broadcom, 3. Texas Instruments, 4. Qualcomm	No
NEC	Yes	Join Open Invention Network	1. Diebold, 2. UTStarcom, 3. ZTE, 4. Siemens AG	No
Nokia	Yes	Specific applications (Linux) Join Patent Commons	1. RIM, 2. HTC, 3. Nortel, 4. Juniper Networks	No

Match based on similarity (with respect to product market offering, overlapping customer segments, and technology base) with private–collective innovators using information taken from Annual Reports and Hoovers. Note that while Microsoft seems to be making two non-assertion pledges during our observation period, these are unrelated to the production or protection of a p–c good, but emerged in the course of Microsoft's efforts to have Office 2003 XML established as ISO standard.

those firms that could clearly be identified as firms that would have publicly communicated their general lack of interest in p–c innovation or would have actively campaigned against p–c innovation in some form prior to 2004,[18] and that had the resources necessary to acquire patents and complementary assets. The resulting list of corporations meeting the aforementioned criteria to qualify as a proprietary innovator in our sample is finite, and we present it in Table 1. For our tests, we deploy all matches when testing H1 and H2. Given the enormous cost of coding product data, however, we had to restrict our tests for H3 to the first two matches in Table 1.[19]

3.3.3. Large-scale data sources

In total we rely on three different data sources. First, to identify patent non-assertion claims/pledges (H1), we revert to information disclosed on patentcommons.org, the most comprehensive library on published patent pledges to OSS. We cross-checked and completed the information on this site through archival (e.g., Factiva) and Web searches (Google), particularly with regards to potentially missing pledges.[20] Also, we collected additional information on the nature of the firm-specific patent pledges made by our p–c and proprietary innovators, or tried to confirm their non-existence (H1). All dates for firm-specific non-assertion announcements lay between August 2004 and September 2005, the period immediately following the publication of the OSRM report. These pledges showed considerable variation in their scope, ranging from those with very specific access to individually delineated patents (e.g., IBM), to firms making all of their IP accessible in the context of Linux Kernel advancement and redistribution (e.g., Nokia). Importantly, however, all of these pledges exceeded the requirements of compulsory relinquishments by even the strictest OSS licenses. Table 2 provides an overview of the different types of pledges present in our sample.

Second, we collected data pertaining to the acquisition of residual exclusion rights (H2) using the U.S. Patent Office patent register as our data source. We collected information on all patent reassignments to the above firms, including their subsidiaries, between 2000 and 2008, the period around the exogenous shock in 2004–2005. Since our empirical setting is infrastructure software, we limit ourselves to patenting activity pertaining to software. Multiple definitions for identifying software patents have been proposed in the past (Bessen and Hunt, 2007; Cockburn and MacGarvie, 2011; Graham and Mowery, 2003; Hall and MacGarvie, 2010). Because plenty of the firms in our sample are not U.S. headquartered and therefore often initially file for patent protection outside the U.S. system, and because we are not specifically interested in Internet business method patents, we elected the classification scheme by Graham and Mowery as our preferred specification.[21] Eliminating false positives (no actual transfer of ownership; intrafirm reassignments) left us with a database of 180 software patent reassignments.[22]

Third, to enable a test of H3, we gathered information on all firms' commercial products for the period 2000–2008 by drawing on their specification sheets. By analyzing the contents of the companies' historic Web sites via the Internet Archive (archive.org), we first established their baseline product portfolio before the beginning of our observation period (December 1999). Based on this, we checked which products were introduced in each of the

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[18] It is interesting to note that eventually some of the proprietary innovators in our sample actually start engaging with the OSS community (as of 2007). For example, Microsoft, historically one of the most outspoken opponents of the open source movement, has very recently embarked on a more open strategy. This includes a cooperation agreement with open source proponent Novell launched in November 2006, as well as the Microsoft Open Specification Promise (see http://www.microsoft.com/interop/osp/default.mspx) and some genuine open source activities. It is thus theoretically possible that our control sample data are somewhat biased as of 2006. We deem this unproblematic for two reasons, however. First, if there were a bias it would be conservative in the sense that it should make it more difficult for us to obtain support for our hypotheses. Second, these changes as of late in our sample may affect patent purchases (H2); however, they will likely not yet have affected the most recent product launch data (H3).

[19] Note that we include all subsidiaries of the firms listed in Table 1, as well as all acquired firms by the corporations listed in Table 1, for any of our tests of H2 and H3.

[20] Specifically, we carried out an extensive search to identify those pledges that might 'fly below the radar' and elude us as they might not be published on patentcommons.org (using a variety of search terms—such as "patent AND (pledge or donate or donation)"—using Google, LexisNexis, and Factiva). While earlier patent donations appear to exist, these exclusively relate to companies giving patents to universities and research centers in return for major tax write-offs (a practice put to a halt by the U.S. Congress at the end of 2003/beginning of 2004; see, e.g., http://www.forbes.com/2004/01/07/cz_ae_0107beltway.html). We examined all these donations in detail; none of them were motivated by considerations that would be relevant to this manuscript.

[21] Note, however, that results for H2 and H3 are entirely consistent across definitions (results are not reported in this paper, but they are available from the authors upon request). See also "Robustness checks."

[22] Ideally, to test H2, we might specifically analyze firms' reassignment efforts regarding the specific 283 patents identified by the OSRM report. However, the individual patents have never been made public—as already mentioned by OSRM in its original press announcement of the report: "Because of the effect that knowledge of potential infringement has, OSRM isn't releasing its list of patents."

Table 2
Archetypes of patent pledges.

Type	Example of firm using it	Specifics of example	How voluntary pledge extends beyond waiving of IP control as mandated by OSS license (in 2004/5)	How the pledge extends to newly acquired patents by the firms (post 2005)
Specific patents	IBM	500 delineated patents which can be used by any entity developing/using OSS	Donations include areas where IBM had not made contributions earlier (e.g., natural language processing)	No direct extension, however, patent enforcement in domains similar to the original pledge of 2004 would lead to social costs. Indirect extension
Specific applications	Nokia	All IP owned by Nokia related to Linux	*Any* patent claim contained in *any* Nokia patent that applies to Linux can no longer be enforced against developers/users of Linux	Direct extension. If newly acquired patens relate to Linux, they are pledged automatically
Join Open Invention Network	NEC	Becoming member of a patent pool that acquires residual exclusion rights for Linux; NEC is investor (i.e., providing funds)	*Any* patent claim contained in *any* patent of member organization that applies to Linux can no longer be enforced against developers/users of Linux	Direct extension. If newly acquired patens relate to Linux, they are pledged automatically
Join Patent Commons	Intel	Joining an organization that advocates social norms of non-execution of IP rights against OSS and Linux	Members cannot credibly commit to and be a member of this organization and enforce its patents against open source and Linux at the same time	*Ibid.* Indirect extension (social cost)

subsequent years and captured the technical specifications of each newly introduced product. In so doing, we manually examined, for each product released by any of the firms during the observational period, whether the product would include or functionally require (a) OSS (in general) and/or (b) the Linux operating system (in particular).[23] We collected fine-grained information for Linux because it is an unambiguous example of an OSS substitute for proprietary infrastructure software, and all of our p–c innovators in the sample draw on and contribute to it.[24] The respective coding was carried out by four different raters with professional backgrounds in the respective technological fields. In a check-coding way of proceeding (Miles and Huberman, 1994), the raters were first trained using a randomly chosen firm that would not be part of the analysis. Here, their share of agreement was 83.3% (Cohen's kappa: 0.67; *p*-value: 0.00). Moreover, for the actual coding, we had the raters duplicate each other's work for randomly chosen subsamples so that we could again assess interrater reliability. Additionally, one of the authors independently coded randomly chosen subsamples. The results of both reliability checks were very reassuring (average share of agreement: 95.3%; average Cohen's kappa: 0.81; all *p*-values < 0.04). We applied this procedure to a total of 2638 products newly introduced during the 2000–2008 period.

3.3.4. *Dependent variables*

We deploy several dependent variables pertaining to our hypotheses. For H1, we register at the firm level whether a given corporation *pledged* its (potentially still enforceable) exclusion rights related to OSS or Linux shortly after the OSRM report was published or not.

For H2, we measure the *investment in the purchasing of exclusion rights* (*PER investment*) as the count of annual reassignments of software patents to each of the firms in our sample (H2). In order to account for the activities by the Open Invention Network (OIN; also see "qualitative evidence" in the Section 4), we distribute the number of patents it acquires equally over the p–c innovators that are members of the OIN. Treating OIN as a separate entity is not possible as it does not formally exist before the shock. Table 2 gives further details on how purchased exclusion rights are contrarily affected by the varying types of pledges.

For H3 we compute the firm's *reliance on the private–collective good* in two alternative ways. We calculate both the firmyear number of products that draw on OSS more generally and the firmyear number of products drawing on Linux more specifically.

3.3.5. *Independent variables*

The only independent variable deployed in our test for H1 is a dummy variable reflecting whether the firm is a p–c innovator or not. Tests for H2 and H3 contain three key independent variables due to our differences-in-differences estimation approach (see below). First, similar to our test for H1, we distinguish between p–c and proprietary innovators by including a dummy variable called d_{treat}. Second, we include a dummy variable to capture whether an observation takes place before or after the publication of the OSRM report (1 = before; 0 = after), which should thus pick up general differences between the two time periods ($d_{post\ announcement}$). Finally, we interact the two dummy variables to capture the effect on our group of interest after the patent pledges.

3.3.6. *Control variables*

For the tests of H2 and H3 we deploy control variables to exclude alternative explanations for our findings as best we can. Accounting for Fosfuri et al.'s (2008) findings that private property rights and engagement in OSS can be complementary, we included a measure for the firms' *complementary proprietary research* (measured as the firmyear stock of software patents) as a control for the tests of both H2 and H3. When testing H3, we additionally control for the *total number of products* released by firmyear to capture the corporate investment in new product development that can differ between firms (Helfat, 1994). Also, in conjunction, these two variables should tease out firm time-variant effects that are caused by firm size; we control for time-invariant firm-level effects in our fixed effect models.

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[23] Note that this is feasible because, in order to include OSS in a commercial product offering, one is required to specify publicly that OSS is contained in the product (see the Open Source Definition at opensource.org). Similarly, products running on the Linux platform will be advertised as being capable of doing just that in product specification sheets.

[24] Our sample includes both hardware and software products. For products that are part of a larger series (Internet Explorer, Word), we count each major release (e.g., Internet Explorer 3, 4, and 5; Word 2000, Word 2003) as a separate product; we do *not* include minor updates (e.g., IE 3.1, 3.2).

Table 3
Descriptive statistics.

	Data pertaining to test of H2 and H3 ($N = 108$)	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	d_{treat}(1 if firm is private–collective innovator; 0 otherwise)	0.33		0	1							
(2)	d_{post}(1 if post non-assertion pledge; 0 otherwise)	0.33		0	1	0						
(3)	Complementary proprietary research$^{\#,A}$	1356.46	3230.12	0	17248	0.47	0.14					
(4)	ln(New product releases in firmyear+ 1)$^{\#}$	2.27	1.43	0	5.89	0.64	0.19	0.5				
(5)	PER investment$^{\#}$	0.6	1.22	0	6	0.3	0.28	0.42	0.47			
	For private–collective innovators ($N = 36$)	1.11	1.45	0	6							
	For proprietary innovators ($N = 72$)	0.35	1.01	0	5							
(6)	Reliance on OSS$^{\#}$	3.31	8.83	0	42	0.51	0.23	0.28	0.51	0.42		
	For private–collective innovators ($N = 36$)	9.67	13.25	0	42							
	For proprietary innovators ($N = 72$)	0.13	0.37	0	2							
(7)	Reliance on Linux$^{\#}$	7.02	27.06	0	234	0.37	0.2	0.72	0.47	0.5	0.55	
	For private–collective innovators ($N = 36$)	20.94	44.04	0	234							
	For proprietary innovators ($N = 72$)	0.06	0.23	0	1							

	Extended data pertaining to test of H2 ($N = 270$)	Mean	S.D.	Min	Max	(1)	(2)	(3)
(1)	d_{treat}(1 if firm is private–collective innovator; 0 otherwise)	0.2		0	1			
(2)	d_{post}(1 if post non-assertion pledge; 0 otherwise)	0.33		0	1	0		
(3)	Complementary proprietary research$^{\#,A}$	916.1	2217.35	0	17248	0.55	0.15	
(4)	PER investment$^{\#}$	0.67	1.47	0	11	0.25	0.1	0.26
	For private–collective innovators ($N = 54$)	1.39	2.04	0	11			
	For proprietary innovators ($N = 216$)	0.47	1.23	0	8			

$^{\#}$ Variable calculated at the firmyear level.
^{A} Measured as software patent stock per firmyear.

3.4. *Model specifications and econometric issues*

In H2 and H3, we suggest that the observable outcomes of a given dependent variable before and after the disclosure of the legal threat to p–c innovation change differently across two different groups of observations: those that are affected by the exogenous shock, and those that are not. In our paper, these groups are the p–c versus the proprietary innovator firms. The classic estimation technique for this type of problem is a difference-in-differences estimator (Wooldridge, 2006) of the following kind:

$$DV = \beta_0 + \beta_1 d_{treat} + \beta_2 d_{post\,announcement} + \beta_3 d_{treat} d_{post\,announcement} + \beta_4 control + \varepsilon \qquad (1)$$

As briefly mentioned above, d_{treat} is a dummy variable that takes a value of 1 if the observation is part of the group that is affected by the event (treatment group), and a value of 0 otherwise (i.e., if the observation belongs to the so-called control group). $d_{post\,announcement}$ is a dummy variable denoting whether the observation is made after the event took place (1) or before (0). Collapsing the data into solely pre and post periods (instead of yearly observations), we manage to obtain consistent standard errors even on our relatively small sample (Bertrand et al., 2004). The coefficient of the interaction effect of d_{treat} and $d_{post\,announcement}$, β_3, captures the actual differences-in-differences. The control variables in our estimations enter linearly and are meant to tease out the variance that is unrelated to our hypothesized effects. Finally, because our dependent variables are count variables, suited estimators will come from the family of the Poisson models.

4. Empirical results

Table 3 contains summary statistics and correlations for the major variables used in the analyses below. Looking at the dependent variables, we see that all three display considerable variation. Their means tend to be higher for the p–c innovators than for the proprietary innovators, providing prima-facie support for our propositions. Regarding the Pearson correlations between the major variables of interest, we find low to moderate correlations across all variables.

Our (statistical) tests for H1 through H3 are presented in Tables 4–6. Table 4 presents results pertaining to H1. Fig. 1 both complements the description of our data and leads to our multivariate tests of H2 and H3, which are summarized in Tables 5 and 6. Specifically, in Fig. 1, we plot the trend of our two dependent variables over time, dividing the yearly mean of the treatment group by the yearly mean of the respective control group, and normalizing these values. Whereas Fig. 1 provides no statistically conclusive evidence, it adds some face validity to our more comprehensive tests (Tables 5 and 6). A simple glance at the graph indicates that, all else being equal (notably control variables), H3 seems to

Table 4
Comparison of private–collective and proprietary innovators on whether they pledged patents to the OSS community.

		Firm makes a pledge		
		Yes	No	Total
Firm is	Private–collective innovator	6	0	6
	Proprietary innovator	0	24	24
	Total	6	24	30

Table 5

Regressions pertaining to H2—purchasing of exclusion rights from 2000 to 2008 ($N = 108, 270$).

Model	A	B	C	D	E	F	G	H
Estimator	Poisson (panel conditional fixed effects)	Neg. bin. (uncond. fixed effects)	Neg. bin. (population-average)	Neg. bin. (panel conditional fixed effects)	Poisson (panel conditional fixed effects)	Neg. bin. (uncond. fixed effects)	Neg. bin. (population-average)	Neg. bin. (panel conditional fixed effects)
d_{treat}		16.966^{**} (1.170)				15.734^{**} (1.059)		
d_{post}	0.101 (0.133)	0.490 (1.080)	0.124 (0.118)	0.124 (0.123)	0.022 (0.099)	−0.061 (0.304)	0.008 (0.098)	−0.016 (0.114)
$\boldsymbol{d_{post}d_{treat}}$	$0.441^{\dagger}$ (0.334)	0.639 (1.211)	$0.470^{\dagger}$ (0.342)	0.555^{*} (0.287)	0.353 (0.276)	$0.891^{\dagger}$ (0.582)	$0.410^{\dagger}$ (0.281)	0.548^{**} (0.212)
Complementary proprietary research[A]	0.000^{*} (0.000)	0.000 (0.000)	0.000* (0.000)	0.000^{**} (0.000)	0.000 (0.000)	0.000 (0.000)	0.000^{*} (0.000)	0.000^{*} (0.000)
Constant		-17.735^{**} (1.152)	0.250^{*} (0.134)	0.260^{*} (0.130)		-16.387^{**} (1.022)	0.415^{**} (0.088)	0.419^{**} (0.086)
Observations	108	108	108	108	270	270	270	270
Groups	12		12	12	30		30	30
χ^2-Test	0.000	0.000	0.000	0.000	0.258	0.000	0.000	0.000
Log-likelihood	−110.4	−72.80	n.a.	−403.208	−302.7	−220.4	n.a.	−1046.276

Cluster-robust standard in parenthesis. p-values are one-tailed per our hypothesis.

We carry out the Poisson conditional fixed effects model using the command “xtpqml” in STATA, and the negative binomial fixed effects model using MPlus. As is well known, the Poisson and negative binomial conditional fixed effects model drops firms that display consistent 0 observations for the dependent variable. In order not to lose these observations (particularly for firms in our control group), we add an intercept of 1 to our dependent variable across all observations. Because we do not interpret the size of the differences-in-differences coefficients, this linear offset is unproblematic. Losing observations would be undesirable, however.

** $p < 0.01$.

* $p < 0.05$.

† $p < 0.1$.

[A] Measured as software patent stock per firmyear.

Table 6

Regressions pertaining to 3—reliance on the private–collective good from 2000 to 2008 ($N = 108$).

Model	A	B	C	D	E	F	G	H
Dep. Var.: *Reliance on...*	OSS	OSS	OSS	OSS	Linux	Linux	Linux	Linux
Method	Poisson (panel conditional fixed effects)	Neg. bin. (uncond. fixed effects)	Neg. bin. (population-average)	Neg. bin. (panel conditional fixed effects)	Poisson (panel conditional fixed effects)	Neg. bin. (uncond. fixed effects)	Neg. bin. (population-average)	Neg. bin. (panel conditional fixed effects)
d_{treat}		3.097**				3.078**		
		(0.896)				(0.462)		
d_{post}	−0.442**	0.841	−0.510**	−0.825**	−0.297**	1.276**	−0.325*	−0.569**
	(0.130)	(1.100)	(0.192)	(0.200)	(0.100)	(0.497)	(0.174)	(0.198)
$\boldsymbol{d_{post}d_{treat}}$	0.707**	−0.274	1.117**	1.565**	1.059**	−0.108	1.390**	1.821**
	(0.230)	(1.135)	(0.234)	(0.262)	(0.139)	(0.593)	(0.252)	(0.248)
ln(New product releases in firmyear+ 1)	0.726**	1.021**	0.631**	0.695**	0.698**	0.931**	0.582**	0.648
	(0.142)	(0.181)	(0.178)	(0.125)	(0.152)	(0.181)	(0.178)	(0.144)
Complementary proprietary research^{A}	0.000**	0.000	0.000**	0.000**	0.000	−0.000	−0.000	−0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant		−5.143**	−0.665*	−0.753*		−5.197**	−0.569*	−0.657*
		(1.010)	(0.322)	(0.340)		(0.635)	(0.267)	(0.315)
Observations	108	108	108	108	72	72	72	72
Groups	12		12	12	12		12	12
χ^2-Test	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Log-likelihood	−216.9	−123.8	n.a.	−478.0	−194.9	−114.2	n.a.	−467.3

Cluster-robust standard in parenthesis. *p*-values are one-tailed per our hypothesis.

We carry out the Poisson conditional fixed effects model using the command "xtpqml" in STATA, and the negative binomial fixed effects model using MPlus. As is well known, the Poisson and negative binomial conditional fixed effects model drops firms that display consistent 0 observations for the dependent variable. In order not to lose these observations (particularly for firms in our control group), we add an intercept of 1 to our dependent variable across all observations. Because we do not interpret the size of the differences-in-differences coefficients, this linear offset is unproblematic. Losing observations would be undesirable, however.

** $p < 0.01$.

* $p < 0.05$.

† $p < 0.1$.

^{A} Measured as software patent stock per firmyear.

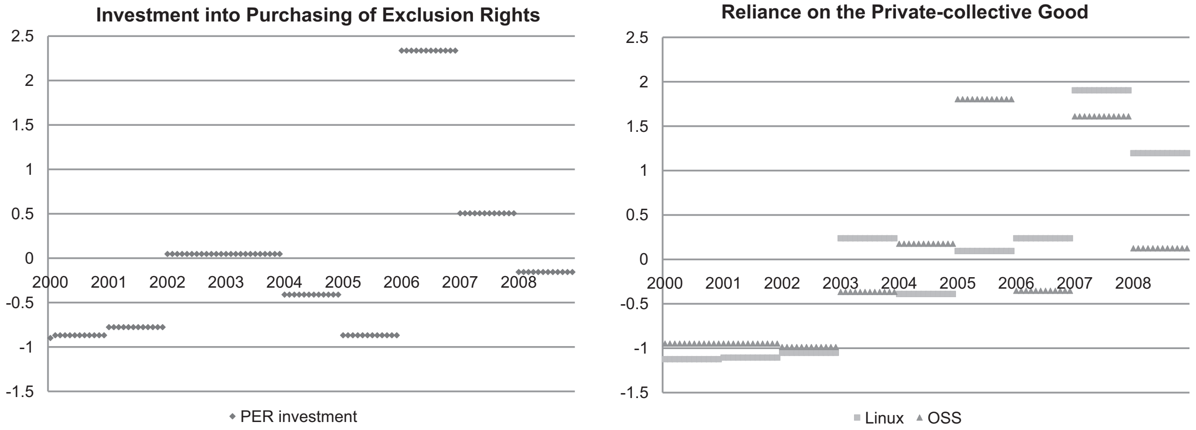

Fig. 1. Temporal development of the dependent variables.
Figures depict the normalized ratio of activity in purchasing of exclusion rights (H2) and reliance on the private–collective good (H3, separated by Linux and OSS). That is, to arrive at the number shown, we first divide the activity of the members of the treatment group by the activity of the control group, and then normalize the resulting values by subtracting the overall mean and dividing by the overall standard deviation. Whereas this mode of display does not allow interpreting absolute values, it is ideal to display a trend over time. Specifically, an increase in the normalized ratios suggests a difference in the relative increase of PER investment and reliance on the private–collective good (i.e., a larger increase in the treatment group than in the control group), lending some face-value support to the hypotheses.

be supported. Results pertaining to H2 are less conclusive from the graph; however, they still appear to be rather confirmatory. Finally, Fig. 1 further indicates that any relative change in behavior between our groups after the shock is probably more attributable to the shock itself, than to the continuation of a pre-existing trend.

Table 4 shows a simple cross-tabulation of the pledging behavior of private–collective and matching proprietary innovators. Results, as expected, clearly support H1, and no further test statistics appear necessary or appropriate (in fact, the evidence is so strong that a simple probability model of a firm pledging being a function of the firm's characteristics [private–collective innovator or not] fails to converge given perfect prediction).

Columns A through H of Table 5 (i.e., Models 5A through 5H) present differences-in-differences pre and post pledge between p–c and proprietary innovators' *PER investment* (Hypothesis 2). The table is divided into two parts (left and right halves), replicating the same set of estimations on two different subsamples—one mirroring the reduced set of firms for which product data are available to facilitate comparison with Table 6 (left side), and the other the full sample of firms included in Table 1 (right side). In each part of Table 5 we deploy four different estimation techniques that seek to cater to our particular estimation challenge, which lies in (a) catering to a count distribution, (b) dealing with overdispersion (see Table 1), (c) clustering standard errors to avoid inflation of *t*-statistics in a d-i-d design (Bertrand et al., 2004), and (d) teasing out unobserved time-invariant heterogeneity. As it turns out, neither of the models we present (with the potential exception of the fourth one[25]) may be individually perfect. As each of them presents individually *different* deficiencies, however, they jointly allow addressing all facets of the estimation challenge at hand, thereby conveying a holistic picture that facilitates inference. Models 5A and 5E draw on a conditional fixed effect Poisson estimator allowing for the clustering of standard errors. The estimator stops short of dealing with overdispersion, which is present in our data. The model is overall well specified, the crucial interaction coefficient is positive and significant at the 10% level (an acceptable level given the sample size); however, results could be biased. Models 5B and 5F present a cross-sectional negative binomial estimator, allowing for clustering of standard errors, but containing unconditional fixed effects in the form of a dummy specification. The results are insignificant. Models 5C and 5G report results from a population-averages negative binomial panel estimation. Results are significant at the 5% level; however, again we cannot specify conditional fixed effects. Finally, Models 5D and 5H present a conditional fixed effects negative binomial panel estimator allowing for the clustering of standard errors. The results again support H2 on both subsamples at the 10% level. Thus, when looking at the entirety of the models presented, particularly with regard to Models 5C/D/G/H, we find strong support for H2.

Table 6 follows the same estimation logic as Table 5, this time using *p–c good reliance* as the dependent variable. Here, the left half of the table examines OSS reliance more broadly, whereas the right part of the table narrows in on reliance on Linux more specifically. Again, all models, apart from 6B and 6E, support H3 empirically, suggesting that controlling for unobserved heterogeneity with a conditional fixed effects model is vital. Including the logarithm of the number of total products per firmyear as an independent variable in the count models allows us to interpret the treatment coefficient ($d_{treat} \times d_{post\ announcement}$) as one relating to the firmyear *share* of products drawing on the hybrid resource of all firmyear products (Cameron and Trivedi, 1998; Hausman et al., 1984).[26] Additional calculations show that the relative likelihood of a p–c innovator relying on OSS for a newly introduced product increases by 25% post shock compared with a proprietary innovator using OSS. Finally, the coefficient for the software patent stock variable shows a positive sign across these latter specifications, in line with Fosfuri et al.'s (2008) argument suggesting that complementarities between OSS development and privately retained software patent rights in adjacent domains may exist.

4.1. Robustness checks and exclusion of alternative explanations

Drawing further on the data we had collected for H1 through H3, we carried out a series of robustness checks for our findings, some of which appear noteworthy. For H2 and H3 we tested whether our

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[25] Whereas Models 5A, B, C, E, F, and G are carried out using STATA 11, we rely on MPlus for the estimation of Models 5D and 5H. As regards the maximum likelihood function underlying these latter models, we were dependent on the suppliers' information that the estimator should cater to all the estimation challenges we face. Since we were not able to verify this information independently, however, we take these theoretically ideal results with a grain of salt.

[26] See Reitzig and Wagner (2010) for a detailed explanation of this application of Poisson models to indirectly cater to nonstandard estimation problems.

results would be susceptible to the actual date of the non-assertion pledge. In order to exclude that 'common knowledge' about an expected release of the OSRM report would distort our findings, we artificially anticipated the shock date to 2003 in a set of robustness tests. Similarly, in order to establish that 2005 was truly our first treatment year, we examined how sensitive our results would be to delaying the shock date to 2006. Based on these additional analyses we can confidently rule out effects of a pre-2004 treatment that would spuriously drive our results with respect to H2 and H3. As regards shifting the shock date to 2006, results are equally robust for H2, and somewhat less solid, although still confidence-inspiring, for H3. While we cannot rule out that general trends of increasing OSS-based product development over time drive parts of the results for our treatment group, our sensitivity checks also indicate that these trends alone could not account for the findings we obtain. This latter finding is reassuring in that it does not create an immediate need for us to model more complex sequential interactions between p–c innovators explicitly to explain our data. Second, and again for both H2 and H3, we compared a series of approaches of categorizing software patents to one another—given the lack of a single-best unique identifier provided by the IPC or US patent class system itself. Whereas for the paper we settled on the categorization proposed by Graham and Mowery (2003), results are qualitatively similar (albeit weaker in some of the estimations) when adopting different definitions (Bessen and Hunt, 2007; Cockburn and MacGarvie, 2011; Hall and MacGarvie, 2010).

Whereas the evidence we have presented so far appears highly supportive of our theoretical arguments, there may be alternative explanations driving our findings. Some of them we cannot rule out by testing. We address these non-testable ones in our Discussion and argue why we are confident that they do not apply. To exclude the testable ones, we can draw on our data collected for the tests of H1 through H3 to some degree. However, we also need to employ additional data at some points. In the following, we exclude three further plausible rationales for why p–c innovators might have waived their property rights: reputational benefits, externalities from increasing upstream or downstream production, and unrelated complementarities between OSS engagement and proprietary research. The first two require the analysis of further data, which we describe briefly in the following section (details are relegated to Appendix A). Finally, we present additional qualitative evidence further supporting our theoretical rationale and quantitative results.

4.1.1. Reputational gains from cheap waivers

We started from the premise that the exclusion rights covered by the non-assertion covenants actually protect valuable assets, and that waiving them means allowing third parties to access a valuable resource. Barring this, our empirical findings pertaining to H1 might otherwise simply reflect a cheap attempt by p–c innovators to look "openly" good (Henkel, 2004) to (downstream) buyers and/or (upstream) suppliers by waiving the rights to some irrelevant technology. When examining this possibility, we find no evidence for its support. In Appendix A.1, we compare the IBM patents covered by the firm's non-assertion pledge to a matched-pair sample of patents. We find no statistical differences between the groups as far as bibliographic indicators of patent quality can reveal. Overall, the findings allow excluding that the firms pledged low-quality patents to the OSS community. In other words, the pledged exclusion rights appear to protect resource elements that are as rare and valuable as those that are not being pledged.

4.1.2. No benefits from relaxing exclusion-rights constraints on upstream OSS supply

A further assumption underlying our tests is that firms did not waive their OSS-related exclusion rights to benefit from externalities that are unrelated to H2 and H3. Two types of such other externalities of waiving proprietary rights have been discussed in the literature—demand-side (Peitz, 2004; Varian and Shapiro, 1999) and supply-side externalities (Murray et al., 2009).

With regard to the first type, loosening rights ownership can help facilitate adoption and further development of cumulative innovations (Bessen and Maskin, 2009) and platforms (Ethiraj, 2007; Gawer and Henderson, 2007). However, in our setting, it is unclear why the exclusion-rights waivers should create such positive demand-side externalities for the p–c innovators. In fact, while p–c innovators have incentives to guarantee free access to the infrastructure software layers, they are not incentivized to facilitate software application development on OSS more than necessary. This is because they will continue to compete fiercely in the market for downstream applications. IBM, for example, recently made headlines for accusing a competitor of patent infringement who was generating money from running downstream applications on OSS infrastructure. IBM argued that although access to their IP for OSS infrastructure was free, access to their IP underlying the application software was not.[27] When walking the fine line between facilitating the exploitation of OSS and retaining sufficient control over differentiating technology, the firm apparently needed to signal clearly what they were willing to share with competitors and what they weren't. Benefitting from *supply-side* externalities, however, may have been a reason for p–c innovators firms to waive their exclusion rights in the first place. OSS serves as an (upstream) input to these firms, and triggering additional productivity by third parties (Dahlander and Wallin, 2006) through a rights waiver may have been a desired outcome for them. As is known from other industries (Murray et al., 2009), it appears that "openness shocks" (i.e., the removal of exclusion rights) can trigger productivity on the part of vertically related third parties. In line with these rationales, we therefore tested whether p–c innovators' exclusion rights represented roadblocks to the productivity of (upstream) OSS programmers before the exogenous shock, and whether the waivers increased the productivity of OSS programmers (upstream technology suppliers). Such an increase in productivity might indicate enhanced technological functionality of OSS and could provide an alternative explanation for p–c innovators' increased reliance on OSS after 2004.

The detailed results pertaining to our tests are presented in Appendix A.2. In essence, we did not obtain any evidence in favor of supply-side externalities resulting from the patent pledges; that is, we did not obtain any empirical evidence showing that development activity around, and the functionality of, OSS increased following the non-assertion claims.[28]

4.1.3. Independent complementary effects between OSS and firms' proprietary research

A final but crucial condition to test H3 is to ensure that our findings are not spuriously driven by a known mechanism of complementarity between a firm's engagement in OSS and the number of exclusion rights it holds and acquires pertaining to proprietary parts of its business (Fosfuri et al., 2008). In order to disentangle

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[27] See http://arstechnica.com/open-source/news/2010/04/ibm-breaks-oss-patent-promise-targets-mainframe-emulator.ars.

[28] Notably, our findings are considerations pertaining to *ex-post* findings. Whether firms did alleviate IPR constraints with the *intent* to stimulate additional OSS productivity but OSS programmers actually never perceived private exclusion rights related to OSS as roadblocks in the first place cannot be fully disentangled from the alternative explanation; that is, that firms never intended to stimulate additional OSS productivity. Irrespective of which of these two explanations applies, however, our findings pertaining to H2 do not appear to be driven by rational firms' continued and long-term expectations of increasing OSS functionality by waiving their related rights.

this effect from the one we propose, we therefore include the (time-varying) stock of a firm's total software patents as a control in Tables 5 and 6. As our models show, particularly Models 6E through 6H, our treatment effects are robust to the inclusion of the software patent stock measure. These findings indicate that the effects we obtain for H3 are driven by a separate mechanism, which we believe is the value-capturing mechanism we described in detail when deriving the hypothesis. It is encouraging, however, that in most of our estimations we find effects for our controls that point in the same direction as Fosfuri et al.'s (2008) findings.

4.1.4. *Qualitative evidence*

We present qualitative empirical evidence to show that our findings are not just *ex-post* consistent with our theory, but likely reflect the results of consciously chosen moves by the firms *ex-ante*. First, our suggested explanations for the non-assertion claims is supported by industry officials' statements that we gathered through supplementary interviews and from published weblogs. These interviews serve illustrative purposes only and did not undergo explicit coding. However, they clearly show the *ex-ante* motivations for the pledges, as most powerfully summarized by two quotations from Bob Sutor, Vice President of Standards and Open Source at IBM:

> We're trying to get clever with this [non-assert pledge]. We're trying to show by example ...We in no way knew if this would be a major boon to the open source community in practice ...
>
> And [the other firms] are saying—IBM is lining up .... So we will freely give you our patent, but if you sue us or sue that product—that piece of software, then .... First of all, you don't get rights of the patent, and we get after you. So the idea was to [be able to] scare away, basically, everybody except patent trolls. (Interview with one of the authors, 14 May 2008; emphasis and material in brackets added).
>
> We hope that this [patent pledge] action will stimulate discussion about the changing nature of innovation and the new collaboration models enabled by the Internet and realized in the thousands of open source projects around the world. Of course, we also hope others will join us by similarly pledging patents to the commons. (Taken from http://www.sutor.com/newsite/blog-open/, 11 January 2005; emphasis and material in brackets added).

Second, the formation of the OIN supports our theory about the nature of the patent pledges. Specifically, the OIN is a not-for-profit organization co-founded by several p–c innovators in November 2005, *after* a considerable number of firms had asserted unilateral patent pledges. Equipped with financial resources by the founders (and, subsequently, by other p–c innovators joining as investors), the OIN is a separate legal entity with the specific goal of purchasing orphan patent rights that could potentially be used against the Linux operating system. Firms and individuals can become members of OIN for free and can use all patents pertaining to Linux owned by the OIN and its members; in turn, new members are required to grant rights to all existing and future members. Thus, OIN both creates a real (and coordinated) line of defense against private innovators and outsiders, trying to preempt any legal action against OSS users by supporting and promoting its social sanctioning.

5. Discussion, limitations, and conclusion

Our paper extends existing theory on the private–collective model of innovation by integrating the element of competition between proprietary and p–c innovators, and studying its consequences for firms' strategies to appropriate innovation rents. Whereas earlier work in this domain acknowledges the existence of competition between proprietary and p–c innovators (e.g., von Krogh and von Hippel, 2006; West, 2003), its actual impact on p–c innovators' strategies to capture value from innovation has so far largely been ignored (Lerner and Tirole, 2005). Motivated by the initial puzzle of why firms waive their own exclusion rights while also continuing to invest in the acquisition of third-party rights, we presented the following rational explanation for the observable firm behavior.

In order to retain access to the core innovation, the necessary condition for them to operate profitably, p–c innovators seek to shape their surrounding appropriability regime to a "non-enforcement" regime. By waiving their own exclusion rights, they achieve enhanced coordination among p–c innovators on mutual non-enforcement of exclusion rights. In addition, it allows them to set the tone for how to deploy exclusion rights in the industry, and to establish both norms (North, 1990) of non-enforcement and credible sanctioning mechanisms that will eventually hamper the efforts of their competitors, notably proprietary innovators, to enforce their exclusion rights against p–c innovators. In a nutshell, by giving away a part of their formal control, they gain a far more suitable regime for value appropriation in return! In order to limit the danger arising from those competitive firms that are not susceptible to the normative changes in the appropriability regime (such as patent trolls), p–c innovators additionally and simultaneously need to invest in the disarmament of residual exclusion rights by acquiring them.

5.1. *Limitations*

As with every empirical study, our analysis is subject to several data-related caveats. First, our results are obtained in one specific empirical context (infrastructure software) only. Moreover, our empirical tests to rule out alternative explanations, while comprehensive, are not suited to capturing *all* potential effects that may be at work. In addition, the extreme costliness of obtaining our data (particularly with regard to H3, but also with regard to H2) and the resulting need to focus on a subset of p–c innovators and their likely private counterparts limits the empirical picture we can draw. Furthermore, tests for H2 will always suffer from the fact that reassignments are an imperfect way to measure firms' overall patent acquisition activity, and purchases through straw men will continue to elude us.[29]

That said, however, we do think our study reports results that may likely be relevant to a broader group of settings in which p–c innovators compete with proprietary innovators.[30] We also believe that our study offers some unique strengths in terms of data. The custom-tailored product-level coding of the firms we study for H3 is highly original and very costly to reproduce, as is the collection of the reassignment data for H2 and some of the data on OSS

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[29] We are less concerned with the fact that it is not compulsory for firms to report reassignments. We see no reason why corporate omissions of registering reassignments should differ across groups of p–c and proprietary innovators, leading to a systematic bias in our data. Random failure to register reassignments, on the contrary, should make it more difficult to detect effects pertaining to H2, thereby biasing our findings conservatively.

[30] The competitive situation we pay particular attention to, involvement by IT firms in Linux, is not unique. For example, firms in mobile communications currently face a very similar setting. Several p–c innovators have adopted the open Android system, which is being attacked by private innovators. Microsoft, for example, currently seeks to collect patent licensing fees from handset manufacturers running Android on their hardware, claiming that Android is infringing on Microsoft's intellectual property. Similarly, our logic helps explain the recent fierce dispute between p–c and private innovators relating to the acquisition of IP divested after the take-over of (private–collective inventor) Novell, and in Nortel's bankruptcy auction.

programming activity (particularly with regard to the Linux Kernel) we use to rule out alternative explanations. In our eyes, all of our data sources provide powerful testing grounds for our theoretical conjectures. They should lend the appropriate scientific credibility to this study—not least because they characterize a setting in which the crucial assumptions for our tests are being fulfilled.[31] The fact that we obtain our robust results even on relatively small samples (108 and 270 observations) and across estimation techniques is encouraging. Additional robustness checks we conducted point toward the validity of our argument. It also appears unlikely that theoretical yet non-testable explanations in the context of this paper account for our findings. In particular, we consider it unlikely that mimetic isomorphism (DiMaggio and Powell, 1983) or information cascades (Bikhchandani et al., 1992), potentially competing explanations for the (collective) action we observe, drive our findings and render our own interpretation a functionalist fallacy.[32]

5.2. Implications for management theory more broadly

Above and beyond their direct contribution to the field of private–collective innovation, our findings have interesting bearings for other streams of management literature, most notably innovation strategy, resource dependence theory, and coordination and industry self-regulation.

Innovation scholars may find our results intriguing in two ways. First and foremost, our research challenges an established paradigm according to which holding temporary exclusion rights, notably patents, always helps firms capture more rents from innovation, unless these rights pose an obstacle to exploiting supply- or demand-side externalities that would increase the value of the innovation. As we demonstrate in our research, even in the absence of such obvious externalities, firms may be incentivized to waive their exclusion rights ‘only’ in order to ensure the status quo of appropriating value from a collective good. Second, our findings refine our understanding of how appropriability regimes (Teece, 1986) relate to firms' technology strategies. So far, prior research has stressed that the surrounding appropriability regime predetermines how a firm deploys exclusion rights to capture value (Cohen et al., 2000; Teece, 1986), saying that, *within* a given regime, similar firms display similar exploitation patterns, all else being equal. Our study highlights that, even within a given appropriability regime, variation in the incentives of using appropriation mechanisms such as patents as blocking rights exists when proprietary and hybrid business models compete with one another. This conceptualization allows us to better understand earlier phenomenological observations that similar firms behave differently in fields such as OSS when it comes to capturing value from innovation (Pisano, 2006), and we provide the first larger-scale tests in support of such arguments.

Moreover, our findings have implications for resource dependence theory. As we show in the paper, p–c innovators liberate themselves from an external resource constraint—here property rights held by proprietary innovators—by creating reputational cost barriers for the latter to legally exclude third parties from using the p–c resource. Put differently, we demonstrate that different sources of control over resources (Pfeffer and Salancik, 1978) can be mutually exclusive and that sacrificing the benefits of one form of control (here: ownership of exclusion rights) may strictly enhance the benefits of another (here: access). Examining this substitution character in different setups appears to be yet another relevant research question for future studies.

Finally, the way in which p–c innovators collectively abdicated their ownership rights allows us to add to literature on coordination challenges and industry self-regulation. To the literature on coordination challenges (e.g., Mintzberg, 1993; Olson, 1971), we contribute the argument that unilateral commitments to waive property rights, made in the expectation of reciprocal expropriation behavior by other rights-holders, can be a solution to the anticommons problem (Buchanan and Yoon, 2000; Heller, 1998). To us, a whole host of research questions emerge in this respect, the most important being how the number of players influences the performance of such coordination efforts to form a stable cartel that differs from standard price-leadership models (D'Aspremont et al., 1983; Prokop, 1999) and how the viability of this solution depends on explicit communication between players about their actions. Similarly, our study also relates to the literature on industry self-regulation (Ostrom, 1990), particularly on the formation of self-regulatory institutions (Barnett and King, 2008; Ingram and Inman, 1996). We provide an unconventional example of an attempt by a subgroup collective to establish norms of behavior that are, at least in part, meant to force their competitors into a cease-fire. Moreover, we see that associations (OSDL and OIN) seem to have played crucial roles in this process, further suggesting that it was not *one* unilateral pledge but only the *combined and coordinated* efforts of a group of p–c innovators that rendered the rights-waiving strategy efficacious. Current research in other industrial settings (e.g., Perkmann, 2009) suggests that the existence of similar self-regulatory institutions is facilitative or perhaps even a precondition to sustainable value capture strategies by p–c innovators, yet further research on this topic is needed.

5.3. Implications for policy makers

Finally, we believe that our article may be of some interest to policy makers debating and passing legislation pertaining to intellectual property (also see, e.g., Baldwin and von Hippel, 2011). When saying so, we are fully aware that entertaining a full-fledged discussion on the policy implications of the competition between

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[31] In addition to satisfying the time-invariant (basic) assumptions about firms' mode of innovating etc. (see DATA section), this includes the crucial (time-variant) supposition that customers could observe and did dismiss proprietary innovators' enforcement of patents post 2004 (as per H2); articles and blogs abound of software customers complaining about Microsoft's continued unwillingness to team up and co-operate with those firms that work towards creating an ‘ecosystem’ around OSS (as an example, see Turner, 2007). Naturally, we must not exclude that this IP awareness in the infrastructure sector as of late is partly due to the involvement of some of the largest players of corporate America-in turn guaranteeing major media coverage. Final consumers might be less informed in other-more fragmented-industries, in which proprietary innovators might then still be less constrained in exercising their legal rights against p–c innovators.

[32] Mimetic isomorphism denotes the process of organizations imitating others that are perceived to be legitimate and successful (Ghoshal, 1988). So, in theory, the pledges we observe by some firms may be an imitation of the pledging behavior of the first firm to waive its rights. Thus, the behavior by firms such as Nokia, Computer Associates, and NEC might be regarded as a simple imitation of IBM's initial pledging. The possibility of this mechanism driving our results, while theoretically existent, appears unlikely, however. Research suggests that imitation occurs in three modes offering different types of imitation motivations: frequency-based, outcome-based, and trait-based imitation (Haunschild and Miner, 1997; Williamson and Cable, 2003). The first two modes are not applicable in our context, as the number of pledging predecessors was low (<3) for all dedicated firms (0 for IBM), and since the outcomes of the pledging process were not immediately visible. Also, trait-based imitation on the part of Nokia, Computer Associates, and NEC is improbable, as trait-based imitation occurs when “. . . goals are ambiguous, or when the environment creates symbolic uncertainty” (DiMaggio and Powell, 1983, p. 69). It appears extremely unlikely, however, that market leaders such as Nokia, Computer Associates, and NEC would be incapable of reading IBM's pledging actions correctly. Information cascades occur when initial decisions by some players in a market setup coincide in such a way that it is optimal for each of the subsequent individuals to *ignore* his/her private signals and follow an established pattern (Anderson and Holt, 1997). Conformity of followers in the cascade, a crucial mechanistic element in an information cascade, is observable in our data only to the extent that all dedicated firms do pledge patents to OSS. That said, however, the pledges are substantially differentiated between firms. This makes it unlikely that the firms following IBM (Nokia, Computer Associates, and NEC) fully discarded their private information when joining in the non-assertion claiming.

p–c and proprietary innovators would entail assessing the individual welfare contributions by all players involved—p–c innovators, proprietary innovators, trolls, and consumers. Clearly, our article stops short of achieving this notoriously difficult task—and it has never been our intention to accomplish it. That said, we do believe the aforementioned discussion provides some guidance for to how think about the potential actions policy makers are contemplating at present and may ponder in the future. More specifically, we think some interesting thoughts do emerge on the persistent issue of software patent legislation. Whereas many of the initial discussions in the past were led in a rather dichotomous fashion—arguing either for or against allowing software to be protected—as of late some scholars (e.g., Bessen and Hunt, 2007; Hall and MacGarvie, 2010) have provided more nuanced views, which we would like to elaborate on.

In order to do so, we must ponder two hypothetical scenarios. In the first one, we assume that software can no longer be protected via patents (or any other intellectual property, for the sake of taking the argument to the extreme). Under those conditions, so we would expect, p–c innovators in software-related sectors (like the infrastructure sector we discuss in this paper) would flourish *if and only if* they, together with the wider public, could truly independently develop the collective innovation required to fuel their businesses. Consumer rents would increase as a consequence of increased public good production, p–c innovators might be enabled to develop better products, and so forth; at the same time, proprietary innovators would suffer from these developments, and so would trolls. Whether the net effect of such legislation would be positive or not would depend on two questions: first, whether collective software development could function without the initial imitation of proprietary innovation at all; and second, whether p–c innovators—once deprived of their proprietary competition—would erode welfare gains by charging higher margins for their complementary assets.

In the second scenario, let us assume that all software can be patent-protected. P–c innovators would continuously have to invest in protecting the core collective innovation, reducing overall welfare gains. Also, to the extent that independent double inventions take place between the public and proprietary innovators, wasteful duplication of efforts would continue to dominate the marketplace. Moreover, trolls would continue to have incentives to destroy overall value (Bessen et al., 2011). Finally, administrative deadweight losses would occur.

Based on these rationales, we do believe that neither single-sided suggestions favoring software patenting nor unreflected proposals for abandonment should dominate the debate. On the contrary, we believe that the question should be posed which *kind* of software should be protectable using legal means, for it would not be produced (well and early enough) through the collectives or communities without at least initial investment by private firms. Notably, this discussion would substantially differ from the generic debates on patent scope, which conceive of inventive step (or non-obviousness) as an ordinal construct that—if high enough—deserves patent protection, and not otherwise. Instead we argue that certain categories of software may deserve protection whereas others do not. Naturally, far more empirical research would be needed to take this debate to the next level. Only one issue appears non-controversial to us already, based on the findings obtained in earlier articles (Henkel and Reitzig, 2008; Reitzig et al., 2007) and reinforced by the research presented in this paper: that any approach to the software patenting debate must make it a priority to selectively aggravate trolls' access to and enforcement of intellectual property, as there are simply no indications that any of the trolls' actions would ever lead to anything other than a net decrease in welfare, no matter how hard one searches for it (Bessen et al., 2011; Reitzig et al., 2007).

Acknowledgments

The authors express their genuinely felt gratitude towards all those colleagues who helped refine this manuscript over the years. The authors are particularly indebted to Editor Stefan Kuhlmann, three anonymous reviewers, participants at the Wharton Technology Conference 2010, the Darden Strategy Conference 2010, the 9th International Workshop on Open and User Innovation 2011, as well as seminar audiences in Chapel Hill (UNC), Frankfurt (Frankfurt School of Finance and Management), London (London Business School, University College London), Rome (LUISS), and Zurich (ETH). In addition, Oliver Alexy would like to thank Joachim Henkel and Karim Lakhani for their individual feedback, and he acknowledges the support of both the U.K. Innovation Research Centre (RES/G028591/1) (sponsored by the Economic and Social Research Council; the National Endowment for Science, Technology and the Arts; the U.K. Department for Business, Innovation and Skills; and the Technology Strategy Board) and the Engineering and Physical Sciences Research Council (GR/R95371/01).

Appendix A. Exclusion of alternative explanations

A.1. Quality of patent covered by the IBM non-assertion pledge

In order to rule out that the patents covered by the non-assertion claims serve to send cheap reputational signals, we need to compare their quality to that of other patents held by the dedicated firms. We focus on the patent pledge by IBM because it is the most detailed pledge in terms of denoting the actual patents that the firm announces not to enforce against OSS-related endeavors, and we compare pledged and not-pledged patents using a matched-pair sample approach. In more detail, we matched the 500 patents pledged by IBM with other IBM patents using a series of criteria (patent class, ideally same primary class, but at least one shared patent class; issue date, ideally same month, max. 1 year before or after). Using this procedure, we identified unique matches for 454 patents held by IBM itself. We added another 46 patents from other firms (using the same matching algorithm). For all patents (actual and matched sample), we collected established bibliographic indicators used to measure patent value in large-scale empirical studies (Lanjouw and Schankerman, 2004). We then tested whether these indicators would predict whether a given patent would fall under the non-assertion claim. There seem to be no major significant differences between patents covered by the IBM non-assertion claim and their matched twins. The estimation model itself is barely significant. Only one indicator is significant at the 10%-level in Model B of Table A1. The results are robust to alternative matching algorithms (filing date instead of issue date in our search algorithm) as well as to the inclusion of patents donated by other firms (Computer Associates and Blackboard).

A.2. Measuring changes in upstream supply productivity caused by the IBM pledge

For this test, we collected data on programming activity of OSS projects using SourceForge.Net (Madey, 2009), the world's largest repository of OSS data. SourceForge.Net hosts information on over 100,000 OSS software projects. To be able to conduct meaningful tests on this data, we theoretically sample a limited number of projects for which potential changes in productivity should be particularly pronounced (i.e., either a very high effect or no effect). To do so, we first classified project categories within the SourceForge.Net repository into those that should be affected by the patent pledges and those that should not. In order to make this distinction, we reverted to the IBM patent pledge, as this is the most

Table A1
Likelihood of patent being covered by the non-assertion claims as a function of patent quality.

	A ($N = 1000$)	B ($N = 908$)
Sample	All IBM patents	Only those with IBM match
Number of claims	−0.05	−0.04
Forward citations in first 5 years after grant	−0.05	−0.05
Backward citations to patents	**−0.08**[†]	**−0.08**[†]
Backward citations (other)	−0.02	−0.03
Approval time (grant date—filing date, in years)	**0.07**[†]	0.07
Log-likelihood (χ^2-Test)	**10.54**[†]	**10.22**[†]

"p-values are two-tailed; coefficients are standardized."
[**] $p < 0.01$.
[*] $p < 0.05$.
[†] $p < 0.1$.

comprehensive and detailed pledge of all firms and should allow us to identify the majority of technological areas potentially affected. Drawing on this distinction, we then carried out two types of tests. Across different project categories, we first looked for differences-in-differences with regards to new project registration and project activity measures (such as bug reports, patch submissions, help requests, and feature requests) over the period 2000–2008. This test, carried out on a large subset of SourceForge.Net data, did not yield any results drawing our assumption into question. The strength of this test lies in the large number of observations we could draw on, comprising more than 90,000 newly registered projects and more than 1.8 million individual activities during the observation period. Its potential weakness lies in the fact that we need to rely on relatively crude measures pertaining to project activity. We therefore complemented our first test with a second one of similar nature. Here, we narrowed in on only a few projects for which we could then describe project activity at a more fine-grained level. We selected eight specific projects from these two categories (affected and non-affected projects) that had been founded well before the publication of the OSRM report and that were still "active" in 2008. For those we tracked productivity before and after the patent non-assertion claims by downloading all data on programming activity, which allowed us to compute productivity-related measures for these projects. In more detail, we collected information on the number of files that were created, changed, and deleted on a projectmonth basis for a period of 18 months before and after the OSRM report release. Judging from earlier work (Michlmayr and Senyard, 2006), we assume that changes in programming activity, if there were any, should manifest themselves over a rather short period of time, as opposed to changes in firm behavior. Hence, we choose a shorter observational period for the test of this alternative explanation than we did for H2 and H3, and we move to a finer-grained level of observation (projectmonth as opposed to projectyear level) (Table A1).

Fig. A1 provides an illustration of our data. Table A2 above shows empirical results pertaining to differences-in-differences estimations comparing the productivity in affected and non-affected OSS projects before and after the exogenous shock. To complement our findings for one of the commercially most relevant OSS projects, the Linux Kernel, we separately collected information on Linux Kernel programming activity—data that are not available on SourceForge.Net at the fine-grained file level. Whereas we did not succeed in obtaining monthly file-level data for Linux, we did manage to collect information on the inclusion of monthly collective patches to the Linux Kernel (more information is available from the authors upon request). Even though these data are not directly comparable with the more fine-grained file-level variables obtained from SourceForge.Net, it appears that the patent non-assertion claims did not have an impact on Linux Kernel production (measured as collective patch contribution), either.

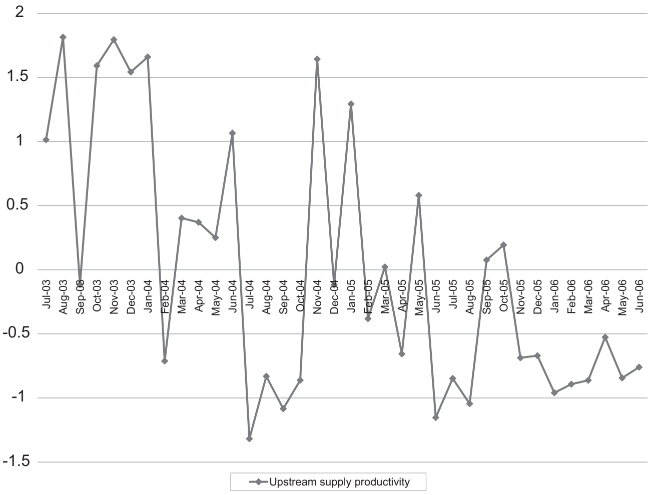

Fig. A1. Temporal Development of Dependent Variable. Note: Numbers represent standardized ratios of affected versus non-affected projects.

Table A2
Differences in upstream supply productivity before and after the publication of the OSRM report between affected and non-affected OSS projects ($N = 288$; eight groups).

	A		B	
Treatment date	August 2004		January 2005	
d_{post}	0.668[**]	(0.248)	0.872	(0.326)
$\boldsymbol{d_{treat}\ d_{post}}$	***−0.415***[**]	***(0.164)***	***−0.383***[†]	***(0.283)***
Project age (in months)	0.006	(0.010)	0.007	(0.011)
Log-likelihood (χ^2-Test)	−3853.037[**]		−38174.805[**]	

"p-values are one-tailed per our hypothesis; standard errors in parentheses."
We carry out the Poisson panel regression using a quasi-maximum likelihood estimator that allows for project-level fixed effects and accordingly corrects standard errors for correlations within the observations of one project (command "xtpqml in STATA").
[**] $p < 0.01$.
[*] $p < 0.05$.
[†] $p < 0.1$.

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