Open Source Innovation by Software Startup Firms: Property Rights Considerations

Abstract

The rise of open source innovation among startup firms presents an intriguing puzzle for strategic management research. While traditional property rights theory suggests that firms typically capture economic value by protecting their innovations through exclusive rights, we observe an increasing number of startup firms sharing their intellectual property through open source platforms. We seek to shed light on this phenomenon by examining how startup firms navigate this tension between exclusivity and open source in value capture. We propose that open source innovations may facilitate startup firms' economic value capture, as open source activities provide *access* to external resources that are otherwise difficult for resource-constrained startup firms to acquire. However, we posit that the startup firm's ability to capture economic value from open source platforms still depends on maintaining exclusivity through proprietary protection. Using a novel dataset of U.S. software startup firms' activities on GitHub, we find empirically that open source engagement increases startup firms' likelihood of achieving a successful exit via acquisition or an initial public offering (IPO). Moreover, this positive effect is more substantial for startup firms that hold complementary patent protection. Our research extends property rights theory by highlighting how resource-constrained startup firms can leverage open source communities to capture economic value.

Keywords: property rights theory, open source innovation, entrepreneurship, value capture

Open Source Innovation by Software Startup Firms: Property Rights Considerations

Introduction

Research on open source innovation has increasingly become a focus in management studies, offering a useful framework that challenges conventional innovation models. Unlike proprietary innovation business models, which typically rely on firms' exclusive control over internal resources, strong intellectual property right regimes, and complementary (and often co-specialized) assets (Barney, 1991; Pisano, 2006; Teece, 1986), firms' purposive open source innovation allows permeable boundaries, enabling these firms to benefit from both internal and external sources of inventions and innovations (Chesbrough, 2003; Lifshitz-Assaf, 2018; Zobel & Hagedoorn, 2020). These external sources can include customers/users, suppliers, competitive rivals, and collaborative complementors, creating a resilient ecosystem that fosters rapid technology development (Chesbrough & Appleyard, 2007; Laursen & Salter, 2014; von Hippel & von Krogh, 2003). Although not completely devoid of conflict and opacity, open source innovation is primarily built on cooperation and transparency (Koch & Schneider, 2002; Shaikh & Vaast, 2016; West & Gallagher, 2006). The effectiveness of open source innovation often depends on a firm's absorptive capacity—the ability to recognize, assimilate, and apply external knowledge (Cohen & Levinthal, 1990; Zahra & George, 2002; Zobel, 2017).

However, capturing economic value from open source innovation challenges traditional property rights theory, often used in the management literature. Indeed, such theories of property rights and the resource-based approach have long emphasized the importance of proprietary knowledge and resources for achieving and maintaining superior economic performance (Barney, 1991; Liebeskind, 1996; Lockett & Thompson, 2001). Indeed, implicit in the resource-based approach is the assumption that property rights are secure (Coase, 1960; Foss & Foss, 2005; Kim & Mahoney, 2002, 2010) due to the inherent attributes of resources, as well as being effectively protected by third-party enforcement such as courts and self-

enforcing agreements (Lippman & Rumelt, 1982; Srinivasan & Brush, 2006; Williamson, 1985). The underpinning logic is that exclusivity over valuable assets—such as technological patents, proprietary processes, or unique knowledge—typically enables firms to extract economic rents and prevent imitation by established and potential competitors (Mahoney & Pandian, 1992; Rumelt, 1984; Somaya, 2012). In contrast, the open source model encourages the free sharing and collaborative development of technologies and knowledge, potentially undermining a firm's ability to capture the economic value generated from its innovations (Chesbrough, 2003; Fitzgerald, 2006; Lerner & Tirole, 2005). This tension between the advantages of exclusivity in economic value capture and the benefits of open source innovation raises questions about whether and how firms can effectively capture economic value from open source innovation.

The open source innovation model is particularly relevant for startup firms, which often have limited access to resources, including credit rationing and the limits of founder and team knowledge (Cassar, 2004; De Meza & Webb, 2006; Fern, Cardinal, & O'Neill, 2012). By participating in open source communities, startup firms can tap into collective knowledge pools and development resources that would be prohibitively expensive to build internally (Chesbrough & Appleyard, 2007; Osterloh & Rota, 2007; von Hippel & von Krogh, 2003). For example, this collaborative approach provides continuous feedback and iteration from the community—by identifying software bugs and proposing new features—which enables startup firms to refine and improve innovations (Lin & Maruping, 2022; Wen, Ceccagnoli, & Forman, 2016; West & Gallagher, 2006). Moreover, open source participation can help startup firms build legitimacy and visibility in their markets, which are crucial factors for attracting both customers and investors (Bonaccorsi & Rossi, 2003; Stuart, Hoang, & Hybels, 1999; Wang, 2012). However, startup firms typically lack protective/isolating mechanisms (Lippman & Rumelt, 1982; Mahoney & Pandian, 1992; Rumelt, 1984) to capture economic value from open

source innovation, making them potentially vulnerable to value appropriation challenges when sharing their innovations on open source platforms.

We address these questions by developing and testing a theory about whether and how startup firms can leverage open source innovation to achieve successful exits. Specifically, we propose that engagement in open source innovation increases startup firms' likelihood of achieving successful exits via acquisitions and IPOs. This likelihood of achieving successful exits increases because collaborative open source platforms provide access to valuable external resources and knowledge necessary for startup firms' innovations. However, the openness that enables these benefits also makes it difficult for startup firms to protect their innovations from being freely adopted or improved upon by competitors. Thus, we propose that a startup's proprietary innovation positively moderates the relationship between open source engagement and successful exits. Effectively capturing value from open source innovation requires complementary proprietary protection, which helps startup firms to secure exclusive rights over core technologies while benefiting from open source activities (Grand et al., 2004; Harv, Sethi, & Zhou, 2008; Pisano, 2006).

The software industry provides an ideal empirical context for examining these relationships. Open source innovation has become a predominant model for fostering advancements in this industry. We test our hypotheses using data from GitHub, the world's largest open source software development platform. GitHub hosts over 200 million repositories and is the primary platform where developers and firms collaborate on open source projects. GitHub's comprehensive documentation allows us to observe startup firms' open source activities in microanalytic detail, including their code contributions, community engagement, and project popularity. We construct a novel dataset combining these detailed GitHub activities with data on startup firms from Pitchbook and their patent records from PatentsView. Leveraging a sample of U.S. software startup firms founded from 2002–2018, our empirical

analyses indicate that open source engagement significantly increases startup firms' likelihood of achieving successful exits. This positive effect is more pronounced for startup firms with patent protection. These empirical findings remain robust across multiple econometric specifications.

The current study makes several contributions to the strategic management and entrepreneurship literature. First, we extend property rights theory by examining how firms capture economic value in contexts where conventional assumptions about exclusivity are challenged. While traditional property rights theory and the resource-based approach emphasize that competitive advantage stems from exclusive (residual) control over valuable resources (Grossman & Hart, 1986; Hart & Moore, 1990; Kim & Mahoney, 2005), our findings provide new insights into how firms can capture economic value in open source environments. Specifically, our empirical findings indicate that while open source platforms facilitate value capture through collaborative innovation, integrating proprietary innovation is crucial for startup firms to capture this economic value effectively. This insight advances property rights theory by showing that exclusivity and openness need not be mutually exclusive forces but can be complements in achieving long-term economic success (Chesbrough, 2003; Pisano, 2006; West, 2003). Second, we advance the understanding of how resource-constrained startup firms can leverage open source communities to enhance economic value. While previous research has highlighted the potential of open source platforms to drive innovation (Chesbrough & Appleyard, 2007; West, 2003; West & Gallagher, 2006), extant studies have primarily focused on established firms that possess substantial complementary assets and market power. Moreover, prior research has often relied on qualitative evidence or indirect measures of open source engagement. The current study uses large-scale GitHub and Pitchbook data and shows that open source engagement increases startup firms' likelihood of achieving successful exits.

This contribution provides a more comprehensive view of startup firms' strategic challenges and opportunities on open source platforms.

Theory and Hypotheses

This section briefly reviews the literature on property rights theory and open source innovation and develops their potential implications for how startup firms capture economic value from open source activities.

Property Rights Theory and Open Source Innovation

Property rights theory offers a fundamental framework for understanding how firms create and capture value from their innovations (Coase, 1960; Foss & Foss, 2005; Kim & Mahoney, 2002). The theory posits that economic value creation and capture depend critically on the ability to establish, maintain, and enforce *partitioned* property rights over valuable resources (Alchian, 1965; Alchian & Demsetz, 1973; Demsetz, 1967). Clear, well-defined, and enforceable property rights enable firms to prevent unauthorized use or appropriation of their valuable assets and thereby capture more fully the economic returns from their investments (Coase, 1960; Mahoney & Qian, 2013; Ziedonis, 1994). When firms hold secure property rights over their resources—whether physical assets, intellectual property, or proprietary technologies—they are better equipped to exclude competitors, establish barriers to entry, and maintain superior economic performance (Barzel, 1997; Kim & Mahoney, 2005; Rumelt, 1984). This exclusivity enables firms to control their innovations and safeguard competitive advantages by preventing unauthorized imitation of their valuable resources (Peteraf, 1993; Rumelt, 1984; Teece, 1986).

The ability to capture value through property rights operates at multiple levels. At the institutional level, the strength of legal regimes, enforcement mechanisms, and industry norms shape firms' ability to protect their innovations (Libecap, 1989; North, 1990; Ostrom, 1990). Research has documented significant variations in property rights protection across

jurisdictions and technological domains (Branstetter, Fisman, & Foley, 2006; Lerner, 2009; Mansfield & Mundial, 1994). At the firm level, the effectiveness of property rights depends on complementary assets, market positioning, and strategic capabilities (Arora & Ceccagnoli, 2006; Rumelt, 1984; Teece, 1986). Established firms often possess advantages in these dimensions, enabling them to capture value even when property rights protection is imperfect.

Strategic management research has extensively documented how firms traditionally secure and benefit from property rights protection. Through legal mechanisms such as patents, copyrights, and trade secrets, firms can prevent competitors from copying their innovations, thereby recovering R&D investments (Granstrand,1999; Levin et al., 1987; Somaya, 2012). Moreover, strong property rights facilitate value-creating transactions by reducing uncertainty and transaction costs, enabling firms to license innovations and form strategic alliances (Oxley, 1989; Pisano, 1990; Somaya, Kim, & Vonortas, 2011). By securing and enforcing property rights, firms can negotiate from positions of strength and capture economic value more effectively (Bel, 2018; Demsetz, 1964; Foss & Foss, 2005).

However, the emergence of open source innovation challenges these traditional assumptions about property rights and value capture. Open source innovation questions the necessity of exclusivity for economic value capture (Grand et al., 2004; O'Mahony, 2003; von Hippel & von Krogh, 2003). It is characterized by collaboration, transparency, and free knowledge exchange across organizational boundaries (Chesbrough, 2003; Shaikh & Vaast, 2016; von Hippel & von Krogh, 2003). In this innovation model, firms voluntarily contribute their innovations to a shared pool of resources accessible to the public, allowing anyone to use, modify, and distribute the innovation. While this approach offers significant advantages—including collective development, accelerated innovation cycles, and diverse community contributions—it also creates strategic vulnerabilities. The open source model exposes firms to the risk that competitors may freely adopt and commercialize their contributions (Alexy,

George, & Salter, 2013; Henkel, 2006; West & Gallagher, 2006), potentially undermining their ability to capture economic value.

This tension between open source and economic value capture is particularly salient for startup firms. Unlike established firms, startup firms typically lack the complementary assets, market power, financial resources for extensive IP protection, and organizational capabilities for managing IP portfolios that traditionally help firms capture economic value from innovation (Gans & Stern, 2003; Somaya, Williamson, & Zhang, 2007; Teece, 1986). Yet paradoxically, we observe increasing engagement of startup firms in open source innovation, particularly in the software industry (Dahlander, 2007; Fitzgerald, 2006; Wen et al., 2016). This trend has accelerated with the weakening of software patent protection and the rise of digital platforms (Hall & MacGarvie, 2010; Lin & Rai, 2024; Nambisan et al., 2017), suggesting that traditional assumptions about property rights and economic value capture may need to be reconsidered in many contemporary innovation contexts.

Open Source Innovation and Startup Firms' Economic Value Capture

Startup firms face distinctive constraints that shape their value capture potential. Unlike established firms, startup firms have limited access to necessary resources for innovation and development. Due to uncertainty and information asymmetries, they struggle to secure adequate funding for R&D activities, face challenges in attracting and retaining top talent due to less competitive compensation packages, and lack established relationships with key industry players that could provide valuable resources and market access (Gompers & Lerner, 2001; Powell, Koput, & Smith-Doerr, 1996; Zahra, 2021). The absence of complementary assets and proven track records that larger firms use to commercialize innovations further compounds these challenges, making it particularly difficult for startup firms to develop innovations independently and demonstrate their value to potential acquirers or investors (Freeman, Carroll, & Hannan, 1983; Islam, Fremeth, & Marcus, 2018; Teece, 1986).

These resource constraints become particularly critical when startup firms pursue exit opportunities through acquisition or IPO, where potential acquirers and public market investors must evaluate a startup's future potential with limited historical information. The challenge of information asymmetry is relevant for startup firms, as they lack an established track record and market position that signals firm quality (Courtney, Dutta, & Li, 2017; Gompers & Lerner, 2001; Stuart et al., 1999). Moreover, due to resource limitations, conventional quality signals such as extensive patent portfolios or established market positions often remain out of reach.

Open source engagement helps startup firms overcome these constraints through three interconnected mechanisms. First, open source platforms provide startup firms access to valuable external resources that would be prohibitively expensive to develop internally. By tapping into global developer communities like GitHub, startup firms can leverage collective knowledge, established codebases, and continuous feedback mechanisms (Chesbrough, 2003; von Hippel & von Krogh, 2003; Wulf & Blohm, 2020). Such boundary-spanning activities enable diverse contributors to enhance a startup firm's innovation efforts, accelerating product development cycles and improving innovation quality despite resource constraints. The collaborative nature of open source development effectively substitutes for the internal R&D capabilities that startup firms typically lack (Bruno & Tyebjee, 1985; Cassar, 2004).

Second, open source engagement creates powerful signaling benefits that help startup firms overcome their liability of newness. While established firms can demonstrate their value through historical performance and extensive R&D investments, startup firms must find alternative ways to signal their potential to acquirers and investors. Open source participation provides uniquely credible signals because its transparency lets stakeholders observe a startup firm's technical capabilities, development processes, and community leadership (Dahlander, 2007; O'Mahony & Ferraro, 2007; Piva, Rentocchini, & Rossi-Lamastra, 2012). Unlike traditional signals such as patents, open source contributions offer real-time, verifiable evidence of a

startup firm's innovation potential and market impact. This transparency reduces information asymmetry by providing clear, demonstrable evidence of the startup's capabilities and market potential (Bonaccorsi et al., 2006; Lerner & Tirole, 2002; Wang, 2012), making them more economically attractive candidates for acquisition or public market investment. Such credibility proves valuable for startup firms seeking exits, as it differentiates them from competitors and signals lower risk to potential acquirers and investors (Conti, Peukert, & Roche, 2021; Lerner & Tirole, 2005; Stuart et al., 1999).

Third, open source strategies enable startup firms to benefit from network effects that enhance their competitive advantages. These effects are powerful in software markets, where technology value increases with user adoption (Gallaugher & Wang, 2002; Katz & Shapiro, 1994; Lee & Mendelson, 2008). Open source engagement accelerates the creation of these network effects by reducing adoption barriers and enabling broader market penetration. Moreover, successful open source projects often facilitate expansion into adjacent markets through digital convergence (Gawer, 2009; Lee & Mendelson, 2008; Yoo et al., 2012), creating additional growth opportunities that make startup firms more economically attractive targets for acquisition or public investment. Such strong network positions signal growth potential to potential acquirers and investors (Lin & Maruping, 2022; Wright, Nagle, & Greenstein, 2023).

These three mechanisms — resource access, credible signaling, and network effects — work together synergistically to enhance a startup's exit prospects (Mahoney & Qian, 2013; Rajan & Zingales, 1998; Scotchmer, 2010). Resource access through open source enables faster and higher-quality innovation development. This enhanced innovation capability creates credible signals of startup quality, which reduces information asymmetry for potential acquirers and investors; as these signals attract more users and contributors, network effects strengthen, increasing the startup's strategic value. This virtuous cycle helps startup firms

overcome their resource constraints and enhance their economic attractiveness as acquisition targets or publicly-traded companies, which leads to our first hypothesis.

Hypothesis 1: Open source engagement increases a startup firm's likelihood of achieving a successful exit through acquisition or IPO.

The Moderating Role of Proprietary Innovation

While open source innovation offers benefits to startup firms—including access to external knowledge, enhanced credibility, and network effects— capturing the full economic value from these benefits can still be challenging. The openness might expose startup firms to the risk that competitors may freely adopt and commercialize their contributions (Alexy et al., 2013; Henkel, 2006; West & Gallagher, 2003). Without effective economic value capture mechanisms, startup firms may struggle to translate their open source engagement into successful exits via acquisition or IPO.

Proprietary innovation, such as patents, can help startup firms address this challenge by providing complementary value capture mechanisms (Cenamor & Frishammar, 2021; Dahlander & Wallin, 2006; Harhoff, Henkel, & von Hippel, 2003). First, proprietary innovation enables startup firms to implement a strategic "selective revealing" approach. By maintaining proprietary rights over core technologies while sharing complementary innovations through open source, startup firms can protect their most valuable assets from competitors' appropriation while continuing to benefit from collaborative development (Haruvy et al., 2008; Pisano, 2006; West, 2003). This selective protection is particularly crucial for resource-constrained startup firms that must carefully balance the advantages of openness with the need to capture value through exclusivity.

Second, proprietary innovation strengthens a startup firm's strategic position in open source ecosystems. Despite their collaborative nature, open source communities involve complex negotiations over technological directions and standards. Strong patent portfolios provide startup firms with strategic leverage, which enables them to influence ecosystem

evolution in ways that benefit their business models. Moreover, proprietary innovations provide additional quality signals that complement open source engagement. While open source participation demonstrates technical capabilities, patents signal a startup's ability to develop novel, non-obvious innovations (Gittleman, 2008; Hsu & Ziedonis, 2013; Spaeth, von Krogh, & He, 2015). This dual signaling is valuable for potential acquirers and investors evaluating a startup's innovative capacity.

Third, proprietary innovation enhances a startup firm's perceived long-term viability and value capture potential. Both acquirers and investors view intellectual property as a tangible asset that can be monetized through multiple channels: licensing, strategic partnerships, or future product development (Gans & Stern, 2003; Pisano, 2006; Shapiro, 1985). The presence of strong proprietary innovation alongside open source initiatives reassures stakeholders that the startup has a comprehensive strategy for capturing value—leveraging community-driven innovation while protecting core assets (Ceccagnoli et al., 2012; Dahlander & Wallin, 2006; Harhoff et al., 2003). This approach reduces perceived risks and enhances a startup firm's economic attractiveness as an acquisition target or publicly-traded company.

Moreover, proprietary innovation can amplify the network effects created through open source engagement. While open source drives adoption and community building, proprietary innovation enables startup firms to monetize this adoption through complementary products or services (Chesbrough, 2003; Cenamor & Frishammar, 2021; Iansiti & Richards, 2006). For example, startup firms can open source foundational technology to build a user base and then capture value through proprietary add-ons or enhanced features (Cusumano, 2004; Franke & von Hippel, 2003; Perr, Appleyard, & Patrick, 2010). This approach creates a virtuous cycle where open source drives adoption while proprietary innovation ensures value capture (Alexy et al., 2013; Baldwin & von Hippel, 2011; Henkel, 2006).

Critical are co-specialized assets (e.g., proprietary components, services, distribution channels) that enhance a startup's ability to capture economic value from open source innovation by creating barriers to imitation (Fosfuri, Giarratana & Luzzi, 2005; Kim et al., 2019; Pisano, 2006). Competitors adopting open source technology may struggle to replicate its full economic value without access to these protected complementary assets. This combination of widely adopted open source technology and protected unique capabilities make startup firms particularly attractive acquisition targets or public market investments (Chesbrough & Appleyard, 2007; Conti et al., 2021; Gans & Stern, 2003).

In this way, the strategic combination of open source and proprietary innovation enhances a startup firm's likelihood of successful exit by increasing economic value creation and value capture opportunities. While open source activities contribute to market visibility, credibility, and adoption (to increase the size of the pie), proprietary innovation ensures that the startup firm can secure and monetize its competitive advantages (to capture its share of the pie), thereby enhancing its economic attractiveness to investors. This reasoning leads to our second hypothesis.

Hypothesis 2: A startup firm's proprietary innovation positively moderates the relationship between open source engagement and the likelihood of achieving a successful exit through acquisition or IPO.

Empirical Design

Research Context

We use a sample of U.S. startup firms in the software industry to test our hypotheses. For several reasons, the software development industry provides an ideal setting for examining the relationship between open source engagement and successful startup exits.

First, the software industry represents a context where open source innovation has become a dominant model of technological development. Unlike traditional industries, where

proprietary innovation remains prevalent, software development has witnessed a fundamental shift toward open source practices (Osterloh & Rota, 2007; von Hippel & von Krogh, 2003).

Second, this industry presents a unique context where the tension between openness and economic value capture is particularly salient. Software development's modular nature enables startup firms to strategically combine open and proprietary components, creating natural variation in innovation strategies. Unlike industries with high fixed production costs, software firms face relatively low marginal replication costs, making protecting intellectual property particularly challenging. This characteristic tension provides rich opportunities to examine how startup firms balance their need for open source engagement with proprietary protection mechanisms.

Third, our empirical setting provides variation in exit outcomes, making it suitable for examining our hypothesized relationships. Software startup firms represent a significant proportion of successful acquisitions and IPOs in the technology sector.

Fourth, the software industry offers unique advantages for empirical investigation through platforms such as GitHub, whose extensive repositories and transparent development processes allow us to observe startup firms' open source activities in unprecedented detail, including code contributions, community interactions, and project popularity. This transparency enables us to measure both the quantity and quality of startup firms' open source engagement (Conti et al., 2021; Thummadi & Paruchuri, 2022; Yang, 2023).

Data Sources and Sample

Our primary data source is GitHub, which has emerged as the world's dominant open source software development platform. Since its launch in 2008, GitHub has experienced exponential growth. By 2023, GitHub hosts over 200 million repositories and serves over 100 million developers globally, with over 90% of Fortune 100 companies hosting projects on the platform.

The basic unit of analysis in GitHub is the "repository." When firms open source their projects on GitHub, they typically create organizational accounts and establish repositories to host their code. Each repository serves as the central hub for a project, containing not only source code files but also documentation, issue discussions, and contribution histories. Subsequent development occurs through a structured process of contributions and interactions. Developers make changes to the code through "commits," which represent discrete units of code modification, which are then submitted as "pull requests" for review and potential integration into the main project. Other developers can "fork" repositories to create their copies for independent development and show support for projects by "starring" them. Specifically, a commit represents a discrete set of code changes, such as adding new features, fixing bugs, or improving documentation. Each commit includes the code modifications and a message describing the changes, creating a detailed record of development decisions. When developers want to contribute to a project, they "fork" the repository, creating their copy of the codebase. This forked repository allows developers to freely experiment with changes without affecting the original project. Code contributions occur through "commits" and "pull requests." Developers "push" these commits to their forked repositories, after which they can submit a "pull request" to propose integrating their changes into the original project. When receiving pull requests, project maintainers (typically the firms initiating the projects) examine the proposed changes for quality, compatibility, and adherence to project standards. They can comment on specific lines of code, request modifications, and engage in detailed technical discussions within the pull request interface.

GitHub Archive has preserved public GitHub timeline events since 2011. This archive creates hourly data dumps of platform activities, capturing events such as repository creation, code "commits," "pull requests," and issue discussions. We collect GitHub data using GitHub's API, which provides detailed JSON-formatted data about repository activities.

We then obtain information about startup firms from Pitchbook. Pitchbook has become the standard database for entrepreneurship research (Taeuscher & Rothe, 2024; Yao & O'Neill, 2022). It provides detailed information about founding dates, headquarters locations, industry classifications, and exit events. We use the Pitchbook database to identify U.S. startup firms founded between 2002 and 2018 in the software industry. We focus on this period because most uses of GitHub began in 2012, allowing us to observe sufficient activity before and after the open source period. Most uses of GitHub began in 2012, allowing us to observe sufficient activity before and after open source engagement. Our initial search identifies 117,420 U.S. software startups.

Patent data are obtained from the PatentsView database, which provides comprehensive information about granted patents. For each patent, we collect application and grant dates as well as citation patterns. Disambiguated assignee names in this database facilitate accurate matching with the startup firms identified in Pitchbook.

We match startup firms from the PitchBook database with entries in the PatentsView database using exact name matching.[12] For mapping startup firms from Pitchbook to their open source activities on GitHub, we focus specifically on organizational accounts rather than individual accounts on GitHub, as these better reflect corporate engagement in open source development. This process reveals 8,538 software startup firms with identifiable open source activities on GitHub. Our initial sample comprises 117,420 U.S. software startup firms, of which 8,538 maintain active organizational repositories on GitHub.

Measures

Dependent variable

Our dependent variable, *Successful Exit*, measures whether a startup firm achieved a successful exit via either acquisition or IPO. Following established research on entrepreneurial

exits (Aggarwal & Hsu, 2014; Stuart & Sorenson, 2003), we construct a binary variable that equals 1 in the year of and after a startup experience, either an acquisition or IPO or 0 otherwise.

Independent variables

Our first independent variable, *Open Source*, is a binary variable that indicates whether a startup firm has open source activities, which is captured by whether it has a public repository on GitHub. Our second independent variable, *After* is coded as 1 for years following a startup firm's initial open source engagement and 0 for prior years. We use the interaction term *Open Source* × *After* to test Hypothesis 1, examining whether startup firms capture economic value from open source activities on GitHub.

Moderators

Our moderator, *Proprietary Innovation*, is measured as the natural logarithm of the number of patent applications filed by a startup in the previous year. Patents serve as a proxy for proprietary innovation because they represent a startup's commitment to protecting its intellectual property through formal legal mechanisms (Hsu & Ziedonis, 2013; Somaya, 2012).

Control Variables

We include several control variables to account for factors that may influence the likelihood of a successful exit. First, to control for patent quality, we include *Patent Claims*, measured as the natural logarithm of the average number of claims per patent. Claims define the scope of patent protection and serve as an indicator of patent value. We also include *Backward Citations*, calculated as the natural logarithm of citations made per patent, which reflects the technological foundation of the innovation.

Second, we include several measures of open source activity intensity. *Commits* is measured as the natural logarithm of the total number of code modifications, reflecting the startup's active development efforts. *Stars* capture project popularity and market validation, measured as the natural logarithm of users who have starred the startup's repositories. *Pull*

Requests, calculated as the natural logarithm of external contribution submissions, indicate community engagement with the startup's projects. *Watchers*, measured as the natural logarithm of users following the startup's repositories, reflect sustained community interest in the startup's open source activities.

Empirical Design

Our empirical analysis addresses potential endogeneity concerns, particularly regarding selection into open source innovation. The decision to engage in open source activities may be endogenous to a firm's innovative capabilities. For example, startup firms with superior, innovative capabilities may be more likely to engage in open source and achieve successful exits. Similarly, better-funded startup firms may have greater resources to pursue open source strategies and exit opportunities. Failing to account for such selection effects could lead to biased estimates of the relationship between open source engagement and exit outcomes.

To address potential endogeneity issues, we use coarsened exact matching (CEM) to create a matched sample of startup firms with and without open source activities. For startup firms that conducted open source activities, we identify counterfactual startup firms that do not conduct open source activities. We match startup firms on several relevant dimensions that could influence open source engagement and the likelihood of a successful exit, including founding year and average patent counts. The matched sample comprises 3,993 startup firms with open source activities on GitHub and 38,228 without open source activities.

Using this matched sample, we estimate our baseline model:

$$Y_{it}=\beta_0+\beta_1 Open\ Source_i+\beta_2 After_{it}+\beta_3 Open\ Source_i \times After_{it}+\gamma X_{it-1}+\delta_t+\varepsilon_{it} \quad (1)$$

where Y_{it} is the dependent variable, indicating whether startup i achieved a successful exit via acquisition or IPO in or after year t. $Open\ Source_i$ and $After_{it}$ are indicator variables. $Open\ Source_i$ is an indicator for startup firms that engage in open source innovation, and $After_{it}$

indicates the years following open source engagement. X_{it-1} is a vector of control variables, δ_t refers to year fixed effects, and ε_{it} is an error term.

We include startup fixed effects in the model to account for time-invariant unobserved heterogeneity across firms. The regression model is specified as follows:

$$Y_{it}=\beta_0+\beta_2 After_{it}+\beta_3 Open\ Source_i \times After_{it}+\gamma X_{it-1}+\delta_t+\varepsilon_{it} \quad (2)$$

where τ_i represents startup fixed effects. This model specification eliminates the time-invariant term $Open\ Source_i$. In this specification, the coefficient β_3 captures the main effect of open source engagement on the likelihood of a successful exit. A positive and statistically significant β_3 would corroborate Hypothesis 1, indicating that open source innovation is associated with an increased likelihood of a startup firm's exit via acquisition or IPO.

To test Hypothesis 2 about the moderating effect of proprietary innovation, we extend our model to include interaction terms with moderator *Startups' Patents*:

$$Y_{it}=\beta_0+\beta_2 After_{it}+\beta_3 Open\ Source_i \times After_{it}+\beta_4 Open\ Source_i \times Patent_{it}$$
$$+\beta_5 Open\ Source_{it} \times Patent_{it}+\beta_6 After_{it} \times Open\ Source_i \times Patent_{it}+\gamma X_{it-1}+\delta_t+\tau_i+\varepsilon_{it} \quad (3)$$

where $Patent_{it}$ measures a startup's proprietary innovation through patent holdings. The coefficient β_6 captures the moderating effects of proprietary innovation on the relationship between open source engagement and exit likelihood. A positive and statistically significant β_6 would corroborate Hypothesis 2, indicating that patent protection enhances the positive effect of open source engagement on exit outcomes.

Results

Table I reports descriptive statistics for our matched sample. The mean value of Successful Exit (0.159) indicates that approximately 16% of startup-year observations in our sample achieved a successful exit through either acquisition or IPO. About 12% of observations involve startup firms with open source activities (Open Source mean = 0.118).

[INSERT TABLE I ABOUT HERE]

Table II presents the correlations for the variables used in the analysis. The GitHub activity measures (Commits, Stars, Pull Requests, and Watchers) show moderate-to-strong positive correlations, which is unsurprising because they capture related but distinct aspects of open source engagement. Among the control variables, no variable shows a statistically significant correlation with the key independent or moderator variables. Additionally, the variance inflation factor (VIF) scores are below the threshold of 10, alleviating concerns about multicollinearity (Kleinbaum et al., 1988; Kutner, Nachtsheim, & Neter, 2004).

[INSERT TABLE II ABOUT HERE]

To corroborate the effectiveness of our matching procedure, we examine differences between startup firms with (i.e., opensource = 1) and without (i.e., opensource = 0) open source activities on GitHub across our matching variables. Table III shows no statistically significant differences between startup firms with and without open source activities regarding founding year or patent counts, thus attenuating endogeneity concerns.

[INSERT TABLE III ABOUT HERE]

Table IV presents OLS estimates of how open source engagement affects startup firms' likelihood of achieving successful exits via acquisition or IPO. We begin with a baseline specification in Model 1, which includes only control variables. Model 2 introduces our main independent variables, *Open Source* and *After*. Model 3 adds the interaction term *Open Source* × *After* as specified in Equation (1). Models 4-6 replicate these specifications with the addition of startup fixed effects, with Model 6 representing our full specification from Equation (2). The empirical results are consistent with Hypothesis 1, which posits that open source engagement increases startup firms' likelihood of successful exit. In Model 3, the coefficient for *Open Source* × *After* is positive and significant ($\beta_3 = 0.0918$, $p < 0.01$). This positive effect remains robust when we include startup fixed effects in Model 6 ($\beta_3 = 0.0848$, $p < 0.01$), indicating that

open source engagement increases exit likelihood even after controlling for time-invariant startup firm characteristics. Specifically, open source engagement increases a startup firm's likelihood of successful exit by approximately 8.5%.

[INSERT TABLE IV ABOUT HERE]

Table V presents empirical results testing Hypothesis 2, which posits that patent protection strengthens the positive effect of open source engagement on exit likelihood. Model 1 introduces the patent measure, and Model 2 adds the three-way interaction *Open Source* × *Patent* × *After* specified in Equation (3). The coefficient for this three-way interaction is positive and significant ($\beta_6 = 0.1601$, $p < 0.05$), corroborating Hypothesis 2. This empirical finding indicates that the positive effect of open source engagement on exit likelihood is more substantial for startup firms with patent protection.

[INSERT TABLE V ABOUT HERE]

These results indicate that open source engagement can significantly enhance startup firms' likelihood of successful exits, particularly when complemented by patent protection. This empirical finding corroborates our theoretical reasoning that while open source activities help startup firms capture economic value through external resource access and market visibility, their ability to capture this economic value is enhanced when startup firms maintain some proprietary control through patents.

Robustness Tests and Additional Analysis

We conduct several additional analyses to corroborate the robustness of our main empirical findings. Table VI presents the results of these empirical tests.

[INSERT TABLE VI ABOUT HERE]

First, we examine whether our empirical results are sensitive to the time period of analysis. Given the evolution of open source practices and GitHub's growing prominence over time, we restrict our sample to startup firms founded from 2010 to 2016. This time period

represents a more mature phase of open source development and ensures that our empirical findings are not driven by early adopters or historical patterns that might not reflect current dynamics. Model 1 in Table VI reports these empirical results. The coefficient for *Open Source* × *After* remains positive and significant ($\beta = 0.1057$, $p < 0.01$), with a magnitude slightly larger than in our main analysis. This result indicates that our empirical findings are robust to focusing on more recent startup firms.

Second, we investigate whether our empirical results hold for startup firms relying solely on open source innovation without patent protection. We restrict our sample to startup firms with zero patents throughout the observation time-period. Model 2 in Table VI shows that the coefficient for *Open Source* × *After* remains positive and significant ($\beta = 0.0859$, $p < 0.01$). This empirical finding is particularly noteworthy as it indicates that open source engagement can enhance exit likelihood without patent protection. However, the effect is smaller than in our full sample results.

Conclusion and Discussion

Our analysis reveals several significant findings about how startup firms can leverage open source innovation to achieve successful exits. First, we find that open source engagement significantly increases startup firms' likelihood of achieving successful exits via acquisition or IPO. Specifically, open source engagement increases exit likelihood by approximately 8.5%, a relationship that remains robust across multiple model specifications and after mitigating endogeneity concerns through our matched sampling approach. Second, our analysis reveals that proprietary innovation through patents strengthens this relationship. The positive effect of open source engagement on exit likelihood is more substantial for startup firms with patent protection. This moderating effect indicates the importance of combining open source activities with intellectual property protection.

Our findings make several contributions to strategic management and entrepreneurship research. First, we extend property rights theory by demonstrating how firms can achieve successful exits without relying solely on exclusive control rights. Traditional property rights theory emphasizes that firms secure competitive advantage through exclusive control over valuable resources (Demsetz, 1967; Kim & Mahoney, 2002). The theory suggests that clearly defined and enforceable property rights are essential for firms to prevent unauthorized use of their innovations and capture economic returns (Barzel, 1997; Teece, 1986). However, our findings reveal that in digital contexts, startup firms can enhance their exit prospects by sharing their intellectual property while maintaining strategic control over select components. This insight contributes to recent research on the evolution of property rights in digital economies (Baldwin & von Hippel, 2011; Henkel, 2006) by specifying conditions under which traditional property rights assumptions need reconsideration.

Our second contribution deepens our understanding of how resource-constrained firms can strategically leverage property rights in innovation contexts. Prior research applying property rights theory has primarily examined how established firms with substantial resources use legal protection mechanisms to secure returns from innovation (Pisano, 2006; Somaya, 2012). Our study reveals how startup firms, despite their resource constraints, can use selective property rights protection to enhance their exit opportunities. Significant is our empirical finding that strategic deployment of property rights can complement, rather than conflict with, value creation through openness. While traditional theory often presents a dichotomy between open and closed approaches to innovation (Kim & Mahoney, 2002; Libecap, 1989), our empirical findings indicate that this dichotomy may need further investigation in digital contexts. Indeed, firms can strategically combine different property rights regimes to enhance their likelihood of successful exits.

Our third contribution advances research on resource acquisition in entrepreneurial settings. Prior research studies have emphasized how startup firms overcome resource constraints through traditional mechanisms such as strategic alliances or venture capital relationships (Hsu & Ziedonis, 2013; Stuart et al., 1999). Our empirical findings reveal open source communities as an alternative pathway for enhancing exit prospects, extending recent work on digital entrepreneurship (Appio et al. 2021; Nambisan et al. 2017). Specifically, we identify mechanisms through which startup firms can leverage open source platforms to increase their economic attractiveness as acquisition targets or publicly-traded companies despite their inherent constraints.

Limitations and Future Research

Our study has several limitations that suggest directions for future research. First, while our focus on successful exits through acquisitions and IPOs captures important value capture milestones, questions remain about long-term value capture. Recent research suggests that exit success may not fully reflect sustainable competitive advantage (e.g., Aggarwal & Hsu, 2014). Following research on the persistence of innovation advantages (Ahuja, Lampert, & Novelli, 2013; Madsen & Leiblein, 2015), scholars could examine how different configurations of open source and proprietary strategies affect post-exit performance. Such research could investigate whether the benefits of open source engagement persist after acquisition or IPO and how firms maintain superior economic performance in increasingly open source innovation ecosystems. Second, our study's context in the U.S. software industry may limit the generalizability of our findings. Property rights research suggests that institutional environments significantly affect how firms capture economic value from innovation. The effectiveness of combining open source and proprietary strategies may vary across institutional contexts with different intellectual property regimes and innovation ecosystems. Future studies could examine how different institutional arrangements affect the relationship between open source engagement

and exit outcomes. Such research would help identify boundary conditions for our theoretical reasoning concerning property rights and economic value capture in different entrepreneurial settings. Third, while we identify patents as a significant moderator, our analysis may not capture the full range of complementary assets that affect successful exits through open source innovation. Prior research emphasizes how different types of complementary assets influence firms' ability to profit from innovation (Dahlander & Wallin, 2006; Teece, 1986). Future research could develop more fine-grained analyses of how different complementary assets interact with open source strategies to enhance exit opportunities. Considering research on strategic asset complementarity (Arora & Ceccagnoli, 2006; Helfat, 1997), scholars might examine which combinations of complementary assets are most effective for achieving successful exits through open source engagement. Furthermore, our measures of open source engagement may not capture all relevant dimensions of community participation and influence. Research on innovation communities suggests that social capital and relational assets play crucial roles in economic value creation and capture (Dahlander & Magnusson, 2008; von Hippel & von Krogh, 2003). Future research studies could develop richer measures of community engagement that capture both technical and social dimensions of participation. Such research might explore how different patterns of community interaction affect a startup's attractiveness as an acquisition target or public company. Finally, while our analysis addresses selection concerns through matching procedures, endogeneity remains a potential limitation. Future research could employ natural experiments or quasi-experiments, such as unexpected policy changes, to identify more precisely the causal effects of open source strategies on exit outcomes via acquisition or IPO.

While there is no universally accepted way to manage intellectual property, it is apparent that property rights protection, open source innovations, and successful strategies that integrate these approaches depend on firms' technological capabilities and evolving laws, such

as the recent Alice Corp. v. CLS Bank (2014) Supreme Court decision that struck down abstract software patents. Future scholarly research can explore strategic questions concerning contingent factors that drive successful innovations and firm success in this environment.

With the growth in two-sided and multi-sided digital platforms (e.g., Netflix, Uber, Google) and innovations originating from different stakeholders in such platforms, significant challenges in attributing/recombining innovations and defending property rights pose important questions for scholars regarding how property rights might impact the evolution of business models and platform success.

Furthermore, there is considerable value in investigating how firms' strategic decisions about product design and mixed technological product architectures (such as those that combine enforceable hardware patents with difficult-to-enforce software patents), especially when open source innovations drive these decisions. These instances provide fascinating scenarios for scholars to examine at the intersection of technological design and property rights. Finally, with extensive software and product design decisions that emerge from open and collaborative communities, it is pertinent for scholars in management studies to examine how property rights arise in such social systems and how the emergence of (partial or complete) design solutions from community-developed products generate implications for the antecedents and consequences of property rights.

NOTES

[1] To reconcile company names that may be spelled differently across databases, this study employs a name standardization procedure. The standardization code is applied to both the source (Pitchbook) and target (Patentsview) company names, which involves converting all strings to uppercase characters, removing non-alphabetic characters and common suffixes (e.g., -OLD, -NEW), and standardizing abbreviations (e.g., LABORATORIES, LABORATORY, LABS are all abbreviated to "LAB").

[2] A potential concern is that startup firms with patents may be systematically different from those without patents prior to their open source activities, which could bias our analysis. To address this concern, we examine whether patent ownership affects the likelihood of successful exit in the time-period before startup firms engage in open source activities. We compare startup firms that had patents with those that did not in the year before their open source engagement. The empirical results indicate no statistically significant difference in exit rates between these two groups (15.2% for startup firms with patents versus 14.8% for those without, t-statistic = 1.31), indicating that pre-existing patent holdings do not systematically bias our estimation of open source effects on exit outcomes via acquisition or IPO.

References

Aggarwal, V.A., & Hsu, D.H. (2014). Entrepreneurial exits and innovation. *Management Science*, 60(4), 867-887.

Ahuja, G., Lampert, C.M., & Novelli, E. (2013). The second face of appropriability: Generative appropriability and its determinants. *Academy of Management Review*, 38(2), 248-269.

Alchian, A.A. (1965). Some economics of property rights. *Il Politico*, 30(4), 816-829.

Alchian, A.A., & Demsetz, H. (1973). The property right paradigm. *Journal of Economic History*, 33(1), 16-27.

Alexy, O., George, G., & Salter, A.J. (2013). Cui bono? The selective revealing of knowledge and its implications for innovative activity. *Academy of Management Review*, 38(2), 270-291.

Appio, F.P., Frattini, F., Petruzzelli, A.M., & Neirotti, P. (2021). Digital transformation and innovation management: A synthesis of existing research and an agenda for future studies. *Journal of Product Innovation Management*, 38(1), 4-20.

Arora, A., & Ceccagnoli, M. (2006). Patent protection, complementary assets, and firms' incentives for technology licensing. *Management Science*, *52*(2), 293-308.

Baldwin, C., & Von Hippel, E. (2011). Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. *Organization Science*, 22(6), 1399-1417.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99-120.

Barzel, Y. (1997). *Economic Analysis of Property Rights* (Second edition). Cambridge, UK: Cambridge University Press.

Bel, R. (2018). A property rights theory of competitive advantage. *Strategic Management Journal*, *39*(6), 1678-1703.

Bonaccorsi, A., & Rossi, C. (2003). Why open source software can succeed. *Research Policy*, 32(7), 1243-1258.

Bonaccorsi, A., Giannangeli, S., & Rossi, C. (2006). Entry strategies under competing standards: Hybrid business models in the open source software industry. *Management Science*, 52(7), 1085-1098.

Branstetter, L.G., Fisman, R., & Foley, C.F. (2006). Do stronger intellectual property rights increase international technology transfer? Empirical evidence from US firm-level panel data. *Quarterly Journal of Economics*, 121(1), 321-349.

Bruno, A.V., & Tyebjee, T.T. (1985). The entrepreneur's search for capital. *Journal of Business Venturing*, 1(1), 61 – 74.

Cassar, G. (2004). The financing of business start-ups. *Journal of Business Venturing*, 19(2), 261-283.

Ceccagnoli, M., Forman, C., Huang, P., & Wu, D.J. (2012). Cocreation of value in a platform ecosystem! The case of enterprise software. *MIS Quarterly*, 36(1), 263-290.

Cenamor, J., & Frishammar, J. (2021). Openness in platform ecosystems: Innovation strategies for complementary products. *Research Policy*, 50(1), 104148.

Chesbrough, H.W. (2003). The logic of open innovation: Managing intellectual property. *California Management Review*, 45(3), 33-58.

Chesbrough, H.W., & Appleyard, M.M. (2007). Open innovation and strategy. *California Management Review*, 50(1), 57-76.

Coase, R.H. (1960). The problem of social cost. *Journal of Law and Economics*, 3(1), 1-44.

Cohen, W.M., & Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128-152.

Conti, A., Peukert, C., & Roche, M. (2021). Beefing IT up for your Investor? Open Sourcing and Startup Funding: Evidence from GitHub (August 25, 2021). Available at SSRN: https://ssrn.com/abstract=3883936 or http://dx.doi.org/10.2139/ssrn.3883936

Courtney, C., Dutta, S., & Li, Y. (2017). Resolving information asymmetry: Signaling, endorsement, and crowdfunding success. *Entrepreneurship Theory and Practice*, 41(2), 265-290.

Cusumano, M. (2004). Reflections on free and open software. *Communications of the ACM*, 47(10), 25–27.

Dahlander, L. (2007). Penguin in a new suit: A tale of how de novo entrants emerged to harness free and open source communities. *Industrial and Corporate Change*, 16(5), 913–943.

Dahlander, L., & Magnusson, M. (2008). How do firms make use of open source communities? *Long Range Planning*, 41(6), 629-649.

Dahlander, L., & Wallin, M.W. (2006). A man on the inside: Unlocking communities as complementary assets. *Research Policy*, 35(8), 1243-1259.

De Meza, D., & Webb, D.C. (2006). Credit rationing: Something's gotta give. *Economica*, 73(292), 563-578.

Demsetz, H. (1964) The exchange and enforcement of property rights. *Journal of Law and Economics*, 7(1), 11-26.

Demsetz, H. (1967). Toward a theory of property rights. *American Economic Review*, 57(2), 347-359.

Fern, M.J., Cardinal, L.B., & O'Neill, H.M. (2012). The genesis of strategy in new ventures: Escaping the constraints of founder and team knowledge. *Strategic Management Journal*, 33(4), 427-447.

Fitzgerald, B. (2006). The transformation of open source software. *MIS Quarterly*, 30(3), 587-598.

Fosfuri, A., Giarratana, M.S., & Luzzi, A. (2005). Firm assets and the rate of product introduction in open source software. DRUID Working Paper No. 2005-10, Available at SSRN: https://ssrn.com/abstract=784945 or http://dx.doi.org/10.2139/ssrn.784945

Foss, K., & Foss, N.J. (2005). Resources and transaction costs: How property rights economics furthers the resource-based view. *Strategic Management Journal*, 26(6), 541-553.

Franke, N., & von Hippel, E. (2003). Satisfying heterogeneous user needs via innovation toolkits: The case of Apache security software. *Research Policy*, 32(7), 1199-1215.

Freeman, J., Carroll, G. R., & Hannan, M. T. (1983). The liability of newness: Age dependence in organizational death rates. *American Sociological Review*, 48(5), 692-710.

Gallaugher, J.M., & Wang, Y.M. (2002). Understanding network effects in software markets: Evidence from web server pricing. *MIS Quarterly*, 26(4), 303-327.

Gans, J.S., & Stern, S. (2003). The product market and the market for "ideas": commercialization strategies for technology entrepreneurs. *Research Policy*, 32(2), 333-350

.

Gawer, A. (2009). *Platforms, Markets, and Innovation.* Cheltenham, UK: Edward Elgar.

Gittelman, M. (2008). A note on the value of patents as indicators of innovation: Implications for management research. *Academy of Management Perspectives*, 22(3), 21-27.

Gompers, P., & Lerner, J. (2001). The venture capital revolution. *Journal of Economic Perspectives*, 15(2), 145-168.

Grand, S., Von Krogh, G., Leonard, D., & Swap, W. (2004). Resource allocation beyond firm boundaries: A multi-level model for open source innovation. *Long Range Planning*, 37(6), 591-610.

Granstrand, O. (1999). *The Economics and Management of Intellectual Property – Towards Intellectual Capitalism*. Cheltenham, UK: Edward Elgar Publishing.

Grossman, S.J., & Hart, O.D. (1986). The costs and benefits of ownership: A theory of vertical and lateral integration. *Journal of Political Economy*, 94(4), 691-719.

Hall, B.H., &MacGarvie, M. (2010). The private value of software patents. *Research Policy*, 39(7), 994-1009.

Harhoff, D., Henkel, J., & von Hippel, E. (2003). Profiting from voluntary information spillovers: How users benefit by freely revealing their innovations. *Research Policy*, 32(10), 1753–1769.

Hart, O., & Moore, J. (1990). Property rights and the nature of the firm. *Journal of Political Economy*, 98(6), 1119-1158.

Haruvy, E., Sethi, S.P., & Zhou, J. (2008). Open source development with a commercial complementary product or service. *Production and Operations Management*, 17(1), 29-43.

Helfat, C.E. (1997). Know-how and asset complementarity and dynamic capability accumulation: The case of R&D. *Strategic Management Journal*, 18(5), 339-360.

Henkel, J. (2006). Selective revealing in open innovation processes: The case of embedded Linux. *Research Policy*, 35(7), 953-969.

Hsu, D.H., & Ziedonis, R.H. (2013). Resources as dual sources of advantage: Implications for valuing entrepreneurial-firm patents. *Strategic Management Journal*, 34(7), 761-781.

Iansiti, M., & Richards, G. L. (2006). The information technology ecosystem: Structure, health, and performance. *Antitrust Bulletin*, *51*(1), 77-110.

Islam, M., Fremeth, A., & Marcus, A. (2018). Signaling by early stage startups: US government research grants and venture capital funding. *Journal of Business Venturing*, 33(1), 35-51.

Katz, M.L., & Shapiro, C. (1994). Systems competition and network effects. *Journal of Economic Perspectives*, 8(2), 93-115.

Kim, J., & Mahoney, J.T. (2002). Resource-based and property rights perspectives on value creation: The case of oil field unitization. *Managerial and Decision Economics*, 23(4), 225-245.

Kim, J., & Mahoney, J.T. (2005). Property rights theory, transaction costs theory, and agency theory: An organizational economics approach to strategic management. *Managerial and Decision Economics*, 26(4), 223-242.

Kim, J., & Mahoney, J.T. (2010). A strategic theory of the firm as a nexus of incomplete contracts: A property rights approach. *Journal of Management*, 36(4), 806-826.

Kim, S.M., Anand, G., Larson, E.C., & Mahoney, J.T. (2019). Resource co-specialization in outsourcing of enterprise systems software: Impact on exchange success and firm growth. *Journal of Science and Technology Policy Management*, 10(5), 1015-1046.

Kleinbaum, D. G., Kupper, L. L., Muller, K. E., & Nizam, A. (1988). *Applied Regression Analysis and Other Multivariable Methods* (Vol. 601). Belmont, CA: Duxbury Press.

Koch, S. & Schneider, G. (2002). Effort, cooperation and coordination in an open source software project: GNOME. *Information Systems Journal*, 12(1), 27-42.

Kutner, M.H., Nachtsheim, C.J., & Neter, J. (2004). *Applied Linear Regression Models.* New York: McGraw-Hill Irwin.

Laursen, K., & A.J. Salter (2014). The paradox of openness: Appropriability, external search, and collaboration." *Research Policy*, 43(5), 867–78.

Lee, D., & Mendelson, H. (2008). Divide and conquer: Competing with free technology under network effects. *Production and Operations Management*, 17(1), 12-28.

Lerner, J. (2009). The empirical impact of intellectual property rights on innovation: Puzzles and clues. *American Economic Review*, *99*(2), 343-348.

Lerner, J., & Tirole, J. (2002). Some simple economics of open source. *Journal of Industrial Economics*, 50(2), 197–234.

Lerner, J., & Tirole, J. (2005). The economics of technology sharing: Open source and beyond. *Journal of Economic Perspectives*, 19(2), 99-120.

Levin, R. C., Klevorick, A.K., Nelson, R.R., Winter, S.G., Gilbert, R., & Griliches, Z. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity*, 1987(3), 783-831.

Libecap, G.D. (1989). *Contracting for Property Rights*. Cambridge, UK: Cambridge University Press.

Liebeskind, J.P. (1996). Knowledge, strategy, and the theory of the firm. *Strategic Management Journal*, Vol. 17(Winter Special Issue), 93-107.

Lifshitz-Assaf, H. (2018). Dismantling knowledge boundaries at NASA: The critical role of professional identity in open innovation. *Administrative Science Quarterly*, 63(4), 746-782.

Lin, Y.K., & Maruping, L.M. (2022). Open source collaboration in digital entrepreneurship. *Organization Science*, 33(1), 212-230.

Lin, Y.K., & Rai, A. (2024). The scope of software patent protection in the digital age: Evidence from *Alice*. *Information Systems Research*, *35*(2), 657-672.

Lippman, S.A., & Rumelt, R.P. (1982). Uncertain imitability: An analysis of interfirm differences in efficiency under competition. *Bell Journal of Economics*, 13(2), 418-438.

Lockett, A., & Thompson, S. (2001). The resource-based view and economics. *Journal of Management*, 27(6), 723-754.

Madsen, T.L., & Leiblein, M.J. (2015). What factors affect the persistence of an innovation advantage? Journal of Management Studies, 52(8), 1097-1127.

Mahoney, J.T., & Pandian, J.R. (1992). The resource-based view within the conversation of strategic management. *Strategic Management Journal*, *13*(5), 363-380.

Mahoney, J.T., & Qian, L. (2013). Market frictions as building blocks of an organizational economics approach to strategic management. *Strategic Management Journal*, 34(9), 1019-1041.

Mansfield, E., & Mundial, B. (1994). *Intellectual Property Protection, Foreign Direct Investment, and Technology Transfer*. Washington, DC: World Bank.

Nambisan, S., Lyytinen, K., Majchrzak, A., & Song, M. (2017). Digital innovation management. *MIS Quarterly*, *41*(1), 223-238.

North, D.C. (1990). *Institutions, Institutional Change and Economic Performance*. Cambridge, UK: Cambridge University Press.

O'Mahony, S. (2003). Guarding the commons: How community managed software projects protect their work. *Research Policy*, *32*(7), 1179-1198.

O'Mahony, S., & Ferraro, F. (2007). The emergence of governance in an open source community. *Academy of Management Journal*, 50(5), 1079-1106.

Osterloh, M., & Rota, S. (2007). Open source software development—Just another case of collective invention? *Research Policy*, 36(2), 157-171.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge, UK: Cambridge University Press.

Oxley, J.E. (1999). Institutional environment and the mechanisms of governance: The impact of intellectual property protection on the structure of inter-firm alliances. *Journal of Economic Behavior & Organization*, 38(3), 283-309.

Perr, J., Appleyard, M.M., & Patrick, P. (2010). Open for business: Emerging business models in open source software. *International Journal of Technology Management*, 52(3), 432-456.

Peteraf, M.A. (1993). The cornerstones of competitive advantage: a resource-based view. *Strategic Management Journal*, 14(3), 179-191.

Pisano, G.P. (1990). The R&D boundaries of the firm: An empirical analysis. *Administrative Science Quarterly*, 35(1), 153-176.

Pisano, G.P. (2006). Profiting from innovation and the intellectual property revolution. *Research Policy*, 35(8), 1122-1130.

Piva, E., Rentocchini, F., & Rossi-Lamastra, C. (2012). Is open source software about innovation? Collaborations with the open source community and innovation performance of software entrepreneurial ventures. *Journal of Small Business Management*, 50(2), 340-364.

Powell, W.W., Koput, K.W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, 41(1), 116-145.

Rajan, R.G., & Zingales, L. (1998). Power in a theory of the firm. *Quarterly Journal of Economics*, 113(2), 387-432.

Rumelt, R.P. (1984). Toward a strategic theory of the firm. In *Competitive Strategic Management*. R. Lamb (Ed.): 556-570. Englewood Cliffs, NJ: Prentice-Hall.

Shaikh, M., & Vaast, E. (2016). Folding and unfolding: Balancing openness and transparency in open source communities. *Information Systems Research*, 27(4), 813-833.

Scotchmer, S. (2010). Openness, open source, and the veil of ignorance. *American Economic Review*, 100(2), 165-171.

Shapiro, C. (1985). Patent licensing and R&D rivalry. *American Economic Review*, 75(2), 25-30.

Somaya, D. (2012). Patent strategy and management: An integrative review and research agenda. *Journal of Management*, 38(4), 1084-1114.

Somaya, D., Kim, Y., & Vonortas, N.S. (2011). Exclusivity in licensing alliances: Using hostages to support technology commercialization. *Strategic Management Journal*, 32(2), 159-186.

Somaya, D., Williamson, I. O., & Zhang, X. (2007). Combining patent law expertise with R&D for patenting performance. *Organization Science*, *18*(6), 922-937.

Spaeth, S., von Krogh, G., & He, F. (2015). Perceived firm attributes and intrinsic motivation in sponsored open source software projects. *Information Systems Research*, 26(1),.224-237.

Srinivasan, R., & Brush, T.H. (2006). Supplier performance in vertical alliances: The effects of self-enforcing agreements and enforceable contracts. *Organization Science*, 17(4), 436-452.

Stuart, T.E., Hoang, H., & Hybels, R.C. (1999). Interorganizational endorsements and the performance of entrepreneurial ventures. *Administrative Science Quarterly*, 44(2), 315-349.

Stuart, T.E, & Sorenson, O. (2003). The geography of opportunity: spatial heterogeneity in founding rates and the performance of biotechnology firms. *Research Policy*, 32(2), 229-253.

Taeuscher, K., & Rothe, H. (2024). Entrepreneurial framing: How category dynamics shape the effectiveness of linguistic frames. *Strategic Management Journal*, *45*(2), 362-395.

Teece, D.J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy. *Research Policy*, 15(6), 285-305.

Thummadi, B.V., & Paruchuri, S. (2022). Presence of location-based agglomeration effects in open source communities: an empirical test on GitHub. *Academy of Management Discoveries*, 8(2), 274-297.

von Hippel, E.V., & von Krogh, G. (2003). Open source software and the "private-collective" innovation model: Issues for organization science. *Organization Science*, 14(2), 209-223.

Wang, J. (2012). Survival factors for free open source software projects: A multi-stage perspective. *European Management Journal*, 30(4), 352-371.

Wen, W., Ceccagnoli, M., & Forman, C. (2016). Opening up intellectual property strategy: Implications for open source software entry by start-up firms. *Management Science*, 62(9), 2668-2691.

West, J. (2003). How open is open enough? Melding proprietary and open source platform strategies. *Research Policy*, 32(7), 1259-1285.

West, J., & Gallagher, S. (2006). Challenges of open innovation: The paradox of firm investment in open-source software. *R&D Management*, 36(3), 319-331.

Williamson, O.E. (1985). *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. New York: The Free Press.

Wright, N.L., Nagle, F., & Greenstein, S. (2023). Open source software and global entrepreneurship. *Research Policy*, 52(9), 104846.

Wulf, J., & Blohm, I. (2020). Fostering value creation with digital platforms: A unified theory of the application programming interface design. *Journal of Management Information Systems*, 37(1), 251-281.

Yang, W. (2023). How Can Open Source Technology Ecosystem Create Value? Evidence from Investors' Reactions to Firms' GitHub Code Releases. Evidence from Investors' Reactions to Firms' GitHub Code Releases (April 30, 2023).

Yao, T., & O'Neill, H. (2022). Venture capital exit pressure and venture exit: A board perspective. *Strategic Management Journal*, *43*(13), 2829-2848.

Yoo, Y., Boland Jr, R. J., Lyytinen, K., & Majchrzak, A. (2012). Organizing for innovation in the digitized world. *Organization Science*, *23*(5), 1398-1408.

Zahra, S.A. (2021). The resource-based view, resourcefulness, and resource management in startup firms: A proposed research agenda. *Journal of Management*, 47(7), 1841-1860.

Zahra, S.A., & George, G. (2002). Absorptive capacity: A review, reconceptualization, and extension. *Academy of Management Review*, 27(2), 185-203.

Ziedonis, R. (2004). Don't fence me in: Fragmented markets for technology and the patent acquisition strategies of firms. *Management Science* 50(6): 804–820.

Zobel, A.K. (2017). Benefiting from open innovation: A multidimensional model of absorptive capacity. *Journal of Product Innovation Management*, 34(3), 269-288.

Zobel, A.K., & Hagedoorn, J. (2020). Implications of open innovation for organizational boundaries and the governance of contractual relations. *Academy of Management Perspectives*, 34(3), 400-423.

APPENDIX

Table I. Descriptive Statistics

Variables	Mean	S.D.	Min	Max
Successful exit	0.1590	0.3657	0	1
Open source	0.1182	0.3229	0	1
After	0.1026	0.3034	0	1
Patent	0.0342	0.2182	0	5.1874
Patent claims	0.1107	0.6393	0	8.4123
Backward citation	0.0829	0.5519	0	9.4863
Commits	0.6137	1.9554	0	12.9484
Stars	0.0727	0.3348	0	2.6070
Pull requests	0.0788	0.3520	0	2.5909
Watchers	0.2924	1.1672	0	9.8847

Table II. Correlations

	1	2	3	4	5	6	7	8	9	10
1. Successful exit	1									
2. Open source	-0.0161	1								
3. After	-0.0019	0.3244	1							
4. Patent	-0.0039	-0.0036	0.0116	1						
5. Patent claims	-0.0105	-0.0017	0.0126	0.6547	1					
6. Backward citation	-0.0066	-0.0053	0.0069	0.3063	0.7969	1				
7. Commits	-0.0436	0.2576	0.3823	0.0282	0.0311	0.0204	1			
8. Stars	0.0156	0.3930	0.2424	0.0115	0.0117	0.0093	0.5679	1		
9. Pull requests	0.0113	0.1113	0.1622	0.0133	0.0142	0.0107	0.6039	0.7041	1	
10. Watchers	0.0176	0.2842	0.3411	0.0111	0.0117	0.0081	0.6154	0.7069	0.8170	1

Table III. Characteristics of Startup Firms in the Matched Sample

	Open Source = 1	Open Source = 0	t-statistics
Found year	2013	2014	0.03
	(0.02)	(0.02)	
Startup's patent counts	0.86	0.85	0.12
	(0.07)	(0.07)	
Number of Startups	3,993	38,228	

Note. Standard errors are in parentheses.

Two-tailed test for all variables.

Table IV. The Effect of Open Source Engagement on Startup Firms' Successful Exit Likelihood

				Startup fixed effects		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Open source		-0.0563***	-0.0713***			
		-0.0059	-0.0062			
After		-0.0136*	-0.0479***		-0.0343***	-0.0652***
		-0.008	-0.0101		-0.0102	-0.0124
Open source × After			0.0918***			0.0848***
			-0.0169			-0.0211
Patent claims	-0.0137***	-0.0138***	-0.0137***	-0.0116***	-0.0116***	-0.0115***
	-0.0038	-0.0038	-0.0038	-0.0039	-0.0039	-0.0039
Backward citation	0.0036	0.0036	0.0036	-0.0042	-0.0043	-0.0043
	-0.0045	-0.0045	-0.0046	-0.0048	-0.0048	-0.0048
Commits	-0.0161***	-0.0138***	-0.0118***	-0.0123***	-0.0119***	-0.0108***
	-0.001	-0.0011	-0.0011	-0.0014	-0.0014	-0.0014
Stars	0.0297**	0.0238**	0.0318***	0.0433***	0.0369**	0.0453***

	-0.0121	-0.0121	-0.0122	-0.0165	-0.0166	-0.0168
Pull requests	-0.0470***	-0.0503***	-0.0517***	-0.0387**	-0.0381**	-0.0397**
	-0.0122	-0.0122	-0.0121	-0.0166	-0.0166	-0.0166
Watchers	0.0308***	0.0402***	0.0264***	0.0169***	0.0252***	0.0115*
	-0.004	-0.0044	-0.0052	-0.0054	-0.006	-0.007
Constant	-0.1034***	-0.0981***	-0.0973***	-0.3783***	-0.3779***	-0.3786***
	-0.0336	-0.0337	-0.0337	-0.0394	-0.0395	-0.0394
Observations	105752	105752	105752	105752	105752	105752
R^2 (within)	0.1517	0.1512	0.1512	0.1639	0.1641	0.1644
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Startup fixed effects	No	No	No	Yes	Yes	Yes

Notes. Robust standard errors are in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01.

Table V. The Moderating Effect of Patents on the Relationship Between Open Source Engagement and Successful Exit Likelihood

	Model 1	Model 2
After	-0.0361*	-0.0683***
	-0.0198	-0.0228
Patent	-0.0198*	-0.0209
	-0.0116	-0.0133
Open source × After		0.1058**
		-0.0434
Open source × Patent		-0.1040*
		-0.0535
Patent × After		0.0007
		-0.0292
Open source × Patent × After		0.1601**
		-0.0755
Patent claims	-0.0156**	-0.0158**
	-0.0071	-0.0071
Backward citation	-0.0007	-0.0005
	-0.0081	-0.0081
Commits	-0.0150***	-0.0134***
	-0.0028	-0.0029
Stars	0.054	0.0606*
	-0.0363	-0.0359
Pull requests	-0.0489	-0.0628*
	-0.034	-0.0343

Watchers	0.0191	0.0034
	-0.0123	-0.0135
Constant	-0.4309***	-0.4316***
	-0.0931	-0.0933
Observations	105752	105752
R^2 (within)	0.1698	0.1706
Year fixed effects	Yes	Yes
Startup fixed effects	Yes	Yes

Notes. Robust standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01.

Table VI. Robustness Check and Additional Analysis

	Model 1	Model 2
After	-0.0696***	-0.0619***
	-0.0203	-0.0125
Open source × After	0.1057***	0.0859***
	-0.0339	-0.0212
Patent claims	-0.0132**	-0.0200***
	-0.0063	-0.0039
Backward citation	-0.0057	-0.0032
	-0.0072	-0.0049
Commits	-0.0132***	-0.0105***
	-0.0019	-0.0014
Stars	0.037	0.0440***
	-0.0252	-0.0169
Pull requests	-0.0229	-0.0409**
	-0.0251	-0.0167
Watchers	0.0119	0.0118*
	-0.0105	-0.0071
Constant	-0.2311***	-0.3826***
	-0.0298	-0.0417
Observations	46270	105752
R^2 (within)	0.1766	0.1629
Year fixed effects	Yes	Yes
Startup fixed effects	Yes	Yes

Notes. Robust standard errors in parentheses. *p < 0.1; **p < 0.05; ***p < 0.01.