Essays on Value Creation in the Open Source Phenomenon: Understanding the Influence of Work Structures, Team Composition, and Community Ideologies

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# Introduction

In the current digitally enabled collaborative environment, free (libre) and open source software (FLOSS) projects have become ubiquitous. Founded on the principles of openness and co-operation, FLOSS has over time come to refer to software in which the source code is available to the general public for use and modification from its original design. Since the 1980s, which saw the formalization of the concept of FLOSS through the creation of licenses and institutions that protected its principles, open source has been transforming the information technology (IT) organizational landscape. The decade that followed its formalization, saw the first releases of Linux, Apache webserver, and Python; projects which would go on to become the poster children for the FLOSS movement. In the 2000s, motivated by the success of FLOSS projects, IT organizations started cautiously embracing the phenomenon. In 2001, IBM opened the source code of several of its software tools (estimated at $40 million) to the public domain, creating the Eclipse open source project[[1]](#footnote-1). The current decade, the 2010s, has seen the phenomenon sustain its exponential growth - both in terms of contributors coming together on collaborative development platforms like GitHub, as well as in terms of organizations supporting and taking ownership of FLOSS projects. The importance of the FLOSS model of development for the future of IT organizations became evident in June 2018, when Microsoft announced that it was purchasing GitHub for an estimated $7.5 billion[[2]](#footnote-2).

The transformation of FLOSS from an ideology in the 1980’s to a phenomenon that has become central to the strategic decision of IT organizations leads to the question - what does it have in store for the future? A clue for answering this question comes from Microsoft’s GitHub acquisition announcement, where they [Microsoft] state the bright future for FLOSS and collaborative development.

“Computing is becoming embedded in the world, with every part of our daily life and work and every aspect of our society and economy being transformed by digital technology. Developers are the builders of this new era, writing the world’s code. And GitHub is their home…

… In short, developers will be at the center of solving the world’s most pressing challenges. However, the real power comes when every developer can create together, collaborate, share code and build on each other’s work.”(Microsoft News Center 2018)

With digital transformations (e.g. 3D printing, blockchain, digitally enabled development platforms etc.) making industries increasingly information oriented, new opportunities have emerged in non-IT organizations to adopt practices that have been successful in the IT industry. Predictably, the FLOSS model of development has attracted considerable attention from other disciplines. The allure of being able to tap into the vast reserves of skills spread across the globe, enabling the creation products and services of high quality and functionality at a low cost is appealing for many organizations and industries (Coverity Inc. 2013). For example, with life sciences increasingly becoming an information orientated science, it has been suggested that what worked for FLOSS development might be an answer to the spiraling cost of drug R&D (Munos 2006). Although some initiatives (e.g. MMV , DNDi , CAMBIA ) have looked towards adopting a FLOSS approach for drug discovery, they have been successful at adopting it only in the early phases, where ideas and solutions are crowdsourced from the community. While many organizations are considering the FLOSS approach for developing their products, migrating to a model of development that does not conform to traditional contractual, governance mechanisms, and organizational boundaries can seem daunting. Practically, organizations are seeking to benefit from the strengths of open collaboration but are unsure about how to integrate it with their own strengths and practices that they have painstakingly built over time. As information systems (IS) researchers, we are in a unique position to enrich the theories surrounding the FLOSS artifact and inform organizations on how they can facilitate value by adopting a FLOSS approach to development. Herein lies my long terms research objective, for which, this dissertation is the first step - to unearth the value creation mechanisms associated with the FLOSS model of development and understand how these mechanisms can be replicated more widely across IT and non-IT organizations

The theoretical enquiry of the value creation mechanisms associated with the FLOSS model of development starts at the information technology artifact, the actual software developed, which creates value through its use in the community. And fundamental to building the complex FLOSS artifact is the unique work orchestration mechanisms that emerge to motivate and coordinate task work of geographically distributed individuals and organizations (Howison and Crowston 2014; Lindberg et al. 2016). Hence, replicating the FLOSS model of development requires careful understanding of the work structures that provide the framework for effectively organizing task work, the mechanisms through which these works structures can facilitate value, and the boundaries of its applicability. Gathered around the FLOSS artifact, is the team of contributors comprised of both individuals and organizations who collaborate to build the software. In the absence of formal management and governance practices like requirements and release management, communities of practice sustain themselves by nurturing informal network governance mechanisms like – access restrictions, collective sanctions, macroculture, and reputation (Jones et al. 1997). Understanding how project owners can foster informal network governance mechanisms in order to protect social exchanges and overcome coordination challenges is an important element of sustaining collaboration in FLOSS teams. Encompassing both the work structures and teams of contributors are the ideological undercurrents that shape the objectives and motivations of the FLOSS community (Daniel et al. 2018). Given its effect on the motivation of the contributors, ideological changes are expected to moderate the value creation mechanisms associated with different FLOSS attributes, like the project’s work structures. Therefore, harnessing the full potential of the FLOSS phenomenon would require a clear understanding of the ideologies that shape the community and ensuring a seamless fit between the ideological needs and the different project attributes.

Given the importance of the aforementioned three aspects of FLOSS, the three essays of this dissertation explore the value creation mechanisms associated with – work structures, teams and governance structures, and community ideologies. An important aspect of this dissertation is to expand our knowledge regarding organizational participation in FLOSS projects. Organizational participation in FLOSS projects can result in a trade-off between openness (increasing autonomy and stimulating innovation, creativity, and organizational growth) and control (over platform activities, efficient development practices, and intellectual property right appropriation; Engeström 2007; Jarvenpaa and Lang 2011). The trade-off manifests as a boundary management problem that, if effectively managed, can directly influence the innovative and absorptive capacity of the FLOSS community (Teigland et al. 2014). Each essay in this dissertation explores the implications of the trade-off between openness and control when organizations own open source projects in the context of the value creation mechanism being studied. Specifically, my dissertation has three essays, which address each of the following broad research questions:

1. How does *work structures* influence the success of FLOSS projects?
2. How does *informal governance mechanisms* that emerge in FLOSS *teams* influence the survival of FLOSS projects?
3. How do *ideological shifts* transform the value creation mechanisms associated with FLOSS work structures?

## Structure of The Dissertation

The dissertation is structured as three similarly themed but separate essays exploring the value creation mechanisms associated with FLOSS projects. The three essays have separate theoretical foundations and their implications contribute to different aspects of FLOSS research and practice. To collect data for our analysis, we selected FLOSS projects started by both organizations and individuals in GitHub, in early 2014. We collected detailed task level data and followed the projects for a period of three years. During this period, some projects in our sample grew and become popular, for example, POP[[3]](#footnote-3) project started by Facebook, and Slick[[4]](#footnote-4), an individual owned project; while some tended to loose popularity and become inactive.

The first essay, examines how the unique nature of FLOSS work which is dominated by the sequential layering of individual tasks, referred to as superposition, acts as an antecedent to the project’s success. Building on the theory of collaboration through open superposition (Howison and Crowston 2014), the essay theorizes the motivational mechanisms that operate within superposed work structures and unearths the contextual conditions that may limit the influence of superposition on FLOSS project value. Furthermore, given the increasing usage of FLOSS by organizations, the study investigates the specificities brought to these motivational mechanisms when FLOSS projects are owned by organizations. Developing an innovative operationalization of the work structures of FLOSS projects, this essay finds support for a non-linear relationship between the degree of superposition and the success of the project. Further, this relationship is moderated by the type of ownership of the project. Overall, the first essay advances our understanding of work structures, motivation, and organizational participation in FLOSS environments. It also provides FLOSS practitioners with valuable insights for modeling the project’s task work to facilitate their success.

While the first essay establishes the importance of task-work organization in FLOSS projects, the second essay expands the inquiry into the role of team composition in the project’s success. Building on the theories of coordination (Malone and Crowston 1994) and network governance (Jones et al. 1997), this essay studies the influence of source code access restrictions imposed on team members in mitigating coordination challenges. The study also investigates the changes brought to the coordination mechanisms when open source projects are owned by organizations. Using a Cox proportional hazard model (Hosmer et al. 2008), the study demonstrates that the relationship between the proportion of contributors who are given write access to the source code in the team and the survival of the project, is moderated by the nature of project ownership. Interestingly, the observed moderation is a crossover interaction effect that changes from negative for individual owned projects to positive for organization owned projects. Overall, the second essay advances our understanding about contributor roles, access restrictions, and organizational participation in open source environments. The findings provide open source researchers and practitioners with fresh insights for better understanding and modeling project teams to facilitate their success.

The third essay pursues an overarching view of the FLOSS community by examining the ideological foundations of the FLOSS community and studies its influence on project success. This essay scrutinizes two ideological shifts seen in the FLOSS community that have altered the beliefs of ‘openness’ and ‘prevention of commercial appropriation’, on which the open source phenomenon was founded. First, the emergence of ‘permissive FLOSS licenses’ that allow commercial appropriation of the collaboratively developed code, and second, ‘organizational ownership’ of FLOSS projects. Rooted in self-determination theory (Ryan and Deci 2000), this essay theorizes the mechanisms through which ideological changes influence the pathways through which work structures in FLOSS projects are related to their success. Using an instrument variable approach, this essay finds that the ideological shift pertaining to license type has a significant influence on the relationship between the work structures and project success for both individual and organization owned projects. Overall, the third essay advances our understanding of the important role that ideologies play in shaping the relationship between work structures and success of the FLOSS projects.

Each essay is self-contained in terms of literature review, hypotheses development, and implications for research and practice. The essays together contribute to different aspects of literature on FLOSS. The theoretical foundation and research hypotheses for all the three essays are summarized in Table 1-1. Further, Table 1-2 presents the research questions, methods & variables, and important findings from all the three essays at a glance

Table1. : Three essays at a glance: Theoretical foundation and research hypotheses

|  |  |
| --- | --- |
| **Essay** | **Theoretical Foundation and Hypotheses** |
| 1 | **Theoretical foundation:**   * Theory of collaboration through open superposition (Howison and Crowston 2014) * Self-determination theory (Ryan and Deci 2000) * Affective events theory (Weiss and Cropanzo 1996)   **Hypotheses:**   * Hypothesis 1. In the context of FLOSS projects, the degree of superposition has a nonlinear relationship with project popularity such that project popularity increases with an increase in the degree of superposition up to a particular value (the turning point). Beyond this optimal degree of superposition, any further increase reduces the popularity of the project. * Hypothesis 2a: In the context of FLOSS projects, the project ownership type moderates the relationship between the degree of superposition and project popularity such that the degree of superposition has a significantly lower influence on the popularity of the project for organization-owned projects than for individual-owned projects. * Hypothesis 2b. In the case of organization-owned projects, the degree of superposition at which project popularity is at a maximum (the turning point) is significantly lower than for individual-owned projects. |
| 2 | **Theoretical foundation:**   * Coordination theory (Malone and Crowston 1994) * Theory of network governance (Jones et al. 1997)   **Hypotheses:**   * Hypothesis 1: A greater proportion of core contributors in a project will lead to a lower chance of survival of the project * Hypothesis 2: Organizational ownership mitigates the negative influence that the proportion of core contributors has on project survival * Hypothesis 3: The average code contributions per core contributor decreases in the case of organization owned project as compared to individual owned projects. |
| 3 | **Theoretical foundation:**   * Theory of collaboration through open superposition (Howison and Crowston 2014) * Self-determination theory (Ryan and Deci 2000) * Ideological fit in open source communities (Daniel et al. 2018)   **Hypotheses: First Ideological shift - license choice**   * Hypothesis 1a: The type of license moderates the relationship between the degree of superposition and the popularity of FLOSS projects, such that, for projects with restrictive licenses an increase in the degree of superposition tends to have a higher positive influence on the popularity of the project than for projects with permissive licenses. * Hypothesis 1b: The type of license moderates the relationship between the degree of superposition and the survival of FLOSS projects, such that, for projects with restrictive licenses, an increase in degree of superposition tends to have a higher positive influence on the survival of the project than for projects with permissive licenses.   **Hypotheses: Second Ideological shift - organizational ownership**   * Hypothesis 2a: For organization owned projects, the moderating influence of license type on the relationship between the degree of superposition and the popularity of FLOSS projects is less in comparison to individual owned projects. * Hypothesis 2b: For organization owned projects, the moderating influence of license choice on the relationship between the degree of superposition and the survival of FLOSS projects is less in comparison to individual owned projects. |

Table 1. : Three essays at a glance: Research questions, methods, and main findings

|  |  |
| --- | --- |
| **Essay (Research Questions, Method)** | **Essay (Main Findings)** |
| **Essay 1: Work structures of FLOSS projects**  **Research questions:**   * How does the extent of task superposition influence FLOSS project success? * How do organization-owned FLOSS projects differ from individual-owned FLOSS projects in terms of task superposition, and does this difference influence project success?   **Empirical model:** OLS, Negative binomial regression  **Unit of analysis:** Project level of analysis  **Dependent variable:**   * Project popularity measured as the number of stars that a project has received   **Independent variable:**   * Degree of superposition, operationalized as the ratio of number of versions of the project to number of individual task contributiosn in the project * Ownership type of the project | **Main findings:**   * Empirical analysis of a large sample of FLOSS projects hosted on GitHub indicates that the emergence of sequentially layered and individual task work, referred to as the superposed organization of work, exhibits an inverted-U shaped relationship with the popularity of a project * For individual-owned projects, as the degree of superposition increases from 0 to its turning point, the popularity, is found to increase by more than five times on average, from 11.53 to 71.79 stars, holding everything else constant, while for organization-owned projects it is found to increase from 28.26 to 38.08 stars * For individual-owned projects, the popularity of the project is found to decrease on an average from 71.79 to 37.12 stars as the degree of superposition increases from its turning point to its highest value of 1, keeping everything else constant, while this number decreases from 38.08 to 20.78 stars for organization-owned projects |
| **Essay 2: Team Composition and Governance of Open Source Projects**  **Research questions:**   * What role does contributor access restrictions have in influencing the survival of FLOSS projects? * How does organizational ownership moderate this relationship?   **Empirical model:**   * Cox-proportional hazard model * Hierarchical linear model   **Unit of analysis:**   * Project level of analysis – Hypotheses 1 and 2 * Contributor level of analysis – Hypothesis 3   **Dependent variables:**   * Hazard rate: Likelihood a project becomes inactive at time *t* given that it has survived till time *t* * Average code contributions per contributor   **Independent variables:**   * Proportion of contributors with write access (core contributors) * Contributor type (core or peripheral contributor) * Ownership type of the project | **Main findings:**   * Based on the survival analysis of a large sample of FLOSS projects owned by individuals and a wide range of organizations, this study finds that the proportion of contributors who are given write access to the source code exhibit opposing effects on project survival, which is conditional on the ownership of the project * For individual owned projects, as the proportion of core contributors increases from 0 to 1, the hazard rates increases by 0.96, which translates to a 21% increased chance of survival * For organization owned projects, as the proportion of core contributors increases from 0 to 1, the hazard ratio decreases by 0.34 which translates to a 10% decreased chance of survival. |
| **Essay 3: Community ideologies**  **Research question:**   * How have the ideological shifts invoked by (a) the emergence of permissive licenses, and (b) the shift towards organizational ownership, transformed the influence of FLOSS work structures on project outcomes?   **Empirical model:**   * OLS and 2SLS (Instrument) * Accelerated failure time analysis, GMM (Instrument)   **Unit of analysis:** Project level of analysis  **Dependent variables:**   * Project popularity measured as the number of stars that a project has received * Likelihood of survival of the project   **Independent variables:**   * Choice of license (Permissive or restrictive) * Degree of superposition, operationalized as the ratio of number of versions of the project to number of tasks in the project   **Instrument variable for choice of license:**   * Geert Hofstede dimension – Individualism vs. collectivism * Country’s social protection contribution as a percentage of total expenditure in the year 2014-2015 | **Main findings:** |

# Essay 1: Work Structures of FLOSS Projects

## Abstract

Collaboration through open superposition describes the dominant work orchestration mechanism observed in Free (Libre) and Open Source Software (FLOSS), wherein the software development occurs by the sequential layering of individual tasks. This work orchestration mechanism is different from the traditional idea of software development, where the focus is towards co-work and concurrent development facilitated by a modular software design architecture. This essay theorizes and examines the motivational mechanisms that operate within superposed work structures to influence the success of FLOSS projects. We also unearth the contextual conditions that may limit the influence of the superposed nature of work on FLOSS project success. Furthermore, given the increasing usage of FLOSS by organizations, we investigate the specificities brought to these motivational mechanisms when FLOSS projects are owned by organizations. The results from our analysis of over 6500 FLOSS projects hosted on GitHub support a nonlinear relationship between the degree of superposition and the success of the FLOSS project. Moreover, we find that the type of ownership moderates this nonlinear relationship such that (1) organizational ownership mitigates the influence of the degree of superposition on the success of the project, and (2) under organizational ownership, the optimal degree of superposition (the point at which the success of the project is at a maximum) is lower than for individual-owned projects. This research advances our understanding of work structures, motivation, and organizational participation in FLOSS environments by describing the influence of task structures on the success of projects. The study also provides FLOSS practitioners with valuable insights for modeling project task structures to facilitate their success.

*Keywords:* open source software; collaboration; virtual teams; motivation; task structure; IS development; superposition; project success; econometrics

## Introduction

In the current digitally enabled collaborative environment, Free (Libre) and Open Source Software (FLOSS) projects have become ubiquitous. This model of development allows project owners to effectively tap into the vast reserves of programming skills spread across the globe to create software that surpasses proprietary software in both quality and functionality (Coverity Inc. 2013). In addition, FLOSS also offers advantages in terms of evolved coordination and improved motivational mechanisms, which are increasingly attracting both —individual developers and commercial organizations to experiment with FLOSS as a viable mode of software development (see Ke and Zhang 2010, von Krogh et al. 2012). While this model of development offers several benefits to the project owners, the orchestration of task work across geographically dispersed contributors, who are often sporadically engaged in different projects, can be challenging (Howison and Crowston 2014, Lindberg et al. 2016). This challenge is exacerbated by the fact that governance mechanisms commonly used to organize task work in traditional software development projects have been found to conflict with the contributors’ motivational needs (Ke and Zhang 2010) and established social practices of FLOSS communities that epitomize the principles of openness and autonomy (von Krogh et al. 2012).

Recent works of Howison and Crowston (2014) and Lindberg et al. (2016), have called attention to the characteristics of the software artifact, such as the emergent structures of work —which may be instrumental in overcoming the challenges related to FLOSS task work orchestration. These studies have observed the emergence of unique routines in the work structures of FLOSS projects that are surprisingly effective at establishing the delicate balance between —managing developers’ contributions, and sustaining the contributors’ needs for openness and autonomy. In this context, Howison and Crowston (2014), observed and conceptualized superposition of tasks as the dominant work orchestration mechanism in FLOSS projects, wherein motivationally independent tasks are incrementally layered to create the software. This work orchestration mechanism is different from that observed in the case of traditional software development, where the focus is towards co-work and concurrent task development through a modular task design. The authors found evidence of this form of work orchestration in the Fire and Gaim FLOSS projects, where approximately 80 percent of tasks involved no co-work (Howison and Crowston 2014).

Although the dominance of the superposed orchestration mechanism in FLOSS projects has been attributed to its ability to satisfy the psychological needs of the intrinsically motivated contributors, it is still unclear if this motivational influence, theorized using self-determination theory (SDT; Ryan and Deci 2000), could be scaled up to the project level. This calls for a deeper theoretical enquiry to better understand if and how these unique ways of organizing task work influence project success. Following this line of enquiry, the current paper attempts to enrich the theory of collaboration through open superposition (Howison and Crowston 2014) by unearthing the boundaries describing the influence of task superposition on FLOSS project success. This leads us to our first research question:

*RQ1: How does the extent of task superposition influence FLOSS project success?*

Given that organizations are increasingly shifting their strategic focus towards FLOSS development (Microsoft News Center 2018), it is imperative to understand if the assumptions and mechanisms that form the basis of the theory of superposition are also applicable to the context of organizational ownership. Apparently, organizations and FLOSS communities are grounded in very different premises (profit maximization versus sharing ideology) but the coexistence of these seemingly orthogonal social practices and institutional norms is imperative for the success of organization owned FLOSS projects (von Krogh et al. 2012, Howison and Crowston 2014). We posit that organizational participation in FLOSS projects will have strong implications for developers’ motivations and the underlying mechanisms that influence project success —which leads us to our second research question:

RQ2: *How do organization-owned FLOSS projects differ from individual-owned FLOSS projects in terms of task superposition, and does this difference influence project success?*

By answering these research questions, we aim to make the following contributions to theory and practice. First, we enrich the theory of superposition (Howison and Crowston 2014), by examining whether satisfying the psychological needs at the level of contributors could be effectively scaled-up to the level of the project and made to manifest as project success. By doing so, we offer a more nuanced conceptualization of the mechanisms that explain the role of superposition of task work in facilitating FLOSS project success. The usefulness of this conceptualization is exhibited by the boundary conditions that we uncover for the applicability of the phenomenon (Suddaby 2010). Second, we contribute to the theoretical understanding of the different ways in which superposition influences project success in individual and organizational-owned FLOSS projects. Prior research has examined many important aspects related to organizational participation in FLOSS projects and has laid the groundwork for a deeper theoretical inquiry (e.g., Capra et al. 2011, Fitzgerald 2006). Building on this prior research stream, we show that the influence of superposition on the success of the project is sensitive to the actors involved in the project and their models of engagement. Cognizance of these influences is crucial for understanding how organizations can establish the delicate balance between openness (stimulating innovation, creativity, and organizational growth) and control (over platform activities, efficient development practices, and intellectual property right appropriation; Engeström 2007, Jarvenpaa and Lang 2011), which is an important antecedent to the success of FLOSS projects (Teigland et al. 2014). Lastly, the results of this study may help advance theories regarding FLOSS success and offer practical insights to project owners. Management scholars have expressed considerable concern about the failure of academic research to penetrate the practitioner community (Rynes et al. 2001). We believe that a better understanding of the influence of the nature of task work on the success of the project can lead to better management practices for planning potentially successful FLOSS projects.

## Conceptual Development

Before discussing the relationship between degree of superposition and FLOSS project success, we develop the notion of FLOSS project success in the context of this study. We then provide a brief literature background regarding the nature of task work in FLOSS projects, following which we develop the theoretical arguments surrounding the main relationship between superposition and project success (Hypothesis 1). Subsequently, we present the different models of organizational engagement in FLOSS projects and describe how these models of engagement can influence the relationship between superposition and project success (Hypotheses 2a and 2b).

### FLOSS Project Success

Despite the widespread use of FLOSS projects by individuals and organizations, measuring the success of such projects can be challenging because of the open source nature of these projects, which precludes their association with the usual monetary measures such as prices, revenues, and sales (Fershtman and Gandal 2004). Furthermore, FLOSS projects are freely available in the public domain, where there is no need to request permission to use them. Nonetheless, researchers have continually attempted to describe the meaning of success in the context of FLOSS projects. Crowston et al. (2006) identified seven measures of FLOSS project success: system and information quality, user satisfaction, use, individual and organizational impacts, project output, process, and outcomes for project members. Similarly, Lee et al. (2009) adapted Delone and McLean’s (1992) IS success model to develop a FLOSS project success model in which they identified five measures of FLOSS project success: software quality, community service quality, use, user satisfaction, and individual net benefits. Most empirical studies that examine the mechanisms associated with FLOSS project success have operationalized success along one or more of the aforementioned dimensions (Crowston et al. 2012). The choice of the success measures in these studies is not only a result of the nature of the relationship being examined but also conditional on the availability of data that would allow their operationalization.

Among the different available measures, ‘popularity of the project’ is a particularly useful measure of success because popular projects tend to engage a larger community of users which leads to improved ideas (Howison and Crowston 2014). Moreover, measures of popularity are also correlated to the number of bugs, the number of participants in the bug trackers (Crowston et al. 2006), and the total number of developers overall (Krishnamurthy 2002, Subramaniam et al. 2009). These correlations suggest that project popularity can capture the essence of both quality and functionality of the FLOSS software. Given this salience, different measures of popularity have been frequently used to determine FLOSS project success, for example —number of downloads (Fershtman and Gandal 2011; Rebeca and García 2009), commercial success (Grewal et al. 2006; Midha and Palvia 2012), user interest (Subramaniam and Nelson 2009, Stewart et al. 2006), OSS product awareness (Setia et al. 2012) and project viewership and downloads (Crowston et al. 2006). Following the example of these studies and in recognition of the importance of attracting greater attention from the community, we adopt popularity as the measure of FLOSS project success and use it to hypothesize and test our relationships.

### Nature of Task Work in FLOSS projects

Drawing from traditional commercial software development practices, early research on the task characteristics of FLOSS projects indicates the importance of modular software architectures for ensuring successful collaboration. For example, Baldwin and Clark (2006) show that a high level of modularity coupled with greater design options not only attracts more contributors but also helps to sustain their cooperation in FLOSS projects. However, an increased number of FLOSS contributors can make task coordination difficult. Recognizing the problem of task coordination in large FLOSS projects, researchers soon began to examine the unique mechanisms through which FLOSS projects could overcome coordination issues. For example, Crowston et al. (2005) used coordination theory (Malone and Crowston 1994) to contrast coordination mechanisms in commercial software development projects with those of FLOSS projects. Another study by Crowston and Scozzi (2004) examined the coordination mechanisms involved in bug-fixing processes and found that the tasks involved are sequential and comprise only a few steps. Chua and Adrian (2010) examined how the characteristics of material artifacts impact cross-project coordination in large open source projects. Mockus et al. (2002) examined the impact of project size on the coordination mechanisms adopted.

While this large body of research provides an excellent understanding of FLOSS task work from the perspective of codebase architecture (e.g., modularity; Baldwin and Clark 2006) and of coordination mechanisms (e.g., Chua and Adrian 2010, Crowston et al. 2005, Mockus et al. 2002), rather less is known about the sociotechnical nature of work organization during the production process. Recognizing this gap, two recent works have attempted to provide a greater understanding from this perspective - a) Howison and Crowston, (2014) who found that superposition of tasks is the dominant work- orchestrating mechanism in FLOSS environments, on the basis of which, they conceptualized the theory of collaboration through open superposition b) Lindberg et al. (2016) who theorized developer and developmental interdependencies outside the purview of superposition, which are resolved by unique task and knowledge routines. The current research attempts to advance the theory of collaboration through open superposition by scrutinizing the assumptions that define the boundaries for the influence of superposition. While the current study is restricted to understanding the influence of task work orchestration as proposed by the theory of collaboration through open superposition, we acknowledge that future studies delineating the works of Howison and Crowston, (2014) and Lindberg et al. (2016) would supplement the effort to understand the influence of work structures on the success of projects.

**Theory of Collaboration through Open Superposition.** Superposition is the process through which software development occurs in a sequential manner, with changes to the software added incrementally, on top of one another. Each change represents a task that is independently built by a contributor and has its own functional payoff through the improvements it brings to the application (Howison and Crowston 2014). Superposed task work is characterized by (a) individual task work, and (b) incremental layering of motivationally independent tasks. This unique work-breakdown structure has been found to accomplish complex work through a process of ‘productive deferral’; Productive deferral is the process by which, tasks that are envisioned to be too large to be implemented through individual, motivationally independent layers are deferred until code written by someone else (and sometimes for entirely different reasons) makes the envisioned task easy enough to be undertaken through relatively simple, quick individual work (Howison and Crowston 2014). Thus, FLOSS contributors often wait for the ‘missing piece’ of code to be developed by someone else in the community before getting back to complete the large task. We leverage on the latent mechanism of productive deferral, prevalent in FLOSS development, to describe the hypothesized relationships.

The theory of collaboration through open superposition states that in the case of FLOSS projects, an emergent superposition of tasks provides the most effective work-breakdown structure for enhancing motivation to contribute, and at the same time allows for the creation of complex software. To build their argument, Howison and Crowston (2014) invoke theories of motivation and coordination. Specifically, they expand the work of Ke and Zhang (2010), who apply self-determination theory (SDT; Ryan and Deci 2000) and affective events theory (AET; Weiss and Cropanzo 1996) to show that superposition creates an effective work-breakdown structure that satisfies the three psychological needs of autonomy, competence, and relatedness posited by SDT, leading contributors to expend greater task effort in FLOSS projects. First, superposition minimizes the interdependencies among contributors, thereby satisfying their need for *autonomy*. Second, superposition promotes contributors’ sense of *competence*, because each task independently results in an improvement to the shared output of the project. Third, superposition addresses the need for *relatedness*, as the layering of tasks on the work of others and the potential support from other contributors provides connectedness in a manner that does not undermine contributors’ autonomy. In the subsequent subsection, we look at how satisfying the motivational mechanisms invoked by superposition may influence the popularity of the project.

**Relationship between Degree of Superposition and FLOSS Project Popularity.** By providing the motivational mechanisms that satisfy the innate psychological needs of competence, autonomy, and relatedness, superposition generates a positive affective state for contributors (Richard M. Ryan and Deci 2000). The increased positive affective state enhances the task effort that an individual will expend (Weiss and Cropanzo 1996), encouraging greater contributions to the FLOSS project and leading to an increase in the quality, functionality, and usability of the software for the end user (Ke and Zhang 2010). Consequently, an increase in the degree of superposition is expected to positively influence the popularity of a FLOSS project among users. But will continual increases in the degree of superposition be associated with progressive growth in the FLOSS project’s popularity? To answer this question, we need to delve deeper into the mechanisms that contribute to the increased popularity of FLOSS projects.

While superposition provides a positive motivational mechanism for individuals to contribute to FLOSS projects, we contend that there is a potential cost involved in adopting a superposed work-breakdown structure. This cost, which stems from the inefficiencies involved in adopting a sequential pattern of development (with very little co-work), becomes a concern at higher degrees of superposition, where contributors tend to predominantly defer complex/big tasks rather than engage in co-work. This increased adoption of the productive deferral mechanism and avoidance of co-work associated with a high degree of superposition will encourage potential contributors to wait until the missing piece has been provided by someone else in the FLOSS community. This may lead to a perceived loss of the contributor’s control over the project (Guenter et al. 2014), leading to some frustration (Selvidge et al. 2002). Overall, this may result in an arousal of negative affect in contributors (Zhang 2013), especially if they have to face long delays while waiting for the work of others to make the envisioned task simpler (Selvidge et al. 2002). Prior studies have shown that negative affective states caused by loss of control and frustration result in reduced task effort (Greenberger and Strasser 1986; Weiss and Cropanzo 1996; Zhang 2013), which may result in a decrease in the quality, functionality, and usability of the software. This may in turn be instrumental in reducing the popularity of the project.

Hence, we can see that superposition has both positive and negative latent influences. The positive motivational environment enabled by enhanced autonomy tends to be countered by the negative influence of loss of control and frustration due to avoidance of co-work at increasing levels of superposition. To understand the combined effect of these latent influences we can envision their approximate functional forms and combine them additively (Haans et al. 2015). In our case, the two latent functions are - a) the influence of superposition in increasing the positive affective state of the contributor due to increased autonomy, and b) the influence of superposition in increasing the negative affective state of the contributor due to increased loss of control and frustration. We propose that the relationship between degree of superposition and the positive affective state of the contributor due to increased autonomy follows the law of diminishing returns. That is, with each additional increase in superposition while keeping other aspects constant, there is a decline in the marginal benefit that a contributor perceives from an increase in autonomy. On the other hand, we propose that loss of control and frustration caused due to avoidance of co-work and productive deferral mechanisms tends to manifest itself at high values of superposition. That is, the influence of superposition on increasing the negative affective state of contributors follows an increasing trend. Thus, we see that the latent effect of superposition on the positive affective state (through an increase in autonomy) increases at a decreasing rate and eventually levels of; while its effect on the negative affective state (through an increase in frustration and loss of control) is low at lesser levels of superposition but increases at an increasing rate (see Figure 1). When latent relationships of these forms are combined, the result is an overall inverted U-shaped relationship between degree of superposition and the net affective state [[5]](#footnote-5)( Figure 1; Haans et al. 2015). Following AET (Weiss and Cropanzo 1996), changes in the affective states of contributors can result in corresponding changes to the task effort they expend. In turn, the changes in task effort manifest as variations in its popularity.

Thus, we posit that in the FLOSS context, the relationship between superposition and the popularity of a project is positive until the popularity of the project reaches a maximum, after which the relationship becomes negative. That is, as the degree of superposition initially increases, the popularity of the FLOSS project increases because in the beginning superposition provides the right motivational mechanisms to attract and retain contributors. But at a certain degree of superposition (the turning point), the marginal benefit from an increase in autonomy is counterbalanced by a reduction in project popularity, which is attributable to the negative affect arising from productive deferral mechanisms and avoidance of co-work. Hence, we hypothesize:

*Hypothesis 1. In the context of FLOSS projects, the degree of superposition has a nonlinear relationship with project popularity such that project popularity increases with an increase in the degree of superposition up to a particular value (the turning point). Beyond this optimal degree of superposition, any further increase reduces the popularity of the project.*



### Organizational Ownership of FLOSS Projects

By early 2000, organizations began to realize the commercial potential of FLOSS (Wagstrom 2009). This led to a transformation of FLOSS communities, which had mainly been volunteer driven, to communities that attracted organizations and commercial interests (Fitzgerald 2006). Organizational ownership in FLOSS projects has not only been found to provide extrinsic motivation through rewards and signaling (Lerner and Tirole 2003), but can also create an environment that enhances the intrinsic motivation of contributors (Spaeth et al. 2015). The added influence of organizational ownership on the project contributors’ motivations and the owner’s potential need for control may influence the relationship between superposition and the popularity of the project. This influence can be studied through three non-mutually-exclusive models of organizational engagement: the coding, support, and management models (Capra et al. 2011)[[6]](#footnote-6). In the *coding model* of engagement, the organization owner supports the development activities of the project by involving its employees and/or opening some of its proprietary code to the FLOSS project. In the *support model*, the organization owner provides support to nondevelopmental activities through direct or indirect financial contributions. In the *management model*, the organization owner engages in project management and coordination activities. In the subsequent subsections, we study how the models of organizational engagement tend to influence the relationship between superposition and popularity of the project.

Coding model.In the coding model, organizations engage in development activities by contributing to the code, often in cooperation with volunteer contributors**.** Here, paid employees of the organization commit to writing the code that helps fix bugs, customizing the existing code, and building distribution packages (Capra et al. 2011). For example, Facebook contributed more than nine million lines of code to the open source community through 200 different projects in the first six months of 2014 alone (Pearce 2014). This includes some of their major projects, such as React and Pop that also receive many contributions from the external community.

In this model of engagement, an organization contributes the bandwidth of its employees to the FLOSS project. Unlike volunteer contributors, who often contribute during their free time, the employees of an organization receive tangible rewards (in terms of salary) for their contributions. The effect of the coding model on the relationship between degree of superposition and the popularity of a project can be related to the effect of introducing extrinsically motivated contributors to a FLOSS project. Extrinsically motivated contributors who receive tangible rewards have less need for autonomy than intrinsically motivated volunteer contributors (Deci et al. 1999). Further, the introduction of organizational employees affords the project owner more control over the execution of big or complex tasks. That is, organizations can direct their employees to devote their effort to addressing the big or complex tasks through co-work rather than relying on productive deferral to complete the task; making such deferral less of a factor[[7]](#footnote-7). Therefore, we posit that organizations’ engagement in the development activities of their FLOSS projects will tend to dampen the net effect of superposition on the positive affective state of the contributors, due to the inclusion of more extrinsically motivated employees with less need for autonomy. Thus, by participating in the development activities of the projects they own, organizations tend to mitigate the influence of superposition on the popularity of these projects.

In addition to including extrinsically motivated employees in a FLOSS project, organization ownership of FLOSS projects can also provide certain extrinsic motivations for the volunteer contributors. Specifically, signaling for career advancement has been identified as an important extrinsic motivation for contributing to FLOSS projects (Lerner and Tirole 2003). Thus, in organization-owned FLOSS projects, volunteer contributors may also be extrinsically motivated by the opportunity to signal their abilities to the organization owner. Provision of this additional extrinsic motivation to participate can further dampen the influence of superposition on the popularity of the project.

Support (non-development) model**.** In the support model, organizations provide financial, infrastructure, marketing, and/or customer support (Capra et al. 2011). Each of the non-developmental support activities is an organizational investment in the project. Organizational investment in FLOSS projects creates opportunity costs, increasing the time cost of money and pressure to see payoffs sooner rather than later (Howison and Crowston 2014). Because of the increased time cost of money, delays due to productive deferral and avoidance of co-work have a larger negative influence on project popularity. Thus, in the case of organization-owned projects, increased productive deferral and avoidance of co-work associated with a high degree of superposition may not only lead to a negative affective state for the contributors, due to frustration and loss of control, but may also increase the time cost of money for their investments. The increase in the time cost of money can de-incentivize the organization owner from making future investments in the project leading to a reduced focus towards adding new functionality and improving quality of the software. Because of the added negative influence of the time cost of money, we posit that projects with higher superposition tend to lose out on investments that would otherwise have helped enhance their popularity compared to projects with lower superposition.

Management model. In the management model, an organization contributes to a project by performing activities related to project coordination and management (Capra et al. 2011). This model of participation has been described by Fitzgerald (2006) in terms of strategic planning initiatives and project management practices that organizations bring to FLOSS projects for the efficient coordination and management of development activities. This model of participation has also been empirically observed. For example, a study of 83 Eclipse projects found that FLOSS projects initiated by organizations employed both leadership and resource deployment control, as compared to projects that are initiated by individuals belonging to the FLOSS community (Schaarschmidt et al. 2015). Using Raymond’s (1998) bazaar metaphor, it can be said that organizational ownership of FLOSS projects leads to the introduction of management practices that tend to transform the adopted model of development from a bazaar into a cathedral-like form. On the other hand, individual-owned projects tend to retain the bazaar model of FLOSS development, with fewer formal management practices than found in organization-owned FLOSS projects.

The introduction of well-defined goals and mechanisms for coordinating and controlling FLOSS development activities can also influence how the degree of superposition relates to the popularity of a project. Given that there are extrinsically motivated contributors who have less need for autonomy and the increased time cost of money, the formal practices and coordination structure allow organizations to focus on more efficient development practices and eventually lower the product delivery times. Thus, by engaging in the management model, the organization owner can set up practices that facilitate co-work instead of relying on superposition to accomplish the tasks. For example, in the GNOME project, the GNOME Foundation acts as a centralized release coordination authority, creating release schedules and coordinating modules for release (O’Mahony 2005). These practices allow the organization owner to best leverage the presence of extrinsic motivation in the contributors and minimize the negative influence of the time cost of money. We posit that this increased emphasis on organized and concurrent work when organizations own FLOSS projects facilitates the moderating influence of the coding and support model on the relationship between superposition and the popularity of the project.

**Moderating Effect of Owner Type on the Relationship between Degree of Superposition and FLOSS Project Popularity**. Based on the three models of organizational involvement, the moderation influence of organizational ownership manifests as two related effects that tend to change the shape of the inverted U-shaped relationship between degree of superposition and popularity of the project. The changes to the shape of the curve is observed (a) as a flattening of the inverted U-shaped curve, and (b) as a left shift of the turning point. Table 1 summarizes the moderating influence of organizational ownership through the different models of engagement and its expected influence on the shape of the curve.

**Table 1. Moderating Influence of Organizational Ownership through Different Models of Engagement**

|  |  |  |  |
| --- | --- | --- | --- |
| **Model of Organizational Engagement** | **Expected Changes to FLOSS Project** | **Expected Latent Influence** | **Expected Influence on the Relationship between Superposition and Popularity** |
| Coding model | Inclusion of extrinsically motivated contributors and increase in the net extrinsic motivation of the contributors to the project | Diminishes the influence of superposition on the net affective state of the contributors | Primarily weakens the curvilinearity and results in a flattening of the curve (Hypothesis 2a) |
| Support (nondevelopment) model | Provision of direct and indirect financial contributions for nondevelopment support for the project | Introduces the latent negative influence of time cost of money | Primarily results in the inclusion of a negative linear effect that results in a left shift of the turning point (Hypothesis 2b) |
| Management model | Introduction of project management and coordination practices for more efficient development | Facilitates and promotes co-work in the presence of extrinsically motivated contributors and an increased time cost of money | Facilitates hypotheses 2a and 2b |

Flattening of the curve occurs when the moderator influences the latent mechanisms in such a way that the overall shape of the observed relationship becomes flatter, *although the turning point of the relationship need not change* (Haans et al. 2015). When the influence of organizational ownership is seen as an increase in the net extrinsic motivation of the contributors (through the coding model of engagement and the effect of signaling), the moderation effect is to weaken the latent positive influence of superposition on the net affective state of the contributors. Following AET (Weiss and Cropanzo 1996), changes in the affective states of contributors can result in corresponding changes to the task effort they expend. In turn, these changes in task effort manifest as variations in the popularity of the project. As shown in Figure 2, weakening the curvilinearity of the latent influence of degree of superposition on the positive affective state of the contributors largely results in a flattening of the curve (Haans et al. 2015). Based on this understanding, we believe that for organization-owned FLOSS projects, superposition will play a smaller role in determining the popularity of the project. Hence, we hypothesize:

Hypothesis 2a: *In the context of FLOSS projects, the project ownership type moderates the relationship between the degree of superposition and project popularity such that the degree of superposition has a significantly lower influence on the popularity of the project for organization-owned projects than for individual-owned projects.*



A shift in the turning point occurs when the moderator influences the latent mechanisms in such a way that the turning point of the observed relationship changes location, *although the shape of the curve may not change* (Haans et al. 2015). When organization ownership is seen in terms of increasing the time cost of money, we can think of the moderating effect as strengthening the negative influence of superposition on the popularity of the project. This added negative influence can be approximated as a latent linear effect.[[8]](#footnote-8) The inclusion of the negative linear mechanism largely results in the left shift of the turning point of the curve (Figure 3; Haans et al. 2015). Therefore, we contend that the degree of superposition at which the popularity of the project is at a maximum (the turning point) is significantly lower for organization-owned than for individual-owned FLOSS projects. Hence, we hypothesize:

Hypothesis 2b. *In the case of organization-owned projects, the degree of superposition at which project popularity is at a maximum (the turning point) is significantly lower than for individual-owned projects.*

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## Construct Development

The phenomenon of superposition was conceptualized by Howison and Crowston (2014) based on their exhaustive observations of FLOSS projects. The detailed approach adopted by these researchers offered the necessary depth for a rich theorization of the concept. But to examine the influence of superposition on the popularity of a FLOSS project, we first need to translate the concept into a well-defined theoretical construct —*degree of superposition* (Suddaby 2010). While developing this construct, we try to remain true to the concept of superposition as introduced by Howison and Crowston (2014). In the subsequent subsections we elaborate on the important characteristics specific to the FLOSS model of development, namely (1) task, and (2) version and development release, before we define our focal construct —degree of superposition.

### Task

A task is a unit of contribution to a FLOSS project. Howison and Crowston (2014) describe a task asa sequence of actions that leads to a change in the shared output of the project, which could be a new feature, a bug fix, updated documentation, and so forth. The actions within a task may include adding/deleting code, changing files, incorporating comments, or even reviewing code. Thus, a task can begin with messages on a FLOSS community mailing list signaling a project need, continue with development, involve peer reviews, and subsequently result in a functional change to the application itself (Howison and Crowston 2014).

In Git based FLOSS development platforms such as GitHub, there are two ways that contributors can add (merge) their tasks to the main project code. Contributors who have push (write) access to the project can directly add their tasks to the project. Push events are typically used by the core set of developers to include certain immediate changes in the project. In contrast, contributors who do not have write access to projects will need to issue a request to “pull” their tasks into the project. Once a pull request is submitted, a contributor with push access can choose to merge the task into the main project, suggest modifications, or reject it. This pull-based software development model allows a project to be forked (cloned) into a different local branch so that changes can be worked independently of the main project code. When a set of changes is ready to be added to the main project code, the contributors create a pull request. A member of the project’s core team (the contributors with “push” access) is then responsible for inspecting the changes and merging them in to the project’s main project code (Gousios et al. 2014). It is important to note that once a project is forked, the local code branch might include contributions from several contributors who collaborate to implement changes before the pull request is made. Online Appendix AI (included as an online supplement to this article) details the approach we used to calculate the number of tasks by identifying their associated push and pull request events using the GitHub project log data.

### Version and Development Release

Each version is a snapshot of the project at a point in time. Version control is a system that maintains these snapshots of the project and records changes to a file or set of files over time and between versions. Such a system allows us to revert files back to a previous state, compare changes over time, determine the authors of the changes, and more.

In Git based version control systems like GitHub, we can define versions as the snapshot of the project available at the end of a specific day. Based on this definition, we can say that a new version of a project is created on any day that sees tasks being added to the project. The new version differs from the previous version of the project by the tasks that have been included to it through push and pull request events created on that day. A version in this context can be compared to a development release (Michlmayr and Fitzgerald 2012). Development releases are aimed at contributors interested in working on the project or experienced users who need the most updated version of the code. Development releases need not be thoroughly tested and documented (unlike major releases) and may not ensure stability. These releases come with the latest code changes that will be merged to the project after some unit testing and/or some form of peer review. Online Appendix A2 (included as an online supplement to this article) details the approach we used to operationalize versions using the GitHub project log data.

### Degree of Superposition

While theorizing collaboration through open superposition, Howison and Crowston (2014) contended that in the case of FLOSS projects, tasks are implemented by *individual* contributors who realize some functional payoff from the creation of the task. Over time, these individual tasks are *layered* on top of one another to incrementally build the FLOSS software. The superposed organization of individual tasks accomplishes complex tasks by the process of productive deferral.

In essence, there are three characteristics of the concept of superposition that need to be considered: (a) task work is accomplished by individual contributors, (b) individual tasks are sequentially layered on top of one another, and (c) productive deferral occurs in order to accomplish complex tasks through (a) and (b). While individual task work and sequential layering of tasks define how superposed the organization of the tasks is, productive deferral provides the mechanism that allows complex work to be accomplished by a superposed organization of tasks. In our operationalization of superposition, we capture the two aspects of superposed organization of tasks, sequential layering of tasks and individual task work. Because productive deferral can be considered as a latent mechanism that allows the orchestration of work through superposition rather than being a part of the measure of superposed task work structure, we do not include it in our operationalization of the construct.

Consequently, we define the construct *degree of superposition* as the ratio of the *total number of versions* of the FLOSS project to the total number of *individual task contributions* to the project. Based on this definition, the degree of superposition for projects increases as they adopt a more sequential and individual development approach, reaching a value of 1 when each individual task contribution represents a new version, and decreasing as projects adopt a more concurrent and collaborative development approach in which more tasks are concurrently added to a version and more contributors are collaboratively working on tasks. We can also conclude that projects which predominantly adopt productive deferral to accomplish complex tasks, will exhibit higher degrees of superposition than projects that do not adopt productive deferral mechanisms.

Consider the example illustrated in Figure 4. Task A, developed by one contributor, and task B, developed by two contributors, are added to version 0 of the project, which was available on January 15th. The addition of tasks A and B results in version 1 of the project on the 17th. Task C, developed by three contributors, builds on the version that was available on the 17th (version 1), creating version 2 of the project. Task D, developed by one contributor, task E, developed by two contributors, and task F, developed by three contributors, build on the version available on the 21st (version 2), creating version 3 of the project. This example has six tasks (tasks A–F), has a total of 12 individual task contributions that result in the three versions; hence the degree of superposition is 3/12, or 0.25.



## Methodology

To understand the mechanisms through which superposition influences FLOSS projects, we conducted an empirical analysis of FLOSS projects hosted on GitHub. GitHub’s popularity among programmers, its developer-focused environment, its integrated social features, and the availability of detailed metadata makes it a popular environment for FLOSS research (Kalliamvakou et al. 2014). Our adopted methodology comprised three steps: data collection, measurement, and analysis. In the data collection step, we collected detailed project log data for a sample of FLOSS projects from the GH Archive database (https://www.gharchive.org/). In the measurement step, using the collected project log data, we measured the dependent, independent, and control variables. Finally, in the analysis step, we carried out regressions at the project level to test the hypothesized relationships. By improving the data collection, measurement, and analysis methods over the course of several months, we tried to ensure that the methodology we adopted was exhaustive and robust.

### Data Collection

We employed Google’s bigquery tool to query the archived project log data available in the GitHub Archive database (Grigorik 2012). Since this database is large (about 432 GB, with 134 million rows for the year 2014 alone; Google 2014), we needed the bandwidth provided by a tool like Google’s bigquery to run queries and export the results. We restricted our analysis to projects that were started during the first five months of 2014 to reduce the number and size of queries. Further, the event-level data collection for each project was restricted to the development work that was undertaken in the year 2014. In all, we ran more than 30,000 queries over a period of 20 days.

While GitHub provides a rich dataset, care needs to be taken to overcome common perils in using this dataset (Kalliamvakou et al., 2014). For example, projects that do not involve software development, are too small, or are mirrors or personal stores should be avoided. The complete list of perils identified by Kalliamvakou et al. (2014) and a summary of the methods we adopted to address these appear in Online Appendix A3. After filtering the dataset to address the perils, we were left with a sample of 6571 FLOSS projects, of which 3086 are individual-owned and 3485 are organization-owned that we considered for our analysis.

### Measurement

GitHub offers a good environment for measuring the degree of superposition and studying its relationship to the project’s popularity. More specifically, two features of GitHub make it ideal for this research. First, the granularity of the data and the availability of time stamps for all events enabled us to clearly identify the versions of each project and the task order, which allowed us to operationalize the degree of superposition. Second, the availability of detailed contributor- and project-specific data allowed us to measure the dependent variable and create a rich set of controls. The different variables that we used in this research and their measures are detailed in the following subsections.

**Dependent variable.** *Popularity of project* is the dependent variable of interest for this research. As mentioned in the section “FLOSS Project Success,” we consider the popularity of the project to be an important measure of FLOSS project success. In GitHub, users can “star” projects in order to keep track of those that they find interesting and also to show their appreciation for these projects (Borges and Tulio Valente 2018; GitHub 2017a). The number of stars a project has received indicates approximately the number of people who are interested in and show support for that project. Count of stars is therefore a commonly used measure for identifying popular projects in the GitHub environment: GitHub itself uses stars to identify trending projects and in its project rankings (GitHub 2017a), Jarczyk et al. (2014) use the log transformation of the number of stars as a measure of the quality and popularity of GitHub projects, and Tsay et al. (2014) use the number of stars as a measure of popularity and project establishment. In recognition of the usefulness of count of stars as a measure of popularity, we adopt it as the dependent variable to test our relationships.

Popularity measures have often been operationalized using count of downloads (e.g., Crowston et al. 2006, Grewal et al. 2006, Midha and Palvia 2012, Setia et al. 2012). In GitHub, a potential problem of using the count of downloads as a measure of FLOSS popularity is that this measure is available only for major releases of projects. Code reuse in GitHub can occur by forking a project, developing on the forked branch, and then merging that branch into a different project (without the actual download of a major release). This aspect of code reuse is not captured by the count of downloads. Further, this measure could underestimate the popularity of younger projects or projects that take longer to be packaged into a major release and distributed to end users. Because our study considers the first year in the life of a project, a relatively smaller percentage of projects in our sample see major releases for which GitHub provides a count of downloads. Hence, we adopt count of stars rather than downloads as the measure of popularity in our study.

**Independent variables.** To study the influences of the degree of superposition and ownership on the popularity of a FLOSS project, we employed two independent variables – *degree of superposition* and *project ownership*. The *degree of superposition* was measured as the ratio of the total number of versions of the project to the total number of individual task contributions made to the project (refer to the section “Construct Development”). The method we adopted for identifying tasks within a project is based on the understanding that a task is a sequence of actions that leads to a change in the shared output of the project (Howison and Crowston 2014). The project logs maintained by GitHub provide detailed information regarding the timing and ownership of push and pull request events that allowed us not only to identify tasks for each project but also determine the version that they belong to. Online appendices A1 and A2 (included as an online supplement to this article) detail the approaches that we adopted to identify tasks and versions leveraging the workflow of Git based FLOSS development platforms. Based on this operationalization, the degree of superposition for a project takes a value between 0 and 1.If *degree of superposition* = 1, all the project’s tasks were implemented individually and added sequentially, with each individual task contribution representing a new version of the project. The degree of superposition decreases as a project adopts a concurrent development approach and approaches 0 as greater number of individual task contributions get piled onto individual versions of the project.

To study the moderating influence of project ownership on the relationship between the degree of superposition and the popularity of a FLOSS project, we also used a flag, *project ownership*, which takes the value 1 if the project is owned by an organization and 0 if it is owned by an individual. Organizations in GitHub are shared accounts that can be used to centralize a group’s code and adopt a workflow that is suitable for business (Neath 2010). This workflow provides multiple levels of permission controls that enables companies to create nested teams with hierarchical access to the code, allowing them to replicate their organization structure on GitHub. Most companies hosting projects on GitHub, use their own organization accounts to consolidate monitoring and management of their FLOSS projects. GitHub recognizes projects that are owned by organizations’ and makes this attribute publicly available through its API. By accessing this GitHub determined project attribute, we identify if a project is owned by an organization or an individual.

**Control variables.** GitHub maintains detailed project- and user-level data, which allows the introduction of a rich set of control variables. Consequently, we identified two kinds of control variables for our analysis: contributor/owner characteristics and project characteristics.

Contributor/owner characteristics. We identified three measures to control the influence of contributor and project owner characteristics on the relationship between the degree of superposition and the popularity of a project. An increase in the *number of contributors* is often associated with an increase in the number of task contributions and consequently an increase in the popularity of the project (Stewart et al. 2006; Subramaniam et al. 2009). At the same time, as the number of contributors increases, there is a tendency to adopt a more concurrent form of development to coordinate multiple contributors. In addition to the number of contributors, the *average number of contributions per contributor* is also expected to positively influence the popularity of a project (Subramaniam et al. 2009). Hence, we also control for the average number of commits per contributor, where a commit is any change or set of changes that is locally saved to file (GitHub 2017b). Lastly, we control for the *experience of the project owner* in terms of the number of FLOSS projects the owner participates in. The existence and density of prior ties between the project owner and contributors has been found to positively influence the probability that the project will attract more individuals (Rebeca and García 2009). Based on this finding, we would expect that the experience of the project owner plays a role in enhancing the popularity of the FLOSS project.

Project characteristics. We identified eight measures to control for different project characteristics. First, we controlled for *project size* measured as megabytes of code. Smaller projects are usually associated with fewer contributors and contributions than are larger projects. Thus, projects of different sizes are expected to differ in terms of their capacity for attracting contributors and coordinating new tasks (Setia et al. 2012). Second, we controlled for the *number of programming languages*. While projects that involve multiple languages may have greater functionality, coordinating contributions across different languages can be challenging. Third, we controlled for the *average task size*, measured as the average number of commits made within the project’s tasks. As the tasks within a project increase in size and complexity, the average number of commits per task increases. It is important to control for the average task size in the project because projects with a greater number of large tasks will have a higher need for co-work than projects with smaller tasks. Fourth, popular FLOSS projects see continuous enhancement and maintenance of the code, which results in multiple stable versions delivered one after another (Raymond 1998). The *project completion flag* identifies whether the project ended within the data collection period (i.e., in 2014) and became inactive. Because popular projects show continuous activity, we expected project completion or a short project life to be negatively correlated to the popularity of the project. Fifth, we controlled for the type of license attributed to the project. We classify licenses as being either restrictive or permissive. FLOSS software that adopts a restrictive license follows a “copyleft” policy that forces any enhancement made to the software to be bound by the same or compatible license scheme (Singh and Phelps 2013). Permissive licenses, on the other hand, do not have the copyleft feature and allow contributors to use open source software to build proprietary or “closed” software. Previous studies of the impact of the FLOSS license type have found that the type of license used influences a project’s popularity and the number and productivity of contributors (e.g., Colazo et al. 2005, Stewart et al. 2006). Hence, we used the flag *restrictive license regime* to control the effect of the type of license (restrictive vs. permissive) on the popularity of a project. Sixth, we controlled for the *average idle time* between tasks in a project. The average idle time between tasks in a project is a measure of the activity level of the project. Popular FLOSS projects have been found to show high activity, with releases occurring early and often (Raymond 1998). This relationship has also been empirically observed, with project activity found to positively impact popularity of the project (Subramaniam et al. 2009). We also include two fixed effects: the fixed effects of the *main programming language* and the fixed effects of the *month of creation*. Despite mixed results in the extant literature, the type of programming language used has been found to be an important antecedent to FLOSS project success (Subramaniam et al. 2009). Further, the ease of coordinating development activities may differ across programing languages, with languages more conducive to modular architecture displaying greater ease of coordination (Baldwin and Clark 2006). We controlled for these effects by including a dummy variable for each programming language used in our sample. Lastly, time is expected to influence the nature of routines associated with FLOSS projects (Lindberg 2015). Since our analysis includes projects that were started during the first five months of 2014, it was necessary to include the fixed effects of the month of creation to control for the influence of time on the hypothesized relationships.

### Analysis

We include two regression models in our analysis. The main regression model is based on ordinary least squares (OLS) with the log transformation of the number of stars as the dependent variable. The second model, based on the negative binomial approach, addresses the count nature of the dependent variable. Hypothesis 1 predicts that the degree of superposition has an inverted U-shaped relationship with the popularity of a project. To test this hypothesis, we included the square of the degree of superposition and created a polynomial regression model. Hypothesis 2 predicts that the project ownership moderates the relationship between the degree of superposition and the popularity of the project. To test this hypothesis, we introduced the interactions of project ownership with the degree of superposition terms in the regression models. The following section details the results of the regression models and the checks we employed to ensure the validity of the results.

## Models and Results

From Table 2, which provides the means, standard deviations, and correlation coefficients for the variables used in the analyses, we can observe a strong positive skew in some of the variables. In particular, the residuals of the variables *stars*, *size of project*, and *average task size* show significant positive skew in their distribution.



In order to normalize the positively skewed data, statistical texts commonly recommend the use of log transformations (Carte and Russel 2003; Singh et. al. 2013). After log transformation of the variables *stars*, *size of project*, and *average task size*, their residuals were found to closely match a normal distribution. Moreover, previous research that uses the number of GitHub stars as an outcome measure recommends using its log transformation. For example, Jarczyk et al. (2014) used the log transformation of the number of stars to measure project quality because of the power-law distribution that GitHub stars follow.

Table 3 provides the results of the regression models we employed. Models 1a to 1c provide the results of the stepwise log-linear OLS regression analysis. Models 2a to 2c provide the results of the negative binomial regression analysis with the number of stars as the dependent variable. Because the inclusion of higher-order terms (the square of the degree of superposition and the interaction terms) in the regression equation may lead to computational errors due to multicollinearity (Aiken and West 1991), we also tested the results for the mean centered model. In the mean centered model, multicollinearity as indicated by the variance inflation factor (VIF) is less than 5 for all constructs. This indicates that the results are not confounded by multicollinearity (Hair et al. 2010). Further, to correct for any potential heteroscedasticity in the error terms, we used heteroscedasticity consistent standard errors in all of our models (Hayes and Cai 2007).



### Hypothesis Linking the Degree of Superposition and Project Popularity

Hypothesis 1 predicts a nonlinear relationship between the degree of superposition and the popularity of a FLOSS project. This nonlinear relationship resembles an inverted U-shaped curve, with the turning point representing the maximum value of project popularity. To test hypothesis 1, we regressed the dependent variable (project popularity) on the independent variable (degree of superposition) and its squared term. It is essential to retain the linear term of the degree of superposition (Aiken and West 1991), as leaving it out would assume that the turning point occurs at 0 degrees of superposition (Haans et al. 2015). We followed the three-step procedure proposed by Lind and Mehlum (2010) to confirm the presence of an inverted U-shaped relationship in Model 1b. In the first step, we checked the direction and significance of the coefficient of the squared term of the degree of superposition . From Table 3, Model 1b, we can see that is negative and significant, a necessary condition for the existence of an inverted U-shaped relationship (Haans et al. 2015; Lind and Mehlum 2010). In the next step, we checked whether the slopes at both ends of the data range (i.e., when the degree of superposition = 0 or 1) are significant and in the directions characterizing an inverted U. For an inverted U-shaped relationship to exist, the slopes at the low end of the range of the independent variable (i.e., when the degree of superposition is 0) should be positive and significant, while those at the high end of the range (i.e., when the degree of superposition is 1) should be negative and significant (Haans et al. 2015; Lind and Mehlum 2010). We tested Model 1b to confirm that the slope when the degree of superposition is 0 is positive and significant ( and that when the degree of superposition is 1, the slope is negative and significant (. In the last step, we checked whether the turning point lies within the data range for the degree of superposition (i.e., the turning point should lie between the values 0 and 1 for the degree of superposition). The turning point for the quadratic equation is given by . Since our sample was large, the delta method (Rao 1972) could be used to calculate the confidence interval. Using this method, the test for the 99% confidence interval for the turning point confirmed that it lies between 0 and 1 . The results of these three tests provide the necessary and sufficient conditions (Lind and Mehlum 2010) to support Hypothesis 1. That is, the popularity of a FLOSS project increases with an increase in the degree of superposition until it reaches a maximum (the turning point), after which any further increase in the degree of superposition will result in a decrease in the popularity of the project.

### Hypothesis Linking Ownership and Project Popularity

Hypothesis 2 predicts a moderating role of owner type on the relationship between the degree of superposition and the popularity of a project. To test this hypothesis, we included the interaction of owner type with the degree of superposition and its squared term in Model 1c (Table 3). We found that inclusion of the interaction terms helps explain significant variance in the dependent variable over and above the main effects .

Hypothesis 2a predicts that the influence of the degree of superposition on the popularity of the project is lower for organization-owned FLOSS projects than for individual-owned FLOSS projects. This interaction effect is expected to flatten or reduce the curvature of the inverted U-shaped relationship. To test this interaction effect, it is sufficient to check the significance and direction of the coefficient of the interaction with the squared term of the degree of superposition Haans et al. 2015). From Model 1c (Table 3), we can see that is positive and significant (2.928, *p* < 0.01), confirming that organizational ownership tends to flatten the inverted U-shaped relationship. Thus, Hypothesis 2a is supported, and we can conclude that organizational ownership of FLOSS projects tends to reduce the influence of the degree of superposition on the popularity of the project. Figure 5 plots the relationship between the degree of superposition and the popularity of the project for individual- and organization-owned FLOSS projects based on the results of Models 1c (Table 3). The flattening effect can be observed in the plots, with organization-owned FLOSS projects exhibiting a relatively flat curve compared to individual-owned FLOSS projects.

Hypothesis 2b predicts that the turning point for organization-owned projects occurs at a lower degree of superposition than for individual-owned projects. To test this hypothesis, we derived the turning points for individual- and organization-owned FLOSS projects and tested for their equality (Haans et al. 2015). Since the relationship is quadratic, the turning points are given by for individual-owned projects (*z* = 0) and for organization-owned projects (*z* = 1)[[9]](#footnote-10). The generalized Wald type test for this nonlinear inequality rejects the null hypothesis that the turning points are equal ; Model 1c; Phillips and Park 1988). This provides support for hypothesis 2b. The shift of the turning point can be observed in the plots depicted in Figure 5. From the plots, we can observe that the degree of superposition at which popularity is at a maximum for organization-owned projects is considerably lower than that for individual-owned projects .



### Negative Binomial Regression Model

Taking into account the overdispersed nature of the number of stars, we estimated the negative binomial model (Model 2, Table 3; see Cameron and Trivedi 2013, Chapter 4). In this model, we used the original scale for the number of stars (not log-transformed) as the dependent variable and regressed it against the quadratic terms of the degree of superposition and their interactions with the ownership flag. We followed the three-step procedure proposed by Lind and Mehlum (2010) to test Hypothesis 1, 2a and 2b. We find support for the three hypotheses in the negative binomial model. Since the model predicts the log of the expected number of stars as a function of the predictor variables, the interpretations of the coefficient are like the log-linear OLS model (Model 1c). That is, for a one-unit change in the predictor variable, the number of stars is expected to change by the respective regression coefficient, given that the other predictor variables in the model are held constant.

In addition to the negative binomial model, we present three robustness tests in Appendix 1: (a) tests for model specification, (b) test for the dependent variable and, (c) test for the nature and treatment of data. In tests for model specification, we test if the relationship is indeed quadratic and not due to a few outliers. As a test for the dependent variable, we include survival analysis to provide an independent view of project success that is not captured by counts of stars. Lastly, we included a falsification test to show that the observed relationships are more likely due to the theorized mechanisms rather than an outcome of the nature of the sample and the approach we adopted to operationalize the constructs.

## Discussion and Contributions

Despite the FLOSS development model’s increasing prominence in practice and research, the antecedents to its success have not been completely understood. In particular, the sociotechnical aspect of its work structures and the role that this plays in a project’s ability to attract users and developers has received only limited attention from previous researchers (Howison and Crowston 2014). Considering the steady shift towards FLOSS in recent years and its expected acceleration in the future, clarifying the influence of its work structures is important for better understanding the phenomenon and informing project owners about how they can benefit from adopting this unique model of development. As a step forward in this direction, our research sought to unearth the mechanisms through which superposition influenced the success of individual- and organization-owned FLOSS Projects.

Using a large sample of FLOSS projects owned by individuals and a wide range of organizations, we find that the emergence of sequentially layered and individual task work, referred to as the superposed organization of work, can enhance the popularity of a project. Superposed organization of work encourages task effort by satisfying intrinsically motivated contributors’ need for greater work autonomy (Howison and Crowston 2014). The contributors’ increased task efforts may be invested in adding new functionalities and improving the quality of the project, resulting in an overall increase in the popularity of the project. For individual-owned projects, as the degree of superposition increases from 0 to its turning point, the popularity, measured as the average number of stars for the project is found to increase by more than five times, from 11.53 to 71.79, holding everything else constant, while for organization-owned projects it is found to increase from 28.26 to 38.08 (see Model 1c, Table 3). As mentioned in the initial part of the paper, an increase in popularity signifies project success — because greater popularity implies a larger community of users participating in bug identification and improvement of ideas (Crowston et al. 2006). And some of these users, over time, may progress to become active developers for the project (Krishnamurthy 2002, Subramaniam et al. 2009).

Although our study confirms the proposition laid out by Howison and Crowston (2014) by showing that superposed organization of tasks has important benefits in terms of enhancing the success of a project, it also indicates that the degree of superposition exhibits decreasing returns to scale and eventually dampens project success. We theorize that as the degree of superposition increases, delays due to the avoidance of concurrent work and co-work may induce a sense of frustration and loss of control for the contributors, which tends to influence the success of the project negatively. In our study, the decreasing returns are evident for both individual- and organization-owned projects,[[10]](#footnote-11) both of which show an overall negative influence of the degree of superposition beyond the turning point. For individual-owned projects, the average number of stars is found to decrease from 71.79 to 37.12 as the degree of superposition increases from its turning point to its highest value of 1, keeping everything else constant, while this number decreases from 38.08 to 20.78 for organization-owned projects. These findings have strong implications for both theory and practice.

### Implications

Our research contributes to IS and organization theory in three ways. First, our study advances the existing literature on motivation (e.g. Ke and Zhang 2010, von Krogh et al. 2012, Ryan and Deci 2000) and work structures (e.g. Howison and Crowston 2014, Lindberg et al. 2016) in FLOSS projects, as it takes a significant step in establishing the role of work organization as a key driver for contributors’ motivations and also as an antecedent to project success. Sociotechnical mechanisms associated with work structures have been largely neglected in studies of communities of practice. For example, the theory of network governance (Jones et al. 1997) identifies four social mechanisms that emerge in communities of practice in-order to overcome coordination challenges - imposing access restrictions, collective sanctions, reputational identity and creating a macroculture. By progressing the research agenda initiated by Howison and Crowston, (2014) and Lindberg et al. (2016), we demonstrate that work structures can perhaps be a fifth mechanism of network governance that not only helps overcome coordination issues but also motivates contributors in FLOSS-like environments. Further, although SDT has predominantly been used to study the motivation of the contributors in FLOSS environments (e.g., Ke and Zhang 2010; Lakhani and Wolf 2005; Roberts et al. 2006), relatively few have tried to link individual motivation to the success of the project (von Krogh et al. 2012). By providing theoretical arguments and finding empirical support for an inverted U-shaped relationship, our study shows that the complete picture of individual motivation in the context of task work often goes beyond the three psychological needs postulated by SDT. From the standpoint of motivational theories (e.g. SDT), our study cautions against assuming that the mechanisms operating at the individual level directly scale-up to the team or project level. Our findings suggest that the difficulties in scaling these mechanisms up to the project level manifest as boundary conditions describing the application of theories from one level of analysis to another. Understanding these boundary conditions and their implications for project success can be beneficial as it enriches the response to the question raised by von Krogh et al. (2012, p. 650): “How and why do OSS developers produce high-quality software when they do?*”.*

Second, our research advances the literature surrounding organizational participation in FLOSS projects (Capra et al. 2011; Fitzgerald 2006; Spaeth et al. 2015; Stewart et al. 2006; Wagstrom 2009) by enhancing our understanding of how organizational participation influences FLOSS projects in general and their work structures in particular. Practically, organizations seek to benefit from the strengths of open collaboration but are unsure about how to integrate it with their own strengths. By trying to introduce controls and/or speeding up development, organizational involvement can “kill the goose that lays the golden egg”[[11]](#footnote-12) by undermining the community process. This leads to a trade-off between openness and control (Engeström 2007; Jarvenpaa and Lang 2011; Teigland et al. 2014), that when effectively managed can lead to the success of FLOSS projects (Teigland et al. 2014). Our inquiry is one of the first to understand this trade-off in the realm of work structures and the nature of the ownership of FLOSS projects. With organizational ownership, the increased net extrinsic motivation of the contributors and the higher time cost of money undermine the need for openness and autonomy of work, allowing the project owner to exert a greater influence the relationship between superposed work structures and project success . The extent to which the organization owner can influence the relationship between superposed work structures and project success depends on the models of organizational involvement. The greater the organization owner is willing to invest in the coding model of engagement by contributing code and employees’ time, the lesser will be the overall influence of superposed work structures on the success of the project. The greater the organization owner invests in the support activities of the FLOSS project, greater is the time-cost of money —creating a higher need for efficient development practices in-lieu of superposition.

Third, our work develops a clear construct for the concept of superposition that can be used for future theory development anchored around this construct. A well-defined theoretical construct with delineated scope conditions is essential to the process of building strong theory (Suddaby 2010; Sutton and Staw 1995). As a step towards this goal, we have defined and operationalized the construct -*degree of superposition,* and examined its behavior in relation to project success under different contextual conditions, i.e., at low and high degrees of superposition and under different ownership types and models of organizational engagement. In doing so, we have tried to establish the scope conditions associated with space and value for the construct (Suddaby 2010). Further, this construct can be easily operationalized using task-specific data that are available in the change logs for projects. We believe that this construct will not only help researchers to advance the theory of superposition and unearth new relationships, but can also be used as a tool to measure and monitor project work structures.

### Limitations and Directions for Future Research

Although we have carefully tried to ensure theoretical and methodological rigor in this research, there are certain limitations that need to be considered. First, our choice of GitHub as a source of data was based on its popularity among programmers, its integrated social features, and the availability of detailed metadata. While GitHub offers a good dataset for the purposes of this study, certain perils are associated with its use (Kalliamvakou et al. 2014). To minimize the effect of these perils, we introduced multiple controls, filters, and manual checks. The details of the perils in using this dataset and the checks we adopted to overcome them are listed in Online Appendix A3. Second, our operationalization of tasks and versions is tuned to Git based platforms like GitHub and limited to the nature of data made available by that platform. When it comes to operationalizing tasks, we have taken special care to ensure that each identified task is unique (i.e., we have avoided double counting of tasks) and made a significant change to the shared output of the project (see Online Appendix A1 for details). However, it is possible that some events involved a greater amount of effort and implemented larger changes to a project than others. Ideally, each event should be manually analyzed to determine whether it made a significant change to the shared output of the project before qualifying it as a task. But this is practically very difficult, because many active projects have several hundred events in a year. However, to minimize the impact of varying task sizes across projects, we included the control variable *average task size of the project* in our regression models. When it comes to versions, we operationalize it as the state of the project at the end of a specific day of activity (see Online Appendix A2 for details). While this operationalization allows us to generalize the construct and leverage the workflow of Git based FLOSS development platforms, the actual meaning of versions may differ across platforms and sometimes even across projects. This problem is exacerbated by the fact that the literature is overloaded with multiple terms that conflate the meaning of versions. For example, major release, minor release, development release, user version, and patches[[12]](#footnote-13). Despite these issues, we have retained the term “version” and presented one approach to operationalize it. Future studies could tune their approach for operationalizing versions to one that is more suitable for the nature of workflow adopted by the platform under study. As a robustness test to confirm that the observed results were not due to the way we have operationalized the constructs, we included a falsification test (results provided in Appendix 1) to show that the hypothesized relationships are not significant in projects that are unlikely to see the mechanism of superposition in action. Third, we used counts of stars as the measure of success because it captures how popular a project is. In their empirical analysis of FLOSS project success, Crowston et al. (2006) found that the common measures used for success, such as popularity, are correlated to each other but that project lifespan was unique in not correlating to the other measures of success. Given this multidimensional nature of the success construct, we included survival analysis to provide an independent view of project success not captured by counts of stars. The result of the survival analysis provides support for Hypotheses 1 and 2a but is not significant for the shift in the turning point proposed in Hypothesis 2b (see Appendix 1 for details). The nonsignificance may be because the meaning of the lifespan of a project might be slightly different for organization-owned FLOSS projects—that is, while successful individual-owned projects are expected to remain active for a prolonged period, organization-owned projects may come with specific end goals and timelines. The mixed results we have seen for Hypothesis 2b call for a deeper inquiry into the temporal effect of the work structure, which might exhibit changes across years and along the life cycle of a project (Lindberg 2015). The temporal effect of superposition provides a potential area for future research, which can try to unearth the scope conditions for the construct associated with time (Suddaby 2010). Understanding the temporal effect can deepen our understanding about the impact that the life-cycle stage of a FLOSS project has on its work structures and how the impact may differ in large, mature projects like Eclipse, Firefox, and GNOME. Fourth, one of our goals in taking up this research was to call attention to the importance of sociotechnical mechanisms invoked by the work structures in FLOSS projects. Along this line, we have tried to enrich the theory of superposition by establishing a better context and identifying boundaries to its influence. However, Lindberg et al. (2016) identified unresolved developer and developmental interdependencies that tend to be resolved through two unique sociotechnical mechanisms i.e. direct implementation and knowledge integration. While these mechanisms seem to address dependencies outside the purview of superposition, they are possibly related to the productive deferral mechanism of superposition because they serve the same purpose of addressing complexities in coordinating development work. Since productive deferral has been treated as a latent mechanism in this study, a more thorough development of this concept may be necessary to integrate the works of Howison and Crowston (2014) and Lindberg et al. (2016) so as to provide a full picture about the role of work structures in FLOSS projects. Although these linkages remain unresolved and require deeper investigation, our study contributes to the literature by taking a modest step forward in enriching our understanding of work structures in FLOSS development and the mechanisms through which superposition influences FLOSS project success in individual as well as organizational contexts

# Essay 2

# Essay 3

1. http://www.nytimes.com/2001/11/05/technology/05OPEN.html?pagewanted=all [↑](#footnote-ref-1)
2. <https://www.theverge.com/2018/6/4/17422788/microsoft-github-acquisition-official-deal> [↑](#footnote-ref-2)
3. <https://github.com/facebook/pop> [↑](#footnote-ref-3)
4. <https://github.com/kenwheeler/slick> [↑](#footnote-ref-4)
5. The latent relationships proposed are illustrative and may differ slightly. See Haans et al. (2015), for a more detailed explanation of the different conditions under which the U-shaped relationship can emerge. [↑](#footnote-ref-5)
6. We thank one of the anonymous reviewers for suggesting this reference for enriching our theory development. [↑](#footnote-ref-6)
7. We thank the AE for helping us expand the theoretical understanding of this model of organizational engagement. [↑](#footnote-ref-7)
8. The time value of money is often calculated using the formula , where is the present value, is the future value of the investment, is the interest/discount rate, and is the time for realization of the investment. Given , we can use binomial approximation to reduce the equation to a linear form: . In our case, we consider the time cost of money as the value of . If we assume the time of completion of a major release to be linearly dependent on the degree of superposition, then the time cost of money linearly increases with increases in superposition. [↑](#footnote-ref-8)
9. The full regression model with interaction (Table 3, Model 1c) can be represented by:

   where

   In this quadratic equation, the turning point is given by , with z= 0 representing the turning point for individual-owned projects and z= 1 representing the turning point for organization-owned projects. [↑](#footnote-ref-10)
10. For individual-owned projects: , and

    for organization-owned projects: [↑](#footnote-ref-11)
11. We thank one of the reviewers for helping us better articulate the contribution of our research. [↑](#footnote-ref-12)
12. We thank one of the anonymous reviewers for pointing out the limitation with our operationalization of versions and suggesting ways to improve the clarity surrounding the construct [↑](#footnote-ref-13)