Beyond Pecuniary Incentives: How Openness-Preserving IPR Shapes Cumulative Innovation

ABSTRACT

A central assumption in innovation policy is that stronger intellectual property rights (IPR) hinder cumulative innovation. This view, however, largely rests on the premise that innovators are primarily extrinsically motivated. We challenge this assumption by examining how IPR affects cumulative innovation when contributors are intrinsically motivated and when IPR is designed to preserve openness. Using a quasi-natural experiment from a landmark lawsuit, we implement a difference-in-differences analysis on GitHub repositories. We find that strengthened copyleft enforcement increases both the quantity and novelty of external follow-on innovations. We further find that a stronger openness-preserving IPR regime can amplify the use of available knowledge in cumulative innovation. Our findings extend the dominant IPR framework built around rent maximizing agents and exclusion rights by highlighting how the impact of IPR depends on what is being protected and on the motivations driving those who contribute to follow-on innovation.

INTRODUCTION

A fundamental trade-off in innovation policy concerns the strength of intellectual property rights (IPR). Stronger IPR, such as patents or copyrights, grant innovators greater exclusive control and profit opportunities, but they also raise barriers for others who might build on that knowledge (Green & Scotchmer, 1995; Hall & Harhoff, 2012). In theory and in practice, IPR regimes have been conceptualized primarily as value appropriation mechanisms that incentivize rent-maximizing agents. By increasing expected monetary returns for initial innovators while restricting access for follow-on users, tighter protections are expected to impede cumulative innovation (Heller & Eisenberg, 1998; Mazzoleni & Nelson, 1998). Empirical research largely supports this view: strengthening IPR protections tends to reduce downstream innovation, as potential adopters face higher costs and legal risks when building on protected knowledge (Murray & Stern, 2007; Galasso & Schankerman, 2015; Sampat & Williams, 2019). Under these traditional assumptions—where all actors respond mainly to pecuniary incentives—stronger IPR is predicted to suppress external follow-on innovation.

However, not all innovation is driven by monetary gain. Intrinsic motivation – the desire to exert effort for the inherent interest and enjoyment of the work itself – plays a pivotal role in creative endeavors (Amabile, 1988; Grant & Berry, 2011). Prior studies show that such intrinsic motivation can fuel greater creativity and persistence in complex problem-solving tasks (Sauermann & Cohen, 2010; Zhang & Bartol, 2010). Yet, the cumulative innovation literature has only begun to grapple with this reality. Most IPR scholarship continues to assume innovators are extrinsically motivated, focusing on how IPR shapes financial incentives for innovators and followers (Bessen & Maskin, 2009; Hall & Harhoff, 2012). As a result, we know little about how changes in IPR regimes affect innovation when contributors are motivated by curiosity, desire to learn, or ideology (Ryan & Deci, 2000; von Krogh et al., 2012) rather than profit. This gap is especially important because many innovation communities – from academic science to open-source software – are populated by individuals who prioritize non-pecuniary rewards (Hertel, Niedner & Herrmann, 2003; Roberts, Hann & Slaughter, 2006). In such settings, contributors openly share knowledge and derive personal fulfillment from the creative process, suggesting that the conventional IPR trade-off might not apply in the same way.

Open source software (OSS) provides an ideal context to examine this boundary condition. OSS development is inherently cumulative: globally distributed developers iteratively build on existing code, and new contributions often explicitly incorporate prior code from others (von Krogh, Spaeth & Lakhani, 2003; Nagle, 2018). These communities are famously fueled by intrinsic motivations, as participants often cite intellectual challenge, skill learning, peer recognition, and a commitment to free knowledge as primary reasons for contributing (Lerner & Tirole, 2002; von Hippel & von Krogh, 2003). At the same time, OSS relies on formal licensing agreements that serve as an IPR regime for openness (von Krogh & von Hippel, 2006). In particular, copyleft licenses like the GNU General Public License (GPL) require that any derivative works remain open-source, using legal enforceability to safeguard the public availability of knowledge and prevent downstream privatization (O'Mahony, 2003; Dixon, 2004; Lin & Moon, 2020). This means that, unlike proprietary patents, these IPR provisions are designed not to secure private rents, but to ensure that innovations stay in the public domain. As von Krogh and von Hippel (2006) argue, "*once we begin to understand how the open source example functions, the entire fabric of assumptions buttressing the necessity of intellectual property protection regimes, with their well-known negative side effects on the freedom to innovate and adopt, can be examined with fresh eyes.*"

Additionally, OSS projects vary in the extent to which they draw on upstream code from other projects (Kalliamvakou et al., 2016), giving us leverage to observe how the availability of cumulative knowledge interacts with contributor motivations. In general, having a rich pool of upstream components is known to enable greater follow-on innovation (Ahuja et al., 2008; Fleming, 2001; Fleming & Sorenson, 2004; Laursen & Salter, 2006). However, in this context, we argue that the benefits of abundant knowledge can be fully realized only when contributors are intrinsically motivated and their work is protected by an openness-preserving IPR regime. Taken together, the OSS setting features intrinsically motivated agents and an unconventional IPR design, allowing us to revisit the IPR–innovation relationship in a context where the usual assumptions no longer hold true.

Building on these insights, we propose that intrinsic motivation is a critical and underexplored boundary condition in the IPR–cumulative innovation relationship. When innovators care about intellectual challenges and the communal value of knowledge, strengthening IPR protections can in fact spur follow-on innovation, provided that those protections are aimed at openness rather than exclusion. In contrast to the traditional prediction, we argue that an IPR regime designed to protect public knowledge can reinforce contributors' intrinsic motivations. A more enforceable copyleft license gives developers greater assurance that their work will remain openly accessible, which amplifies their non-pecuniary rewards (Franck & Jungwirth, 2003). Knowing that follow-on contributions will be freely shared and aligned with a pro-open ideology heightens contributors' sense of purpose and autonomy (Benkler, 2002; Daniel et al., 2018; Stallman, 2006). Put differently, stronger legal safeguards for openness increase the perceived intrinsic returns to engaging in cumulative work. Enthused by the promise that their efforts will benefit a wide community (and not be privatized), intrinsically motivated developers are willing to invest more time and creativity into extending complex, interdependent codebases.

Moreover, a stronger openness-preserving IPR regime can amplify the use of available knowledge: we contend that the impact of such IPR strengthening will be especially pronounced when a rich pool of existing knowledge is at hand. While abundant upstream components provide raw material for innovation, their efficacy in sparking follow-on contributions depends on having the right motivational and legal conditions in place. In projects that build heavily on upstream code, intrinsically driven contributors can fully leverage that abundance only if the IPR framework guarantees continued openness. Thus, contributor motivation becomes a pivotal contingency for cumulative innovation outcomes: the usual inhibitory effect of strong IPR may turn positive when innovation is fueled by intrinsic incentives and protected by openness-focused rights.

We test this theoretical argument by exploiting a recent legal shock in the open source world. In 2017, a U.S. court ruling in Artifex v. Hancom strengthened the enforceability of the GPL license, confirming that open source licenses can be upheld as binding contracts (Artifex v. Hancom, 2017). This decision effectively bolstered IPR protections for openness, creating a natural experiment to observe how OSS contributors respond when copyleft rules gain teeth. Using a difference-in-differences design on a panel of 7,869 GitHub repositories (with 336,553 external contributions), we compare projects under GPL copyleft licenses to similar projects under more permissive licenses. Consistent with our hypothesis, we find that after the legal enforceability of GPL was reinforced, external follow-on contributions to GPL-governed projects significantly increased relative to the control group. This surge is evident not only in the quantity of contributions (more pull requests from external developers), but also in their quality and novelty. Moreover, the increase in follow-on innovation is most pronounced for projects with extensive upstream dependencies, in line with the idea that intrinsically motivated contributors make greater use of abundant open knowledge when its open status is assured. These findings run counter to the conventional wisdom that stronger IPR automatically stifles cumulative innovation. Instead, our study reveals that when IPR is aptly designed to uphold open collaboration, it can activate intrinsic incentives and accelerate downstream innovation. In doing so, we highlight an important boundary condition to prevailing IPR theory and demonstrate how legal mechanisms aimed at protecting the commons can invigorate, rather than impede, cumulative technological progress.

LITERATURE AND THEORETICAL BACKGROUND

IPR and Cumulative Innovation

Recognizing that scientific innovation is built on a "*cumulative, chain-linked impetus to the advance of knowledge*" (Dasgupta & David, 1994, p. 500), research has been exploring the role of IPR in shaping this cumulative process and suggests that the design of IPR regimes affects both the incentives of the initial innovator and the opportunities for follow-on adopters (Bessen & Maskin, 2009; Gaessler et al., 2025; Hall & Harhoff, 2012; Sampat & Williams, 2019). Conceptual and model advancements typically view IPR as value appropriation mechanisms that enable innovators to earn rents by granting exclusion rights through patents, copyrights, and other means over the use and commercialization of knowledge (Hall & Harhoff, 2012). A fundamental trade-off has been emphasized in this line of research, where stronger IPR can raise expected returns and thus stimulate initial innovation, but simultaneously restrict access to prior knowledge, deterring follow-on innovation (Green & Scotchmer, 1995; Mazzoleni & Nelson, 1998).

Empirical evidence, adopting patent and other IPR contexts, also highlights this fundamental trade-off and provide consistent observation that strengthening IPR protection impede cumulative innovation (Giorcelli & Moser, 2020; Mezzanotti, 2021; Williams, 2013). For instance, Murray and Stern (2007) show that when scientific articles describing DNA sequence discoveries are later associated with patents, citations to those articles decline, consistent with a dampening effect of formal IPR protection on follow-on research. Similarly, Sampat and Williams (2019) find that granting patents on genes associated with the human genome is associated with reduced follow-on innovation using those genes. Adopting litigation and policy shocks, Galasso and Schankerman (2015) exploit patent invalidation decisions and find that invalidation leads to significant increases in citations by competitors, particularly in technologies and markets where patents are highly fragmented. Gaessler and colleagues (2025) also show that post-grant opposition in the European patent system affects "freedom to operate" and can spur follow-on patenting when blocking patents are weakened. And the potential mechanisms through which the trade-off may exist include the increasing entry costs into a new technological domain (Noel & Schankerman, 2013), rising complexity and costs of navigating prior patent thickets (Hall & Ziedonis, 2001), higher negotiation and licensing costs (Walsh et al., 2003), and intensified competition and bargaining process (Somaya, 2012).

Taken together, this literature establishes a framework in which IPR regimes are conceptualized as instruments for enabling pecuniary incentives, assuming both initial inventors and follower as rent-maximizing agents who respond to strengthening IPR protections through changes in expected monetary returns, litigation risk, and bargaining power (Bessen & Maskin, 2009; Green & Scotchmer, 1995; Hall & Harhoff, 2012). Therefore, strengthening IPR can reduce external follow-on innovation given the lower economic return. However, these works typically abstract away from other type of motivations in innovation and rarely consider how the effects of IPR might differ in contexts where innovative effort is driven less by pecuniary rewards.

Role of Intrinsic Motivation

Independent to the classic framework on the role of IPR in cumulative innovation, another stream of research in management and organizational psychology highlights intrinsic motivation as a central driver of innovative behavior. Amabile (1988) develops a componential theory of innovation and suggests that inventors are most creative when they are motivated by interests and enjoyment inherent in work itself, forming the foundation for the role of intrinsic motivation in driving innovation through creativity (Amabile & Conti, 1999; Anderson et al., 2014). Similarly, building on self-determination theory, Ryan and Deci (2000) argue that intrinsic motivation arises when individuals experience autonomy, competence, and relatedness in their work, and they describe intrinsically motivated behavior as engaging in an activity "*for its inherent satisfaction rather than for some separable consequence*" (Ryan & Deci, 2000, p. 56). While different in their approaches in understanding intrinsic motivations, these early conceptual advances, along with recent attempts in unpacking the structure of intrinsic motivation (e.g., Fishbach & Woolley, 2022), point to a connection between intrinsic motivation and innovation, suggesting that in addition to pecuniary incentives, intrinsic motivation can also contribute to the development of cumulative innovation (Osterloh & Frey, 2000).

Empirical studies in management and innovation research corroborate this relationship. Grant and Berry (2011) show that intrinsically motivated employees generate more creative ideas, and that this effect is amplified when prosocial motivation is high, as individuals channel their interest and enjoyment into ideas that are both novel and useful. Zhang and Bartol (2010) find that intrinsic motivation mediates the relationship between empowering leadership and employee creativity, with intrinsically motivated employees more likely to engage in creative process activities such as problem identification, information searching, and idea generation. Similarly, Sauermann and Cohen (2010) use survey data on industrial scientists and engineers to show that motives related to intellectual challenge and independence are positively associated with innovative effort and self-reported performance.

The role of IPR, as a type of value appropriation mechanisms, in affecting intrinsic motivation remains to be understudied, as "*intrinsic motivation is not simply additive to the motivation induced by prices (extrinsic incentives)*" (Osterloh & Frey, 2000, p.538). Accordingly, intrinsic and other non-pecuniary motives are studied more in innovation contexts where extrinsic incentives are inhibited, and voluntary contributions are dominant. Specifically, OSS has been a focal context, as it frequently be conceptualized as a "private-collective" innovation model in which private benefits (e.g., learning, signaling, tool improvement) coexist with collective benefits from freely accessible code, emphasizing that intrinsic motivation can sustain substantial innovative effort even when outputs are publicly shared (e.g., von Hippel & von Krogh, 2003). For instance, Lakhani and Wolf (2005) report that many OSS developers cite enjoyment-based intrinsic motivation and the desire to improve programming skills as important reasons for their participation. Hertel, Niedner, and Herrmann (2003) find that identification with the Linux community remains to be an important driver for contribution, in addition to incentives to improve one's own software. Roberts, Hann, and Slaughter (2006) similarly show that OSS developers report ideology and enjoyment as central motivations, in addition to career-related incentives.

As organizations rely more heavily on OSS and other shared knowledge resources, they become dependent on contributors whose primary motivations are intrinsic (Conti, Peukert, & Roche, 2025; He, Puranam, Shrestha, & von Krogh, 2020; Nagle, 2018). Accordingly, this calls for a closer look on how IPR regimes in corresponding environments may affect cumulative innovation when effort is sustained by intrinsic interest, learning, community identification, or ideological commitments, since traditional IPR studies typically abstract away from intrinsic motivations and continue to model followers as rent maximizing agents responding to pecuniary incentives. Correspondingly, we set to address this gap and hypothesize the relationship between strengthening IPR in OSS and innovation, adopting the theoretical foundation of intrinsic motivation.

Intrinsic Motivation as Boundary Condition: Leveraging Cumulative Knowledge

Meanwhile, research in cumulative innovation and knowledge recombination suggests that cumulative knowledge components provide the foundation for follow-on innovation. Conceptual and empirical work on knowledge search and recombination submits that innovators can develop innovation by combining existing components in novel ways, and that the availability, diversity, and integration of existing knowledge components shape the potential for recombination (e.g., Ahuja, Lampert, & Tandon, 2008; Fleming, 2001; Fleming & Sorenson, 2004). Empirical evidence similarly indicates that access to a broader set of knowledge components is associated with more downstream innovation, measured in patents, scientific publications, or other outputs (Giorcelli & Moser, 2020; Murray & O'Mahony, 2007; Williams, 2013). In OSS contexts, open repositories, along with clear contribution records and modular architectures, make prior contributions and knowledge components more available for external contributors to draw upon (e.g., Kalliamvakou et al., 2016; Wright et al., 2023) by broadening the set of knowledge components for recombination and allowing access to distant and novel knowledge (Alexy, George, & Salter, 2013; Boudreau & Lakhani, 2015; Nagle, 2018). Taken together, this line of studies highlights the essential role of cumulative knowledge components in facilitating the development of follow-on innovation.

However, the existence of cumulative knowledge components does not guarantee that they will be creatively recombined and developed into new innovation. Search is costly and cognitively demanding, and innovators are frequently constrained by myopia, relying on familiar components and dwelling on knowledge domains that are proven to be rewarding (Katila & Ahuja, 2002; Laursen & Salter, 2006; Osterloh & Frey, 2000; Sauermann & Cohen, 2010). As a result, the extent to which given cumulative knowledge components contributes to follow-on innovation depends not only on the access to a set of cumulative knowledge components, but also on innovators' motivation to undertake costly investment required to learn, search, and leverage those components. Research on intrinsic motivation and creativity suggests that non-pecuniary motivations, such as enjoyment of problem solving and interest in learning and identification with a broader community, play a central role in whether individuals engage in exactly these investments (Amabile, 1988; Grant & Berry, 2011; Sauermann & Cohen, 2010; Zhang & Bartol, 2010). Accordingly, these studies suggest that contributors' motivations may constitute an important boundary condition for when access to cumulative knowledge components may translate into follow-on innovation, a boundary condition that has been incorporated only to a limited extent in the literature. We therefore conceptualize and hypothesize that intrinsic motivation as a central boundary condition for when access to cumulative knowledge components in the OSS context leads to higher quantity and quality of follow-on innovation.

IPR in OSS: Copyleft License Enforceability

Open source communities have created explicit licensing terms around maintaining and building the commons (Shah & Nagle, 2019), which essentially reallocate intellectual property rights of the software from a single owner to a collective. In traditional proprietary development, governance is enforced through secrecy or restrictive contracts—only the owner has the right to modify or distribute the software. In OSS, however, the license proactively grants IPR permissions to all users, effectively transferring significant usage and modification rights to a community of peers (Harhoff, Henkel, &

von Hippel, 2003; O'Mahony, 2003). For example, a typical open source license grants any user the rights to access source code, create derivative works, and redistribute those derivatives. As Osterloh and Rota (2007) argue, "*when people contribute their developments to OSS projects, they do not simply give up their intellectual property rights. Instead, they use their property rights to protect their developments from ever being appropriated*." In essence, the license is a private-ordering contract that guards the collective interest in the commons while enabling open collaboration. The emergence of OSS licensing is thereby viewed as "institutional innovation" that allows software to survive as common property rather than private property. This approach challenges the traditional notion that innovation requires strong exclusive rights (Demsetz, 1967), illustrating instead a "private-collective" model of innovation (von Hippel & von Krogh, 2003) where individuals and firms voluntarily give up exclusive claims in order to jointly produce a public good.

Open source licenses are broadly classified into copyleft and permissive categories, and these differ markedly in how they allocate rights and shape contributor incentives. Copyleft licenses (also known as "restrictive" or reciprocal licenses, exemplified by the GNU GPL) require that any modified or extended version of the code be distributed under the same license term (Coleman, 2012; Lessig, 1999; Stallman, 2001). Copyleft thus grants freedoms with a condition: you may use and modify the software freely, but if you redistribute your modifications, you must grant the same freedoms to others. In contrast, permissive licenses (e.g., MIT, BSD, Apache) grant freedoms with minimal conditions and allow re-licensing of derivative works under different terms, including proprietary ones (Shah & Nagle, 2020). In other words, permissive licenses place few restrictions on how the code can be used or combined with other software. The two licensing styles represent different approaches to governing IPR in OSS. Copyleft licenses embed a strong share-alike rule, which effectively prevents any party from privatizing the software's improvements. Permissive licenses, by contrast, confer the most rights to downstream users, such that "*others (including competitors) can modify and use the software as they please*" (West, 2003).

Taken together, these distinctions imply that copyleft licenses, relative to permissive licenses, provide stronger institutional protection for the continued accessibility of open knowledge. A growing body of research has accordingly examined how OSS license choice shapes project development, contributor participation, and innovation outcomes (e.g., August, Chen, & Zhu, 2021; Belenzon & Schankerman, 2015; Lerner & Tirole, 2005; Stewart, Ammeter, & Maruping, 2006). However, a central challenge in this literature is that license choice is highly endogenous. Project owners may select a particular license based on unobserved project characteristics, strategic intentions, or anticipated commercial involvement, all of which are themselves correlated with subsequent project trajectories. To address this limitation, we exploit the landmark *Artifex Software, Inc. v. Hancom, Inc.* lawsuit as an exogenous institutional shock. This case established that the GPL constitutes a legally enforceable contract under U.S. law, thereby substantially strengthening the legal credibility of copyleft provisions and the protection of continued access to open knowledge. We leverage this legal clarification as a quasi-natural experiment and implement a difference-in-differences design to examine how strengthened protection of continued access to open knowledge—an IPR regime embedded in copyleft licensing—affects cumulative innovation in OSS projects.

HYPOTHESES

Intrinsic Motivation and Cumulative Innovation

As discussed, many contributors are primarily driven by intrinsic rather than pecuniary motivations in the OSS context. Prior work on open science and open source communities shows that contributors often report enjoyment of problem solving, learning, and the satisfaction of contributing to public knowledge and upholding ideologies of access to open knowledge as main reasons for their participation (Dasgupta & David, 1994; Hertel et al., 2003; Roberts et al., 2006). In line with this literature, we define intrinsic motivation in the OSS context as non-pecuniary motivations that combine the inherent interests and learning associated with innovations with the value derived from contributing to public and open knowledge (Lakhani & Wolf, 2005; von Hippel & von Krogh, 2003)[1]. Research in creativity and innovation further suggests that such intrinsic motivation is a key determinant of effort allocation in complex tasks, where intrinsically motivated individuals are more willing to invest and sustain time and cognitive capacity (Amabile, 1988; Grant & Berry, 2011;

[1] This definition departs from the taxonomy of intrinsic motivation defined by Ryan and Deci (2000), but it aligns with the context better and is still within the boundary of the literature building on the componential theory of innovation (Amabile, 1988).

Sauermann & Cohen, 2010; Zhang & Bartol, 2010).

Strengthening the protection of the public nature of knowledge affects contributors' intrinsic motivation. Institutional changes ensuring follow-on contributions will remain accessible and reciprocated, rather than being privatized downstream through enhanced GPL License enforceability, reducing the risk that contributors' efforts will be used in ways that conflict with their ideologies and increasing the likelihood that cumulative work will in fact advance the public knowledge and community norms that contributors value (Benkler, 2002; Daniel et al., 2018; Osterloh & Frey, 2000; von Hippel & von Krogh, 2003). For intrinsically motivated innovators, this change improves the alignment between what makes the contribution valuable to them and what actually happens to their contributions, achieving "*means-ends fusion*" (Fishbach & Woolley, 2022). As alignment increases, the non-pecuniary value to follow-on contribution rises as contributors still enjoy and learn from the task, they can now be reassured that their efforts will also lay the foundation for the open knowledge ideology.

Since intrinsic motivation directs where individuals choose to invest their effort, strengthened non-pecuniary motivations enabled by the institutional change should make contributing to OSS projects granting more intrinsic motivation more attractive relative to alternative uses of their time. Conditional on choosing to contribute, stronger intrinsic motivation also entails greater willingness to devote efforts required to complete follow-on innovation in projects with more protections of access to open knowledge, increasing the likelihood that ideas are developed into observable contributions. In OSS context where contributions are code, patches, or derivative projects, this reallocation of effort should manifest as a higher number of follow-on contributions directed at knowledge governed by stronger protections of open knowledge. Accordingly, we hypothesize:

Hypothesis 1a: Intrinsically motivated innovators will contribute more to cumulative innovation when protections of continued access to open knowledge are strengthened.

Besides affecting whether intrinsically motivated innovators choose to participate in cumulative work and how much effort they contribute, stronger protections of continued access to open knowledge should also shape the novelty of their contributions. Research on creativity and innovation suggests that intrinsic motivation is associated not only with greater effort, but also with deeper and extensive creative process, such as deeper and broader search, better problem identification, and more experimentations with non-routine solutions (Amabile, 1988; Grant & Berry, 2011; Sauermann & Cohen, 2010; Zhang & Bartol, 2010).

Meanwhile, such an effect connects with research suggesting how search and expanded knowledge components may lead to novel outcomes. Specifically, research on technological search and recombination suggests that novelty arises when innovators move beyond local knowledge and routine, and instead, engaging in broader search, drawing from more distant knowledge components, and integrating new knowledge components with existing knowledge base (Fleming, 2001; Katila & Ahuja, 2002; Laursen & Salter, 2006). In this view, follow-on contributions in OSS are more novel when contributors can provide more distant knowledge components that can be integrated with the existing projects (Alexy, George, & Salter, 2013; Boudreau & Lakhani, 2015; Murray & O'Mahony, 2007).

Accordingly, as the perceived alignment between contribution and the intrinsic motivation rises as the protection of access to open knowledge strengthens, intrinsically motivated contributors not only participate more frequently, but also have stronger motivations to undertake more exploratory efforts. As the result of these explorations, the likelihood that each follow-on contribution achieves higher novelty increases. As such, we propose:

Hypothesis 1b: Intrinsically motivated innovators' contributions to cumulative innovation will be more novel when protections of continued access to open knowledge are strengthened.

Moderating Effects: Cumulative Knowledge Components

Building on these baseline arguments, we now consider how strengthened protections of continued access to open knowledge differentially affect projects that vary in their access to cumulative knowledge components. Research on knowledge search and recombination suggests that innovators develop new innovation by combining existing components in novel ways, and that the availability, diversity, and integration of existing components shape the potential for recombination (Ahuja et al., 2008; Fleming, 2001; Fleming & Sorenson, 2004; Laursen & Salter, 2006). In the OSS context, projects differ systematically in the extent to which they are built on upstream projects, enabling access to different sets of cumulative knowledge components that can be further recombined and extended by subsequent innovators. Higher reliance on upstream projects indicates that a focal project is itself the outcome of cumulative development and is thus associated with a broader set of cumulative knowledge components that can be drawn on in follow-on innovation (Ahuja, Lampert, & Tandon, 2008; Fleming & Sorenson, 2004; Murray & O'Mahony, 2007; Williams, 2013).

However, the existence of cumulative knowledge components does not guarantee that they will be creatively recombined and developed into new innovation. Search and integration are costly and cognitively demanding, and the extent to which cumulative knowledge components contribute to follow-on innovation depends not only on access, but also on contributors' motivation to undertake the investments required to learn, search, and leverage those components (Amabile, 1988; Laursen & Salter, 2006; Osterloh & Frey, 2000; Sauermann & Cohen, 2010). Strengthened protections of continued access to open knowledge increase the non-pecuniary value of contributing for intrinsically motivated innovators by aligning their enjoyment of problem solving and identification with the ideology of open knowledge (Benkler, 2002; Dasgupta & David, 1994; von Hippel & von Krogh, 2003). Accordingly, intrinsic motivation acts as a boundary condition for when cumulative knowledge components are leveraged in follow-on innovation. Therefore, we expect the impact of strengthened protections of continued access to open knowledge on cumulative innovation to be more pronounced for projects that are more strongly built on cumulative knowledge components, as intrinsically motivated innovators who are willing to engage in more investment in learning and search after the strengthening protection can leverage a broader set of cumulative knowledge components for recombination. Accordingly, we hypothesize:

Hypothesis 2a: The positive effect of strengthening protections of continued access to open knowledge on the quantity of external follow-on contributions will be stronger for projects that rely more heavily on upstream projects.

In addition to the influence on the quantity of follow-on contributions, dependence on upstream projects can also moderate how strengthened protections of the public nature of knowledge affect the novelty of external contributions. As discussed, stronger protections raise the perceived non-pecuniary returns to more exploratory efforts for intrinsically motivated contributors, increasing the likelihood that they will engage in broader and less routine forms of cumulative work (Amabile, 1988; Grant & Berry, 2011; Laursen & Salter, 2006). For projects that rely more heavily on upstream projects, these exploratory efforts can interact with a broader set of cumulative knowledge components, enabling intrinsically motivated innovators to access more components, combine them in new ways, and develop new innovations that adapt or extend a wider scope of upstream knowledge (Fleming, 2001; Fleming & Sorenson, 2004; Katila & Ahuja, 2002). Consequently, when protections of continued access to open knowledge are strengthened, intrinsically motivated contributors' increasing willingness to undertake such efforts should be reflected in more novel follow-on contributions to projects with greater reliance on upstream projects, therefore we hypothesize:

Hypothesis 2b: The positive effect of strengthening protections of continued access to open knowledge on the novelty of external follow-on contributions will be stronger for projects that rely more heavily on upstream projects.

DATA AND METHOD

Research Design

Open source communities (OSCs) constitute a setting where cumulative innovation is salient (Nagle, 2018; Wright et al., 2023). Within OSCs, organizations and individual users publish the source code of their software projects (repositories), enabling voluntary contributors to use, modify, and submit code contributions (pull requests) that enhance or extend the existing codebase (Kalliamvakou et al., 2016; O'Mahony, 2003; von Krogh et al., 2003). This contribution process facilitates cumulative innovation, as improvements and new features are mainly developed through the modification or recombination of existing code artifacts, which remain visible and reusable to all subsequent contributors. Although source code in OSCs is openly accessible, the use of the existing codebase is not unrestricted, and is governed by property rights. Specifically, the allocation of IPR in this environment is defined by open-source licenses, which specify who may access, modify, and redistribute the code, and under what conditions (Markus, 2007; O'Mahony, 2003). These licenses operate as institutionalized IPR arrangements in the public domain, determining whether derivative works can be privately appropriated, must remain open, or are required to preserve reciprocal openness. In this way, OSCs provide a context where the fundamental elements of cumulative innovation and IPR design—public accessibility, reuse constraints, and control over downstream derivatives—are transparently enacted and empirically traceable.

This context is particularly well-suited for our research for three reasons. First, the innovation process in OSCs maps closely onto theoretical formulations of cumulative innovation: contributions are explicitly layered on prior work, derivative relationships are technically traceable, and follow-on innovations are produced through fine-grained recombinations of existing code elements. Second, OSCs are widely characterized by a high prevalence of intrinsically motivated contributors, for whom intellectual challenge, desire to learn, and commitment to open knowledge constitute primary drivers of innovative effort, making this setting especially suitable for examining how IPR regimes shape cumulative innovation under intrinsically driven production. Third, OSCs exhibit substantial variation in licensing regimes while holding many technological characteristics constant. The coexistence of comparable projects operating under copyleft and permissive licenses enables the construction of credible treatment and control groups. In particular, this variation allows us to exploit a legal shock to copyleft enforcement and implement a difference-in-differences design to identify developers' behavioral responses across projects with distinct IPR configurations.

Specifically, to identify the influence of enhanced anti-privatization created by a change in the formal protection of OSS projects, we employ a quasi-experiment design, in which we leverage an unexpected court ruling that shifts the enforceability of GPL licenses and study the change in knowledge development devoted to GPL projects in response to this shock. The exogenous shock is produced by the court ruling made by Judge Jacqueline Scott Corley from the Northern District of California on April 25, 2017, regarding the enforceability of GPL licenses as a type of contract during the trial of Artifex vs. Hancom (*Artifex Software, Inc. v. Hancom, Inc.*, 2017). In late 2016, Artifex, a California company specializing in document management software, sued Hancom, a leading office suite software developer in Korea, over a dual licensed product (AGPL, a variation of GPL license and a commercial license) "Ghostscript," which is a PDL document conversion tool. Alleging both copyright infringement and breach of contract, Artifex claimed that Hancom, who adopted the Ghostscript library without paying the commercial licensing fee, violated GPL license's terms by not open sourcing their derivative product. On April 25 of 2017, Judge Corley denied Hancom's motion to dismiss and affirmed that the GPL license could be enforced as a type of contract. This was the first court ruling, dictating that the violation of GPL can be treated as a breach of contract, affording more damage claims and a broader scope of enforcement in certain circumstances and creating significant legal risk for parties that misappropriate GPL projects (Dixon, 2004; Lin & Moon, 2020; Moody, 2017; Riskin, 2018).

Sample

Our empirical analysis relies on a large-scale, longitudinal panel dataset constructed from publicly available data on GitHub, the world's largest open source software (OSS) platform. To exclude low-visibility or trivial repositories, we begin with repositories that were created at least ten months prior to the legal shock and had received at least five forks (copies made by other users) or stars (bookmarks from other users showing interest), yielding an initial sample of in 429,151 repositories. To further exclude inactive or abandoned projects, we restrict the sample to 91,872 repositories that exhibited activity during the observation window (10 months before and after the legal shock). We then limit the sample to repositories whose owners are located in the United States, ensuring that the repositories in our analysis were plausibly exposed to the legal shock. Based on the repository-level sample, we identify pull requests submitted by external contributors, defined as developers who are neither repository owners nor organizational members. This step yields a sample of 7,869 repositories and 336,553 external contributions received by these repositories. Among these repositories, 872 are licensed under the GNU General Public License (GPL) and constitute the treatment group affected by the legal shock.

To strengthen causal identification, we employed a difference-in-differences (DiD) design that contrasts the post-lawsuit responses of treated projects with those of an appropriate counterfactual. We use Coarsened Exact Matching (CEM) to construct a control group consisting of developers engaged with comparable non-GPL (i.e., permissively licensed) projects that were not directly exposed to the legal shock. This procedure allows us to isolate the effect of strengthened copyleft enforcement from confounding project-level heterogeneity. The matching procedure proceeds in several steps. First, we require treatment and control projects to share the same owner type (individual versus organizational), ensuring comparability in governance and resource profiles. Second, following Ray et al. (2014), we map programming languages into broader paradigms—

procedural, scripting, functional, and other—and match projects within the same paradigm to hold constant underlying architectural and development norms. Third, we aligned projects on pre-treatment development momentum (Zheng and Wang, 2025), proxied by the number of external contributors between December 2015 and May 2016, to mitigate baseline differences in community engagement. Finally, we coarsen additional structural attributes—including the number of forks, watchers, repository size, and repository age—to further ensure similarity along key dimensions known to shape open source development dynamics.

We implement CEM using a 1:2 random matching strategy, pairing each GPL-licensed project with up to two comparable permissively licensed projects that satisfy the matching criteria. This procedure yields a final analytic sample of 544 U.S. GPL projects matched to 763 comparable U.S. permissive projects. The CEM procedure substantially improves covariate balance between the two groups, resulting in a more comparable analytical sample.

Variables

Dependent variables. We conceptualize pull requests (PRs) in open source software communities as instances of cumulative innovation. This interpretation is consistent with research in innovation studies and open source collaboration, which characterizes follow-on innovations as derivative additions that build on and recombine existing innovations (Freilich & Shahshahani, 2023; Gaessler et al., 2025; Murray & O'Mahony, 2007). PRs explicitly represent developers' attempts to extend, refine, or augment a project's codebase (Gousios et al., 2014; Tsay et al., 2014; Kononenko et al., 2018), making them a direct, fine-grained behavioral trace of cumulative innovative activity within open source communities.

Our first dependent variable captures cumulative innovation, measured by *external PRs*. We operationalize this variable as the monthly count of pull requests submitted by external contributors who are neither owners nor organizational members of the focal repository. In our sample, external PRs account for approximately 70% of all pull requests. To verify that our results reflect changes in externally generated innovation rather than broader shifts in project activity, we use the count of internal pull requests (i.e., those submitted by owners or organizational members) as a placebo outcome in robustness analyses.

Our second dependent variable captures cumulative novel innovation, measured by *external feature PRs*. We identify feature PRs by detecting those whose titles, descriptions or labels include the term “feature” or its linguistic derivatives. This classification reflects established conventions in open source development, where PRs introducing new functionality typically denote such contributions through the explicit use of “feature” terminology (Pham et al., 2013). Prior work shows that the textual framing of contributions reliably signals their functional intent and innovativeness in collaborative coding environments (Gousios et al., 2016). Accordingly, the monthly count of “feature”-tagged external PRs provides a granular proxy for the novelty intensity of cumulative innovation.

Independent variables. GPL. This variable was an indicator of the treatment group. It takes the value of one for repositories operating under GPL licenses (i.e., GPL v2.0, GPL v3.0, and AGPL v3.0) and zero for those under permissive licenses (i.e., BSD, Apache, and MIT).

Post Lawsuit. In the *Artifex vs. Hancom* ruling, the court affirmed on April 25, 2017 that the GPL carries legally enforceable contractual obligations. We therefore coded *Post Lawsuit* as one for all months following April 2017 and zero otherwise.

Upstream Dependency (ln). This variable captures the extent to which a focal repository relies on publicly available open source components developed by others. We operationalize this measure as natural logarithm of the number of distinct open source dependencies declared by the focal repository as of March 2017, immediately prior to the lawsuit shock. Conceptually, upstream dependency reflects the breadth of public knowledge components that external contributors can draw upon when engaging in cumulative innovation within the focal repository. Repositories with a larger number of upstream dependencies are embedded in richer knowledge ecosystems, providing contributors with greater opportunities for recombination, extension, and feature development based on existing open source modules. As such, this measure captures variation in the availability of reusable public knowledge that may shape external developers’ innovative contributions.

Control variables. All estimation models included repository fixed effects to account for time-invariant project heterogeneity. We also included month fixed effects to isolate the time trend in the external pull requests.

Empirical Methods

We conducted DiD analyses to study the effect of increasing legal protection of GPL license on cumulative innovation. In particular, we examined cumulative innovation in GPL projects (i.e., the treatment group) before and after the lawsuit, compared with that in permissive projects (i.e., the control group). We used fixed-effects ordinary least squares (OLS) regression models to estimate the coefficients. We clustered all standard errors at the repository level.

RESULTS

Assessment of the Comparability Assumption

A key assumption of our research design required that treatment and control repositories be comparable. We assessed this assumption by visually examining the "parallel trend" of cumulative innovation on repository. As shown in Figure 1, before the lawsuit event, the cumulative (novel) innovation of the treatment and control repositories exhibited similar trends.

Insert Figure 1 about here

Main results

Table 1 reports the summary statistics and correlation coefficients of all the variables. Table 2 presents the regression results for Hypothesis 1. In these specifications, the time-invariant *GPL* indicator is absorbed by repository fixed effects, while the *post lawsuit* indicator is absorbed by month fixed effects. Consistent with Hypothesis 1a, external OSS developers submit more pull requests to GPL repositories after the lawsuit. The coefficient on GPL×post lawsuit is positive and statistically significant ($\beta = 0.552$, $p = .001$), indicating that, relative to permissive repositories, GPL repositories receive on average 0.552 additional external pull requests per repository-month following the lawsuit. Consistent with Hypothesis 1b, external OSS developers also submit more feature pull requests to GPL repositories after the lawsuit ($\beta = 0.159$, $p = .005$). Importantly, this effect remains statistically significant even after controlling for the total number of external pull requests ($\beta = 0.103$, $p = .010$), suggesting that the increase in feature pull requests is not solely driven by a higher volume of external contributions.

Table 3 reports the moderating effects of *protection of continued access to open knowledge* on external developers' contribution behavior. In line with Hypothesis 2a, Column 1 shows that GPL repository with greater upstream dependency is associated with higher innovation output by external developers following the lawsuit shock ($\beta = 0.613$, $p = .038$). Columns 2-3 present the results for feature pull requests and further corroborate the moderating role of protection of continued access to open knowledge ($\beta = 0.149$, $p = .014$). Specifically, after the lawsuit, external developers contributing to GPL repositories with more upstream dependencies exhibit a larger increase in feature pull requests than those contributing to permissive repositories with fewer upstream dependencies, even after controlling for the overall volume of external pull requests. Taken together, these findings are consistent with the view that intrinsic motivation helps explain how public-oriented knowledge protection shapes cumulative innovation.

Insert Table 1,2,3 about here

Robustness Checks

To further strengthen the rigor of our analyses, we have conducted a series of robustness tests. First, re-estimate our difference-in-differences specification using *internal PRs*—that is, pull requests initiated by a repository's organizational members or owners—as the dependent variable. Our theoretical mechanism centers on how the legal shock reshaped external developers' innovation behavior, whereas the innovation behavior of internal developers should not be directly affected by the shock. Results show that the interaction between *GPL* and *post lawsuit* is statistically insignificant across all specifications when internal pull requests are used as the outcome variable. This null result alleviates concerns that our main findings are driven by platform-wide shocks, repository-level development cycles, or other contemporaneous factors affecting overall pull request activity, and supports the interpretation that the documented effects operate specifically through the external contribution channel.

Second, a potential alternative explanation for our main findings is that the documented increase in external pull requests is driven by extrinsically motivated developers, rather than by intrinsically motivated contributors as posited by our theory. Specifically, the GPL-related lawsuit shock may have altered public attention or visibility of GPL-licensed repositories (Stewart et al., 2006), thereby affecting the innovation behavior of external contributors motivated by career concerns, reputation building, or firm-related incentives. While such an explanation is theoretically unlikely, since developers driven primarily by extrinsic incentives should reduce innovative contributions in response to heightened legal uncertainty surrounding copyleft licenses, we nevertheless conduct an additional robustness check to further disentangle this alternative mechanism.

To do so, we partition external pull requests into two categories based on contributors' pre-shock contribution histories, capturing differences in underlying motivation. We classify a contributor as an *intrinsic developer* if, prior to the lawsuit shock, the contributor had made at least one external pull request to an individual-owned repository with fewer than 10 stars, reflecting engagement with low-visibility projects that are unlikely to offer substantial extrinsic rewards. In contrast, we classify a contributor as an *extrinsic developer* if, prior to the shock, the contributor had made at least one pull request to a firm-owned repositor with more than 10 stars, and did not meet the criteria for intrinsic developers. This classification strategy follows the intuition that contributions to highly visible, firm-affiliated projects are more likely to be associated with extrinsic incentives (Smirnova, Reitzig, & Alexy, 2022). The estimates indicate that the post-shock increase in external pull requests to copyleft-licensed repositories is driven primarily by intrinsic developers. Specifically, we find a positive and significant effect for external PRs from intrinsic developers ($\beta = 0.345$, $p = .003$), whereas the corresponding effect for external PRs from extrinsic developers is small and insignificant ($\beta = 0.072$, $p = .190$).

Third, we have rerun our analyses using alternative methods. We conduct same analyses using Poisson pseudo-maximum likelihood (PPML) models, which are well suited for count-based measures of innovation activities. We then conduct robustness checks using an alternative measure of novel innovation, operationalized as the natural logarithm of the cumulative number of added files contributed by external developers to the focal repository. This measure builds on the intuition that, in OSS development, pull requests that introduce new files, rather than merely modifying existing ones, are more likely to reflect the addition of new functionalities or architectural components, and thus capture a more novel form of cumulative innovation (Gousios et al., 2016; Pham et al., 2013). Across both sets of analyses, the results are qualitatively similar to our main findings, lending further support to the robustness of our conclusions.

SUPPLEMENTARY ANALYSES

We further examine whether the impact of the lawsuit shock on cumulative innovation is driven primarily by newcomer developers or by incumbent contributors. Results show that, following the lawsuit shock, GPL repositories attract a significant larger number of external contributors ($\beta = 0.062$, $p = .027$), indicating an expansion in the external contributor base. To more directly identify which type of contributors drives the main effect, we further decompose external pull requests by contributor status. Specifically, we distinguish between pull requests from newcomers, who had not previously contributed to the focal repository before the focal month, and the pull requests from incumbents, who had prior contribution histories with the repository. The estimates indicate that both newcomers ($\beta = 0.106$, $p = .017$) and incumbents ($\beta = 0.428$, $p = .003$) contribute to the overall increase in external pull requests following the lawsuit shock. However, the increase in feature pull requests is primarily attributable to incumbent developers ($\beta = 0.131$, $p = .014$), whereas newcomer contributions exhibit no comparable increase in feature pull requests ($\beta = 0.007$, $p = .223$).

Second, we further provide supplementary analyses to shed additional light on how the lawsuit shock is associated with the characteristics of pull requests, focusing on acceptance outcomes and the magnitude of code changes. Across specifications, we do not observe statistically significant changes in the acceptance rates of pull requests ($\beta = -0.023$, $p = .181$). These results indicate that, while the volume and composition of pull requests change after the shock, the likelihood that a submitted pull request is accepted remains broadly stable. Lastly, we analyze the extent of code modifications in external pull requests. Using the logarithm of average code additions, deletions, and total code changes per external pull request as dependent variables, the estimates ($\beta_1 = 0.110$, $p = .030$; $\beta_2 = 0.096$, $p = .014$; $\beta_3 = 0.129$, $p = .018$) show that external pull requests involve larger code modifications following the lawsuit shock. Together, these supplementary results suggest that the post-shock changes documented in the main analyses are accompanied by shifts in the scale of code contributions, while acceptance remain largely unchanged.

DISCUSSION

Findings of this study have implications for research on IPR and cumulative innovation, intrinsic motivation and creativity, and the governance of OSS and similar open science communities. Leveraging a legal shock that strengthened the enforceability of copyleft licenses, we show that, contrary to classic prediction originated from traditional IPR contexts, stronger IPR protection can *increase* both the quantity and novelty of external follow-on contributions when contributors are intrinsically motivated and the IPR protects the public nature of technological innovation and knowledge rather than private benefits.

First, we contribute to research on IPR and cumulative innovation by complementing the common understanding that stronger IPR protection generally reduces external follow-on innovation. Prior work in traditional IPR contexts (e.g., patents and other means) mostly establishes IPR as value-appropriation mechanisms that grant exclusion rights and afford pecuniary incentives for rent maximizing agents (Bessen & Maskin, 2009; Green & Scotchmer, 1995; Hall & Harhoff, 2012; Mazzoleni & Nelson, 1998). In this framework, increases in IPR strength tend to inhibit cumulative innovation by raising access costs, legal risk, and bargaining frictions for downstream users (Galasso & Schankerman, 2015; Gaessler et al., 2025; Mezzanotti, 2021; Murray & Stern, 2007; Sampat & Williams, 2019). By contrast, our evidence from the OSS context shows that when IPR is designed to protect the public nature of knowledge and prevent downstream privatization, and when cumulative innovation is carried out by intrinsically motivated contributors, a strengthening of IPR enforceability can be associated with more external follow-on innovation. This suggests that the impact of stronger IPR on cumulative innovation depends not only on *how strong* exclusion rights are, but also on *what they are designed to protect* (private rents vs. public access) and on different motivations driving those who contribute to the development of follow-on innovation.

In addition, by showing that strengthening IPR in protecting public knowledge is associated with both a higher rate and greater novelty of follow-on contributions, we extend the intrinsic motivation and creativity literature, by bridging intrinsic motivation into the IPR and cumulative innovation literature and highlighting institutional changes as a driver that shapes the role of intrinsic motivation in driving cumulative innovation. Studies in management and organizational psychology show that intrinsic motivation is a central driver of creative performance in complex, non-routine tasks (Amabile, 1988; Grant & Berry, 2011; Sauermann & Cohen, 2010; Zhang & Bartol, 2010). Building on prior work in open science and OSS, we conceptualize intrinsic motivation in our context as non-pecuniary motivations that combine enjoyment of problem solving and learning with the value derived from contributing to public knowledge (Dasgupta & David, 1994; Hertel et al., 2003; Lakhani & Wolf, 2005; Roberts et al., 2006; von Hippel & von Krogh, 2003). Our results indicate that when a legal change strengthens the protection of continued openness in a way that is aligned with contributors' values, the perceived non-pecuniary returns to cumulative work increase. This improved alignment between contributors' motivations and the protection of their outputs for public access is consistent with the view that intrinsic and extrinsic motivations are not simply additive and that institutional arrangements can promote intrinsic motivations (Osterloh & Frey, 2000).

Third, we also extend research on cumulative innovation and knowledge recombination by examining intrinsic motivation as a critical boundary condition for when cumulative knowledge components are leveraged to develop follow-on innovation. Prior work on knowledge search and recombination typically emphasizes properties of existing knowledge components and access to these knowledge, and shows that such characteristics shape the potential for downstream recombination, using measures based on patents and scientific contributions (Ahuja et al., 2008; Fleming, 2001; Fleming & Sorenson, 2004; Laursen & Salter, 2006). Although this literature recognizes that search is costly and often myopic (Katila & Ahuja, 2002; Laursen & Salter, 2006), studies tend to treat the behavioral side of whether innovators actually undertake these costly investments as largely implicit, while work on intrinsic motivation and creativity has remained in an independent literature (Amabile, 1988; Grant & Berry, 2011; Osterloh & Frey, 2000; Sauermann & Cohen, 2010; Zhang & Bartol, 2010). This paper in turn bridges these two streams: in a context where contributors are predominantly intrinsically motivated, we show that a legal change that strengthens protections of continued access to open knowledge, thereby increasing the non-pecuniary value of cumulative work, is associated with more pronounced increases in both the quantity and novelty of follow-on contributions for projects more strongly built on upstream knowledge components. Our findings are consistent with intrinsic motivation as a behavioral mechanism that determines when the recombination potential associated with cumulative knowledge components is actually leveraged by motivated innovators in developing follow-on innovation, complementing prior research on knowledge recombination that builds on a knowledge based perspective.

Finally, we contribute to research on the governance of OSS and other open science communities by highlighting the role of IPRs in directing intrinsically motivated contributors' efforts. Prior studies emphasize the importance of community norms, project governance, and modular architecture in sustaining voluntary contributions to shared code (Markus, 2007; O'Mahony, 2003; von Hippel & von Krogh, 2003). Licensing choices, such as copyleft versus permissive licenses, are often discussed in terms of firms' downstream appropriation options, with less attention to how they affect the behavior of external contributors. Our analysis shows that a legal shock that increases the enforceability of copyleft licenses, without changing the *de facto* availability of code, shifts the relative attractiveness of GPL-governed projects compared to matched permissive projects for external contributors. This pattern suggests that license design does more than allocate residual values over commercialization: it shapes contributors' expectations about whether their contributions will remain open and reciprocated, and thus where intrinsically motivated contributors choose to direct their efforts. For organizations and communities that depend on OSS and other open innovation, our findings underscore that IPRs protecting openness can be used not only to prevent privatization, but also to attract and organize cumulative innovation from intrinsically motivated contributors.

This study has several limitations that open opportunities for future research. First, our measures of cumulative innovation and novelty are based on counts of pull requests and feature tagged submissions. While well established in management and software engineering research (e.g., Gousios et al., 2016; Lin & Maruping, 2022; Pham et al., 2013), these measures capture only some dimensions of innovative output. Subsequent work could incorporate richer measurements of novelty and impact, such as code-level similarity metrics, text information, downstream adoption through forks or packages, or other user adoption indicators, to better distinguish incremental improvements from radical follow-on contributions. Additionally, although our theoretical foundation builds on intrinsic motivations, we do not directly observe contributors' motives or how they update their beliefs in response to the legal shock. We infer the prevalence of intrinsic motivation from prior research and from characteristics of OSS communities (Hertel et al., 2003; Lakhani & Wolf, 2005; Roberts et al., 2006), but contributors also face career, reputational, and employer-reputation incentives. Future research at the individual-level, instead of repository-level data, including employee data, surveys, interviews, or experiments could more directly examine how contributors with different motivational portfolios adjust their contribution to OSS projects when IPR is strengthened. Finally, our analysis focuses on two dimensions of behavioral responses: the quantity and novelty of external contributions to existing repositories. We do not study other adaptations such as forking, license switching, project exit, or firms' decisions to move away from OSS in an environment with stronger copyleft license enforceability. These explorations could provide a more comprehensive picture of how IPR regimes in OSS reshape the balance between open and proprietary innovation.

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Figure 1. Parallel trends test

(a) External pull requests (b) External feature pull requests

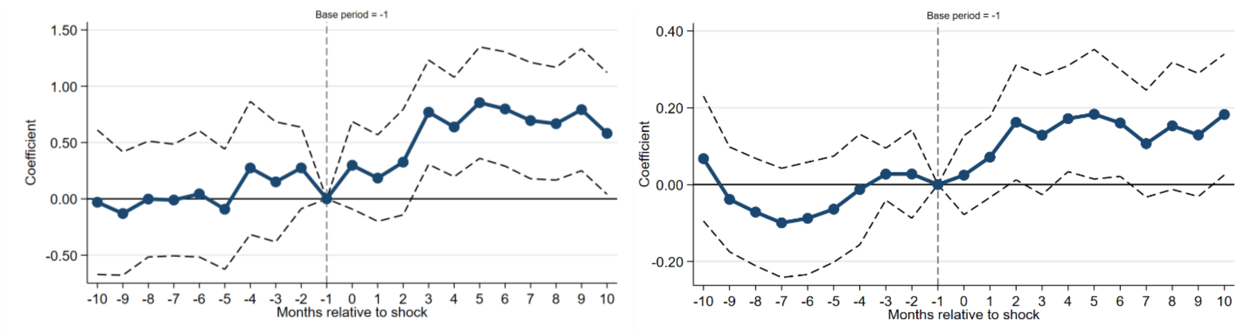

Table 1. Descriptive statistics and correlations

Variable	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1. External PRs	1.99	9.74																	
2. Internal PRs	0.76	3.89	0.58																
3. External Feature PRs	0.20	1.90	0.61	0.42															
4. Internal Feature PRs	0.04	0.38	0.45	0.56	0.55														
5. Adding Code Per Ex PRs (ln)	1.08	2.03	0.37	0.24	0.19	0.17													
6. External New Contributors	0.35	1.39	0.59	0.34	0.47	0.35	0.37												
7. External Contributors	0.75	2.65	0.85	0.48	0.57	0.43	0.46	0.86											
8. External PRs by New Comers	0.48	2.08	0.63	0.36	0.47	0.34	0.35	0.91	0.81										
9. External PRs by Incumbents	1.48	8.25	0.98	0.57	0.60	0.44	0.35	0.48	0.79	0.51									
10. External Feature PRs by New Comers	0.03	0.37	0.43	0.29	0.64	0.42	0.18	0.63	0.56	0.64	0.37								
11. External Feature PRs by Incumbents	0.16	1.59	0.60	0.41	0.96	0.52	0.17	0.39	0.51	0.38	0.61	0.48							
12. External PRs by Intrin	0.96	5.55	0.91	0.57	0.62	0.42	0.30	0.56	0.80	0.60	0.90	0.42	0.62						
13. External PRs by Pure Non-Intrin	0.31	2.53	0.68	0.33	0.34	0.29	0.25	0.28	0.53	0.31	0.69	0.24	0.31	0.49					
14. External Feature PRs by Intrin	0.12	1.40	0.49	0.34	0.91	0.43	0.13	0.40	0.45	0.40	0.49	0.53	0.92	0.57	0.19				
15. External Feature PRs by Non-Intrin	0.02	0.25	0.60	0.33	0.57	0.40	0.17	0.43	0.55	0.44	0.58	0.53	0.49	0.50	0.65	0.38			
16. Upstream Dependency (ln)	1.06	1.49	0.13	0.11	0.15	0.09	0.08	0.09	0.13	0.10	0.13	0.10	0.14	0.14	0.08	0.15	0.09		
17. GPL	0.42	0.49	0.02	0.02	0.02	0.01	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.21	
18. Post Lawsuit	0.52	0.50	0.01	0.00	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.04	0.01	0.00	0.00

Table 2. Main regression results

Variable	(1) External PRs	(2) External Feature PRs	(3) External Feature PRs
GPL×post lawsuit	0.552***	0.159***	0.103***
	(0.169)	(0.056)	(0.040)
	[0.001]	[0.005]	[0.010]
External PRs			0.102***
			(0.026)
			[0.000]
Constant	1.865***	0.164***	-0.027
	(0.037)	(0.012)	(0.058)
	[0.000]	[0.000]	[0.641]
Repository and month FEs	YES	YES	YES
Observations	27,447	27,447	27,447
R-squared	0.869	0.738	0.774
Adjusted R-squared	0.863	0.725	0.763

Note: Standard errors in parentheses are clustered at the repository level. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. P values are reported in brackets.

Table 3. Moderating effects of protection of continued access to open knowledge

Variable	(1) External PRs	(2) External Feature PRs	(3) External Feature PRs
GPL×post lawsuit	0.536**	0.102**	0.048
	(0.225)	(0.049)	(0.039)
	[0.017]	[0.038]	[0.215]
Post lawsuit×upstream dependency (ln)	-0.385***	-0.215***	-0.176***
	(0.121)	(0.074)	(0.057)
	[0.002]	[0.004]	[0.002]
GPL×post lawsuit×upstream dependency (ln)	0.613**	0.210***	0.149**
	(0.295)	(0.080)	(0.060)
	[0.038]	[0.009]	[0.014]
External PRs			0.100***
			(0.025)
			[0.000]
Constant	1.918***	0.193***	0.001
	(0.033)	(0.007)	(0.050)
	[0.000]	[0.000]	[0.989]
Repository and month Fes	YES	YES	YES
Observations	27,447	27,447	27,447
R-squared	0.870	0.743	0.777
Adjusted R-squared	0.864	0.730	0.766

Note: Standard errors in parentheses are clustered at the repository level. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. P values are reported in brackets. Rows with omitted coefficients are excluded because these variables are absorbed by repository fixed effects.