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Abstract:

Online peer production communities such as open source software (OSS) projects attract both identified and anonymous peripheral contributions (APC) (e.g., defect reports, feature requests, or forum posts). While we can attribute identified peripheral contributions (IPC) to specific individuals and OSS projects need them to succeed, one cannot trace back anonymous peripheral contributions (APC), and they can have both positive and negative ramifications for project development. Open platforms and managers face a challenging design choice in deciding whether to allow APC and for which tasks or what type of projects. We examine the impact that the ratio between APC and IPC has on OSS project performance. Our results suggest that the OSS projects perform the best when they contain a uniform anonymity level (i.e., they contain predominantly APC or predominantly IPC). However, our results also suggest that OSS projects have lower performance when the ratio between APC and IPC nears one (i.e., they contain close to the same number of APC and IPC). Furthermore, our results suggest that these results differ depending on the type of application that a project develops. Our study contributes to the ongoing debate about the implications of anonymity for online communities and informs managers about the effect that anonymous contributions have on their projects.

Keywords: Open Source Software, Peer Production, Anonymous Peripheral Contribution, Project Performance.

Fiona Nah was the accepting senior editor for this paper.

1 Introduction

Socially ambiguous identities permeate online collaborative peer production communities (Faraj, Jarvenpaa, & Majchrzak, 2011; Kim, Lee, & Lee, 2019; McDonald, Hill, Greenstadt, & Forte, 2019). Peer production models such as Wikipedia, citizen science, and open source software (OSS) projects allow people to contribute anonymously without revealing themselves to facilitate broader participation (Arazy, Ortega, Nov, Yeo, & Balila, 2015; Jackson, Crowston, & Østerlund, 2018; von Krogh, Spaeth, & Lakhani, 2003). Participants often make valuable anonymous peripheral contributions (APC) to OSS projects in the form of defect reports, feature requests, and forum discussion posts (Franke & Shah, 2003; Lakhani & von Hippel, 2003; Lee & Cole, 2003; von Hippel, 2001, 2005; Zhou & Mockus, 2015). These contributions have led to a shift in the notion of organizing from traditional hierarchy and market-based mechanisms to peer production as customers and end users play a more central role in open, distributed production projects (Benkler 2002, 2006; Ko & Chilana, 2010; Mallapragada, Grewal, & Lilien, 2012; Sutanto, Kankanhalli, & Tan, 2014).

APC often represent a significant portion of all contributions in online communities (Kolbitsch 2006). For example, by 2015 about 13 percent of contributions to Wikipedia came from anonymous individuals, while 13.7 percent of contributions to the citizen science project Higgs Hunters and 7.4 percent of contributions to Gravity Spy came from anonymous individuals (Jackson et al., 2018). In the OSS context, researchers have found up to 50 percent of contributions to come from anonymous individuals (Crowston & Howison, 2003).

Despite their prevalence in OSS projects, APC may have both positive and negative consequences. On the one hand, platforms and projects that allow anonymity facilitate broad participation and generate more solutions than those that mandate identification (McDonald et al., 2019). Creating an identity in a group can take time in terms of registering with the platform and acts as a barrier to participation, which raises challenges (particularly for new or infrequent contributors) (Steinmacher, Conte, Gerosa, & Redmiles, 2015; Steinmacher, Gerosa, Conte, & Redmiles, 2018). For this reason, keeping barriers low by allowing APC allows an OSS project to leverage the Internet and reach expertise across the world (Olleros, 2008). Anonymous contributions minimize concerns about contributors' and firms' self-interest and reputation, and contributors can instead focus their attention altruistically on project goals (Reicher, Spears, & Postmes, 1995; Tsvetkova & Macy, 2015). Anonymity acts as a safety valve and allows contributors to make valuable contributions or suggestions to the community without fearing discrimination based on race or gender, retaliation, or privacy invasions and can even prevent professional reputation loss (Froomkin, 2015; Forte, Andalibi, & Greenstadt, 2017; McDonald et al., 2019; Misoch, 2015). Contributors may also choose to remain anonymous if they feel that making contributions to an OSS project violates their contract with their employer (Baskerville & Dulipovici, 2006).

On the other hand, APC runs counter to the established reasons that help OSS projects sustain development. Research has emphasized the role that identity building plays in sustaining electronic knowledge contributions (Ma & Agarwal, 2007; Wasko & Faraj, 2004) and, in particular, in fostering individuals to participate in OSS projects in the long term (Fang & Neufeld, 2009). If individuals need to develop an identity to sustain their contributions, then APC may limit a project's ability to continue development. Indeed, many citizen science production communities promote participants based on their identified contributions, and contributing anonymously can delay when participants achieve promotion (Jackson et al., 2018). Further, if actions that promote an anonymous contributor's own success lack congruence with actions that promote the project's success, the contributor may opt for the action that promotes their own success as opposed to the project's interests (Barreto & Ellemers, 2000) because peer pressure or other social mechanisms that sanction negative participation when contributing anonymously may not influence contributors. As an example, when people in a group have salient identities, peer pressure could help encourage quality contributions, which, in turn, may lead to status promotion (Jackson et al., 2018; Panciera, Halfaker, & Terveen, 2009; Panciera, Masil, & Terveen, 2014). However, untraceable identities may reduce APCs' trustworthiness and accountability (McDonald et al., 2019; Rains, 2007a, 2007b). Deception, frivolousness, vandalism, sabotage, and deliberate disruption represent potential concerns as well (Hancock, 2007; Kane, 2011; Scott, 2004). Furthermore, because certain kinds of tasks may require follow-up, anonymous contributions mean that one cannot easily (or at all) call on the contributor's expertise in the future (Majchrzak, Cooper, & Neece, 2004). For these reasons, APC may be less valuable than identified peripheral contributions (IPC) when they pertain to certain tasks.

Thus, the impact that APC have on project performance remains unclear (Christopherson, 2007; Faraj et al., 2011). We need to understand this impact because open platforms and others who seek to facilitate distributed innovation face a challenging design choice in deciding whether to allow APC and for which tasks or what type of projects (Faraj et al., 2011; Kane, 2011; McDonald et al., 2019; Ren, Kraut, & Kiesler, 2007).

Anonymity refers to "the degree to which a communicator perceives the message source is unknown and unspecified" (Anonymous, 1998)[1]. With this definition, we can consider anonymity a continuum with one end that describes individuals about whom one knows little and the other end that describes individuals about whom one knows much. We can consider contributors whose name and prior behaviors one does not know anonymous for practical purposes, although their identity may emerge based on the language they use, the tone in their comments, their references, or their IP address (Hayne, Pollard, & Rice, 2003; Jackson et al., 2018; Panciera et al., 2009). Well-known individuals sit at the other end of the continuum and engage the community through persistent identities such as registered user identifiers (IDs). Because they identify themselves with a persistent user ID over time, other participants can trace and know their behavior, which helps to build their build reputation. By interacting with a project in this way, contributors can develop a persistent identity (Ma & Agarwal, 2007; Panciera et al., 2014).

While researchers have theoretically explored the tension between the benefits and drawbacks of such ambiguous social identities in online communities (Christopherson, 2007; Faraj et al., 2011; Scott 2004), we explore the effect that the ratio of APC to IPC has on project performance because OSS projects differ widely in how many anonymous and identified contributions they contain (Crowston & Howison, 2003). By focusing on the ratio, we can assess the relative impact that APC vis-à-vis IPC has on project performance. We also explore how these effects differ across the types of contributions that contributors make and the type of products that the projects they contribute to develop. To do so, we focus on peripheral activities (task requests, which include defect reports and feature requests, and forum discussion posts) but not on code development (i.e., a core activity in OSS projects). Code development (e.g., via code commits) requires contributors to have a visible identity (to gain code commit rights) and is strongly associated with reputation building (Roberts et al. 2006). In contrast, individuals cannot build a visible reputation from making APC, so we expect few anonymous contributions for core developmental tasks.

We draw on the social identity theory of anonymity effects (SIDE) as a basis for theorizing about how the ratio between APC to IPC impacts OSS projects' performance (Reicher et al., 1995). To test our hypotheses, we used archival data on a set of 611 OSS projects hosted on SourceForge that contained 7,458 task requests and 15,766 forum discussion posts. Our results suggest that OSS projects perform the best when they contain a uniform anonymity level (i.e., predominantly APC or predominantly IPC) and that they perform the poorest when the ratio between APC and IPC nears one (i.e., the same number of APC and IPC). We further report some interesting nuances to this relationship across contribution and application types (developer-oriented versus end-user applications).

This research contributes to the literature in several ways. We extend the SIDE model in two directions. First, researchers have typically explored the SIDE model with experiments where all contributors have the same level of anonymity (e.g., Postmes, Spears, & Lea, 1998). We connect the SIDE model to the peer production context where contributions need not have the same anonymity level. Second, we extend the SIDE model by illuminating how the type of application that a project develops influences the impact that APC have on group outcomes. In doing so, we inform the debate about whether APC benefit OSS development or online community building in general (Davenport, 2002). Our contingency approach advances this discussion by delineating the conditions under which APC enhance OSS project outcomes.

In this paper, we also offer practical implications as guidance for managers of peer production projects. We highlight the ratio between APC and IPC that can optimally enhance project performance and suggest how the impact of anonymous contributions differs across application types. Thus, managers can make informed decision about when to allow or disallow APC and leverage their benefits. Our findings suggest that using governing mechanisms to ensure that either all (or a significant proportion of) contributions come from either identified contributors or anonymous contributors should result in optimal performance.

The paper proceeds as follows: in Section 2, we review the literature we used to build our model. In Section 3, we use the SIDE model and related studies to better understand the impact that APC has in the peer production environment. In Section 4, we develop our hypotheses. In Section 5, we discuss our research method and results. In Section 6, discuss our findings and our contributions to theory and practice. Finally, in Section 7, we conclude the paper.

[1] Craig R. Scott, a well-known anonymity researcher, used the pen name "Anonymous" when he published this paper.

2 Background

While researchers have theoretically (Anonymous, 1998; Rains & Scott, 2007; Reicher et al., 1995) and empirically (Jackson et al., 2018; Kim et al., 2019; Klein, Spears, & Reicher, 2007; Kolbitsch, 2006; Pisonneault & Heppel, 1997; Postmes, Spears, Sakhel, & de Groot, 2001; Tanis & Postmes, 2007) examined the role that anonymity plays in group-level outcomes, we lack knowledge about how APC per se affect OSS projects' performance. Some studies suggest a negative relationship between anonymous participation and group outcomes (Kim et al., 2019; Zimbardo, 1969), some suggest a positive relationship (Postmes et al., 2001; Reicher et al., 1995), and still others suggest contingencies that alter the relationship (Ren et al., 2007). In this section, we review these studies as a foundation to develop hypotheses to further understand the role that APC play in open and distributed innovation projects.

In the 1970s, theorists often predicted that member anonymity would be associated with negative group outcomes, and their empirical studies frequently supported this perspective (Donnerstein, Donnerstein, & Evans, 1972; Zimbardo, 1969). This view concurs with IS scholars' concerns about decreasing accountability and social justice due to anonymous online communication (Davenport, 2002) and computer scientists' efforts to create accountable identities online (Ford & Strauss, 2008). Empirical studies, however, have been unable to establish a positive relationship between online anonymity and behaviors that harm group outcomes, such as vandalism (Viegas, Wattenberg, & Dave, 2004). Although flaming (i.e., hostile online interaction) has been a significant concern related to anonymous computer-mediated communication (Alonzo & Aiken, 2004; Turnage, 2007) and knowledge contribution (Wasko & Faraj, 2004), the impact that such negative anonymous contributions have on project performance remains unclear (Jane, 2015).

In contrast to studies that focus on anonymous contributions' negative aspects, two main arguments suggest anonymous contributions may yield a positive impact on group outcomes. First, allowing individuals to contribute anonymously capitalizes on a unique advantage that the Internet provides: its ability to lower the barriers to entry and facilitate a wide range of participation to broaden the discourse (Olleros, 2008). The user innovation literature consistently demonstrates the value of engaging participants beyond the core innovation team as these peripheral members bring new perspectives, challenge existing ideas without fearing retaliation, and often represent the product user's view (Franke & Shah, 2003; Setia, Rajagopalan, Sambamurthy, & Calantone, 2012; von Hippel, 2005; von Krogh et al., 2003). The conjecture that identified contributions are better than anonymous contributions concurs with deindividuation theories in which individual identifiability increases social pressure, which, in turn, leads to greater individual accountability and, consequently, the probability that the contributing individual contributing will act in the group's best interests (Zimbardo, 1969). Enabling individuals to contribute anonymously can increase the range and diversity of contributions that benefit a project that seeks to innovate. It allows people who consider the cost of time to create an online identity greater than the opportunity to participate and can encourage a diverse set of contributions that would not have occurred if identification process had deterred the contributor. Indeed, the success of Wikipedia has been attributed to anonymous contributions to a great extent (Stross, 2006).

The second reason why anonymous contributions may yield a positive impact on group outcomes concerns the salience of the group's identity versus individuals' identity. The SIDE model specifies that anonymity in a group setting induces a shift in focus from one's individual identity to one's social identity as a group member (Postmes & Lea, 2000; Postmes & Spears, 1998; Spears, Postmes, Lea, & Wolbert, 2002). When individuals have a salient identity (i.e., when they participate with their identity revealed), they have a higher likelihood to focus on their individuality and engage in behaviors that promote their own selves over the group. When individuals focus on their own success, they can hinder group outcomes if their goals conflict with group-success measures.

In contrast, anonymity de-emphasizes individual identity and enhances identification with the group (Postmes et al., 2001; Reicher et al., 1995). Postmes et al. (2001) demonstrated that, in computer-mediated groups primed for efficiency, such groups with anonymous contributions performed better than such groups with identified contributions because off-topic discussions were less likely to distract anonymous contributors. When individuals focus more on the group identity as their own social identity (by participating anonymously) rather than their own self-identity, the strengthened group identification should lead to better group, as opposed to individual, outcomes.

Prior research also suggests that the impact that anonymity has on group outcomes may depend on other factors (Postmes et al., 2001). Building on the SIDE model, Ren et al. (2007) showed that the impact of anonymity depends on the group's type and an individual's reason for participating in it. Strong norms and identity at the group level due to participant anonymity may impact online group differently depending on the basis of their attachment to the group. As an example, in bond-based communities, where people have an attachment to individual members in the group, community success depends on individual identity rather than group identity (Ma & Agarwal, 2007; Ren et al., 2007). Anonymous participation in these groups promotes strong group norms and community identity but may weaken the quality of individual bonds, which, in turn, can affect community-level outcomes negatively for bond-based communities. An online cancer-support group exemplifies a bond-based community (Ren et al., 2007). In contrast, participant anonymity may enhance the success of identity-based communities. People who feel attracted to a group's overall identity rather than to particular individuals primarily form identity-based communities. An example identity-based community might include a community that gives technical support (Ren et al., 2007). Based on these reasons, we explore contribution types and application types as potential contingent factors for the impact that anonymity has on peer production project performance.

3 Extensions to the Current Literature

We use the SIDE model and related studies to better understand the impact of APC in the peer production environment. The SIDE model suits this context because it emphasizes both individual and group identities and because researchers have previously applied it in online groups (Clark-Gordon, Bowman, Goodboy, & Wright, 2019; Lee, Lee, Bassellier, & Faraj, 2010; Postmes & Spears, 2002; Ren et al., 2007; Rösner & Krämer, 2016). Drawing on the dynamics of individual and group identities, we apply the SIDE model to explain the impact that APC has in knowledge-intensive processes in the peer production environment. Conventional studies that have used the SIDE model have focused on contexts where exchanging information represents the primary task and explained little about how APC affect project outcomes when various knowledge-intensive contributions drive the production process (e.g., Postmes et al., 2001).

3.1 Peripheral Contribution Types

Peripheral contributions can generally come from any particular group, and both developers and external end users may choose to make anonymous or identified contributions (Arazy et al., 2015; Jackson et al., 2018; von Krogh et al., 2003). OSS projects typically contain two main types of peripheral contributions: 1) task requests (TR) and 2) forum discussion posts (FDP). TR focus on responding to failures in a system or extending software's functionality. They include defect reports about, for example, errors, failures, or faults in the software product so that the core developers can address them (Raymond, 2000; Wang, Shih, & Carroll, 2015a; Wang, Shih, Wu, & Carroll, 2015b). They also include requests to extend software's functionality (e.g., requests for new features). FDP serve a social mechanism for OSS community members to communicate ideas, opinions, coordinate work, and resolve conflict (Crowston, Li, Wei, Eseryel, & Howison, 2007; Filipova & Cho, 2016).

In this study, we focus on TR and FDP to understand the impact of anonymity. TR and FDP represent two important but distinct classes of peripheral OSS contributions, and the distinction may critically pertain to the potential impact of anonymity. As we explore further below, TR serve a performance function, whereas FDP serve a social function (i.e., relationship building and bond development). Both task-related productivity and group relationship strength constitute important project-performance determinants, but member anonymity may impact them in different ways. Specifically, while anonymity may focus team members' attention on group goals rather than personal goals, anonymity may hinder the team's ability to build relationships that improve social cohesion. Core developers must analyze whether TR duplicate prior contributions, whether they need to address them, and who specifically should do so (Lee et al., 2010). TR also constitute an important part of the formal development process (Crowston et al., 2003). In contrast, FDP lack formality, follow no standard format and range in their content and style, and help bring fresh ideas and perspectives. Researchers usually consider FDP to represent peer production projects' social dynamics (Howison, Inoue, & Crowston, 2006).

3.2 Application Type as a Reflection of the Group Identity

Building on the notion from Ren et al. (2007) and Postmes et al. (2001) that groups have characteristics that impact the effect that anonymous contributions have on group performance, we argue that, for peer production projects, the type of application they develop moderates APC's impact. The type of application represents an important part of group identity because it determines who may have an interest in the project and the associated knowledge that interested members contribute. For instance, a statistical tool may have researchers associated with it, while a game may have teenagers associated with it. In addition to requiring different kinds of knowledge, contributors may have different motivations for participation. Individuals who use the statistical tool may do so to improve their professional skills, while individuals who play games may do so for entertainment.

Following Setia, Bayus, and Rajagopalan (forthcoming), we specifically focus on two application types: developer-oriented and end user-oriented applications. As we make the case below, we need to make this distinction because it restricts the type of audience that projects attract and who eventually use the applications they develop. Developer-oriented applications will likely attract TR and FDP peripheral contributions from core developers who have an interest in building their reputation (Shah 2006). On the other hand, end-user oriented applications will likely attract peripheral contributions from an external audience who may lack technical code knowledge but care about its functionality and its growth in general (Setia et al., forthcoming).

In summary, we designed this study to extend the existing literature by examining the impact that APC vis-à-vis IPC has in peer production projects across different contributions (i.e., TR and FDP) and application types (i.e., developer versus end user applications). Understanding the impact of APC will benefit individuals who seek to leverage worldwide user communities, such as GitHub, Wikipedia, and SourceForge. In Section 4, we leverage the SIDE model of anonymity to develop hypotheses about how the ratio between APC and IPC impact outcomes for open, distributed, innovation groups. Specifically, we develop these hypotheses in the OSS-development context.

4 Hypotheses Development

4.1 Task Requests (TR)

As we mention in Section 3, participants can make task requests (usually defect reports or feature requests) to request core developers to perform specific tasks (Chengalur-Smith, Sidorova, & Daniel, 2010; Temizkan & Kumar, 2015). Defect reports focus on highlighting issues and weaknesses in a current application and its use. OSS developers use various tools to collect and address defects, such as Bugzilla or Roundup (Wang et al., 2015a). An effective defect report includes as much detail as possible to help core developers correct the defect. For example, core developers can more easily correct defects when reporters provide specific details about the environment (i.e., operating system, application version, etc.) and the context in which they noticed the defect (Raymond, 2000). Effective defect reports provide information about unique defects in sufficient detail so that others can replicate them (Wang et al., 2015a, 2015b).

Similarly, contributors can provide innovative ideas or create general improvements over time by requesting new features (Belady & Lehman, 1976; Temizkan & Kumar, 2015). While defect reports address problems with developed application areas, feature requests focus on expanding the application in new directions. However, these new "path-creation" activities (Boland, Lyytinen, & Yoo, 2007), while critical for cross-boundary innovation projects, benefit a project only to the extent that they support its mission.

In order to construct a useful defect report or suggest a meaningful feature request, contributor must be conscientious about the project's needs and include all necessary information (Wang et al., 2015a). Task requesters who identify themselves (either because they desire to build a reputation or because they participate in the OSS-development community) could have the motivation to make these requests in a useful manner. When most other task requesters identify themselves, they can build a positive reputation by making clear, detailed, constructive, and helpful requests. However, when most or all task requesters participate in an OSS project anonymously, reputation building may motivate contributors less, and they may have fewer incentives to provide clear and detailed requests. Participants who contribute to a project in which most contributors contribute anonymously may not know if anyone knows about their contributions or appreciates their reputation-building efforts.

Using the between-theorization approach that Haans, Pieters, and He (2016) suggest, we build the case that the ratio between anonymous and identified TR contributions will have a curvilinear effect on project performance based on three broad scenarios. Specifically, we hypothesize that project performance will change as the ratio changes from high to low. First, in a situation with all or mostly anonymous TR (i.e., the ratio is much higher than one), the group identity's salience strengthens, while the importance of building a reputation and individual identity weakens (Postmes & Lea, 2000; Postmes & Spears, 1998). The group identity or an altruistic focus on the application under development becomes much more prominent when contributors can identify few or no individual identities. A task requester may feel connected to the group's goals and could, therefore, contribute tasks that others can act on because the requester may have an interest in facilitating the application development. In this case, whereas the predominance of anonymous contributions makes it difficult for individual participants to build reputation, it also focuses participant attention altruistically on the project's goals as opposed to their own self-interest (Postmes & Lea, 2000; Postmes & Spears, 1998; Reicher et al., 1995; Tsvetkova & Macy, 2015). As such, when contributors predominantly make TR anonymously, we may observe enhanced project performance.

Second, when identified contributors predominantly make TR in a project (i.e., when the ratio is much less than one), the motivation to build a reputation will also facilitate project performance. When everyone in a peer production project make their identity known, each contributor knows that other people who care about their reputation also have an interest in the application (Roberts, Hann, & Slaughter, 2006; Shah, 2006). In this scenario, the reputation effects dominate and create peer pressure to make quality contributions and, thereby, benefits the group as a whole.

Finally, and in contrast to the above two scenarios, project performance will suffer when the ratio between anonymous and identified TR becomes balanced (i.e., closer to one) as the project may contain neither enough identified contributions to allow identified contributors to build their reputation nor enough anonymous contributions to build an altruistic focus on the group's development goal. One cannot easily activate both individual and group identities at the same time (Turner, Hogg, Oakes, Reicher, & Wetherell, 1987), and so a balanced ratio between anonymous and identified TR may do little to optimally benefit individuals and, consequently, improve project performance. Such a ratio weakens peer pressure in the group to focus on group goals. Contributors may become unsure about others' identity and be more likely to do things that do not align well with the group's interest.

A close balance between anonymous and identified TR does not significantly enhance project performance, but, as the ratio becomes more heavily skewed toward anonymous TR, project performance will increase as group identity's influence increases. Alternatively, as the ratio becomes more heavily skewed toward identified contributions the opportunities to build reputation increase, contributors have more incentives to contribute better TR, which improves project performance. Based on this discussion, we follow Haans et al.'s (2016) recommendations and propose that the ratio between anonymous and identified TR contributions will have a curvilinear effect on project performance in that project performance will first decrease as the ratio decreases until it reaches the minimum (i.e., the turning point) after which project performance will increase as the ratio increases. Thus, we hypothesize:

> **H1**: The ratio between anonymous and identified TR contributions (i.e., anonymous TR ratio) has a curvilinear relationship with OSS project performance.

4.2 Forum Discussion Posts (FDP)

FDP among contributors creates social integration that builds connections, shares meaning (Todorova & Durisin, 2007), resolves conflict (Filippova & Cho, 2016), and sustains collaboration (Kudaravalli & Faraj, 2008). In OSS projects, FDP function as a method to resolve conflict and coordinate collaborative work and as a way through which participants establish a sense of community (Filippova & Cho, 2016). Similar to the logic we propose for TR, we consider three broad scenarios to build the case that the ratio between anonymous and identified FDP have a curvilinear effect on project performance.

First, when most or all individuals who make FDP do so anonymously (i.e., the ratio is much higher than one), group identity and altruism effects will predominate because individual anonymity makes the group's identity and common goal more salient, which leads members to focus more on the group topic rather than off-topic interests such as personal discussions (Postmes & Spears, 1987; Reicher et al., 1995; Tsvetkova & Macy, 2015). Because participants do not know each other, they have few topics to discuss other than the application under development, and so they may focus more on the group goal. As such, discussions would be more on topic and more task focused when group members post anonymously (Ren et al., 2007). Researchers have empirically demonstrated these predictions (Sassenberg, 2002). Further, with a more salient group goal, contributors do not fear hurting their personal identities as much. Anonymity encourages participants to post more comments in group settings presumably because anonymity decreases the likelihood of evaluation apprehension and increases their confidence in voicing opinions (Jessup, Connolly, & Tansik, 1990). Because they do not need to fear retaliation, identification, or judgement, participants feel may be more willing to post new ideas or honest criticisms anonymously and, thereby, help project development by bringing fresh ideas (Froomkin, 2015; Forte et al., 2017; McDonald et al., 2019; Misoch, 2015).

Second, in situations where all or mostly all FDP come from identified members and few come from anonymous members (i.e., the ratio is much lower than one), the boundary surrounding the identified members becomes quite strong and impermeable. In this case, the identified contributors' shared mental model allows them to understand one another better and focus on the task at hand (Scozzi, Crowston, Eseryel, & Li, 2008). When individuals maintain persistent identities over time that capture prior behaviors or details about certain skills (as in the case of identified contributors), interactions in FDP could also encourage them to develop bond-based attachment (Ren et al., 2012). Social interaction and personal information constitute critical ingredients for developing strong bonds, which will ultimately allow developers to trust and understand one another better (Kim et al., 2019). Furthermore, reputation, identity, and peer effects will predominate in this case as developers seek to build their reputation among the peers, which will result in more technical, detailed FDP that adhere to the group's strict norms and, thus, help project performance by focusing developers' efforts (Roberts et al., 2006; Shah, 2006).

Finally, in contrast to the above two scenarios, project performance will suffer when the ratio between anonymous and identified FDP becomes balanced (i.e., closer to one) as neither of the two countervailing forces that we discuss above (i.e., identification-based reputation building and anonymity-based group identity) can dominate. In this case, the discussion might contain neither enough identified posts to allow identified contributors to build their reputation nor enough anonymous posts to build a focus on the development goal. Instead, the discussion may even devolve into topics not about the application but about off-topic issues due to the lack of norms (Ren et al., 2007). Off-topic FDP in OSS projects will not likely help project development. If contributors spend time on off-topic discussion, they may not discuss topics related to project development as much. Since OSS developers usually work on the applications in their spare time, core developers may increasingly find it difficult to parse through the discussion to glean useful insights or suggestions that actually aid project development.

Overall, as we hypothesize for TR, we hypothesize that with a balance in the number of FDP that identified and anonymous posters submit, group identity and individual reputation cannot positively affect performance because neither can dominate to optimally benefit the individuals involved, which will result in lower project performance. As the ratio becomes more skewed toward anonymous posts, project performance will increase as group identity's influence increases. Alternatively, as the ratio becomes more skewed toward identified posts, the opportunities to build reputation increase, which results in incentives to contribute via helpful and detailed FDP and, thus, improved project performance. Based on this discussion, we propose that the ratio between anonymous and identified FDP will have a curvilinear effect on project performance in that project performance will first decrease as the ratio decreases until it reaches the minimum (i.e., the turning point) after which project performance will increase as the ratio increases.

> **H2**: The ratio between anonymous and identified FDP (i.e., anonymous FDP ratio) has a curvilinear relationship with OSS project performance.

4.3 Moderating Role of Application Type

Given the focal role that group identity has in the SIDE model, the nature of a group's identity may influence the effect that anonymity has on OSS outcomes. An OSS project's identity large depends on the type of software application under development because it signals users' identity, and the users often play a critical role in developing the application (Ho & Rai, 2017). We consider two broad application categories: applications that developers design and use themselves and applications designed for general end users (e.g., Setia et al., forthcoming).

Applications designed for developers have a narrower and less diverse audience compared to applications designed for general end users. Applications designed for developers (e.g., programming frameworks) tend to have more specialized functionalities than products designed for end users. While applications designed for developers target one specific group (i.e., dedicated developers), applications designed for end users could target organizations, retailers, artists, students, gamers, scientists, or others (Setia et al., forthcoming).

We propose that APC will have a more profound impact on project performance for projects that focus on applications designed for developers because the main stakeholders in such projects comprise developers themselves who, due to their skills and knowledge, are more likely to participate in OSS projects as core members (Crowston & Howison, 2006; Dahlander & O'Mahony, 2011; Wang et al., 2015) and usually care about building their reputation and following community norms (Moqri, Mei, Qiu, & Bandyopadhyay, 2018; Roberts et al., 2006).

A positive reputation in OSS projects can lead to definite improvements in salary or other professional prospects (Hann, Roberts, & Slaughter, 2013). However, reputation building requires identified rather than anonymous contributions over time. If individuals make contributions anonymously, one cannot associate them with past contributions, which makes it difficult for individuals to accumulate and develop a persistent reputation over time. Because developers are more likely than end users to desire reputation building, we expect them to make more identified rather than anonymous contributions (Shah, 2006).

In the presence of other OSS developers who make identified contributions, the pressure to submit quality contributions will likely increase further because fellow identified developers act as a critical peer-evaluation audience to form professional impression (Bosu et al., 2014). Thus, in developer-oriented projects, contributors will have stronger incentives to provide identified and high-quality contributions compared to end user-oriented applications.

Additionally, because developer-oriented applications focus on a specific goal and technically savvy audience, they are more likely to be reputation-driven environments with stricter norms (Shah, 2006). In such environments, developers may resort to making anonymous contributions only if they perceive their contributions to be controversial or against the strict norms to protect their identities (Froomkin, 2015; McDonald et al., 2019; Misoch, 2015). Bad informational inputs in the form of anonymous contributions may also be potentially deliberate acts of vandalism, sabotage, or anti-intellectualism from bad actors looking to create disruption (George, 2007; Kane, 2011; McDonald et al., 2019). As the number of APC increase vis-à-vis IPC, the overall project environment may deteriorate due to disputes and debates, which will result in lower performance.

In contrast, end user-oriented applications have utilitarian goals and a broader audience (Shah, 2006) and draw on peripheral contributions from a wide range of actors, including external stakeholders, who may not necessarily have technical expertise or an interest in building a reputation in that particular community (unless they happen to also be software developers) but who may have an interest in the project's general functionality for their own use (Crowston, Wei, Li, & Howison, 2006; Setia et al., forthcoming). Because end user application development relies more heavily on informational inputs from external users (in the form of TR and FDP related to the general usability, product awareness, and adoption), such communities may better accept and incorporate APC to broaden the reach and reduce barriers (Setia et al., 2012). Overall, we expect developer-oriented projects to function based on bonds and end user-oriented projects to function more as identity-based communities (Ren et al., 2007). Based on this discussion, we hypothesize:

H3: The curvilinear relationship between the anonymous TR ratio and OSS project performance will be stronger (i.e., have a lower turning point) for projects that develop developer-oriented applications compared to end user-oriented applications.

H4: The curvilinear relationship between the anonymous FDP ratio and OSS project performance will be stronger (i.e., have a lower turning point) for projects that develop developer-oriented applications compared to end user-oriented applications.

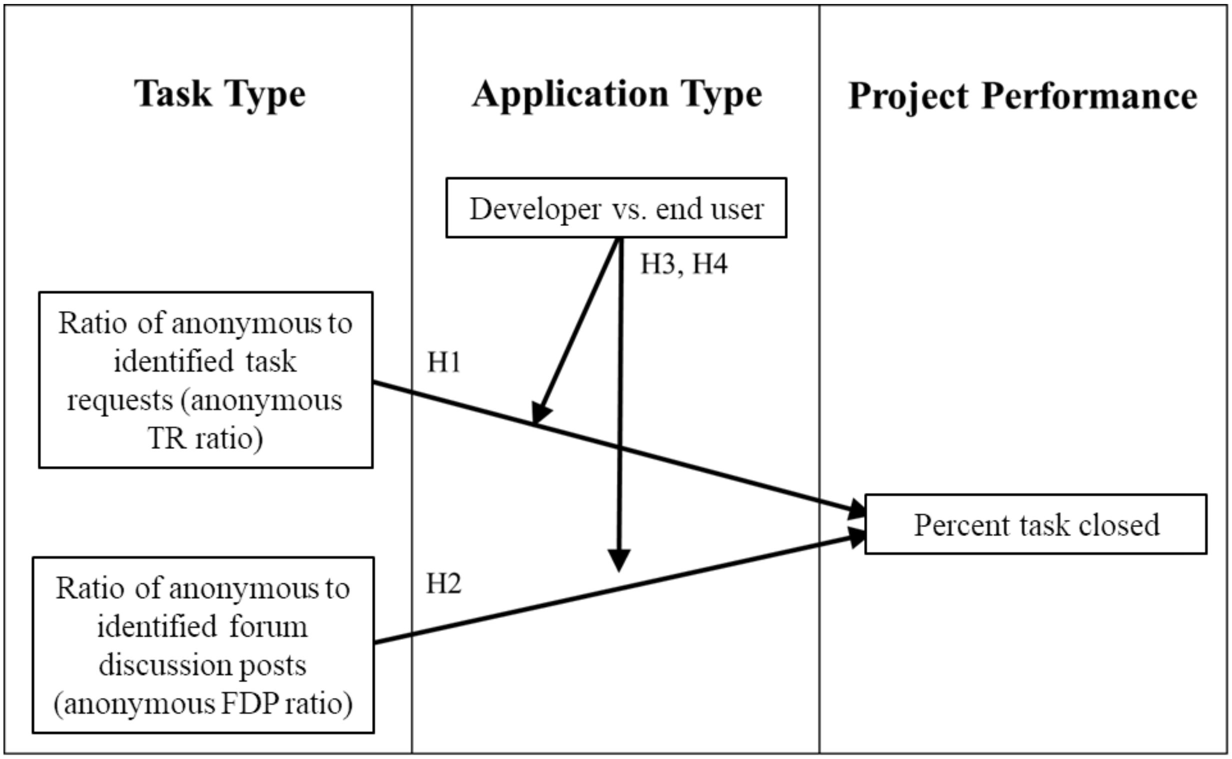

Figure 1. Research Model

5 Research Method

5.1 Data Collection

We obtained data for this study from the SourceForge Research Data Archive, an archival database about OSS projects that SourceForge provides to the University of Notre Dame (Van Antwerp & Madey, 2008). The archival data set includes information about project developers and users, such as participant identification numbers, and how and when they interact with each project. It also includes data about the projects such as they type of license they use, the audience the application targets, and the day each project registered on SourceForge. Recent OSS research has used this data extensively (e.g., Daniel et al., 2018a, 2018b; Daniel & Stewart, 2016; Peng, Wan, & Woodlock, 2013; Setia et al., forthcoming; Sutanto et al., 2014; Temizkan & Kumar, 2015; Wen, Forman, & Graham, 2013). This archive has data on over 150,000 projects, but many lack relevance to the questions that we examine. For instance, we focus on distributed groups, but many projects have small teams or only a single developer (Krishnamurthy, 2002).

We selected the sample of OSS projects so as to minimize the influence of factors that we do not focus on in this research; namely, the number of developers, OSS-development platform, time since the OSS project registered on SourceForge, and the type of license the project used. The number of developers can indicate the amount of resources available to perform the development task and can also indicate the level of management necessary (Chengalur-Smith et al., 2010). We follow the recommendations in existing OSS research (Stewart & Gosain, 2006; Hansen, Jonasson, & Neukirchen, 2011) and only include projects that have at least four developers to ensure that we focused on projects with group dynamics and processes.

Some OSS-development platforms may aid development activity more than others based on the resources that the platform offers and the ease with which individuals can use those resources. For instance, a platform that facilitates communication between developers and users by offering public forums may increase OSS project performance compared to a platform that does not offer public forums. We included only projects that used the SourceForge platform in the sample to control for any effects due to variation in development platform. As one of the most popular OSS-development platforms, SourceForge allows developers and users to observe others' project activities, send defect reports and feature requests, post to forums, launch new OSS projects and join existing ones, coordinate and work jointly in specific OSS projects, and integrate the developed software into a larger software application. Finally, we included only projects that used the GNU public license to ensure that they fulfilled the Open Source Initiative's requirements (e.g., Daniel, 2006). By selecting only GNU-licensed projects, we limited the variation in project performance that prior literature suggests may arise due to the license choice (Stewart, Ammeter, & Maruping, 2006). After we applied these restrictions, we obtained a sample with 611 projects.

The sampled projects focused on developing a broad range of application types that we classified as developer oriented (projects that develop applications help developers develop applications) or end user oriented (projects that relate to software that end users will use for organizational purposes, science, management, statistical analysis, education, online sales, games, entertainment, and so on). For example, a developer-oriented application in our sample included the Spring Rich Client Project, which provides developers a robust way to build rich-client applications by leveraging the Spring Framework[2], while an end user-oriented application included Hero Arena[3] and scientific software such as TRANSFOG DAS, which allows scientists to discover and analyze genes responsible for cancer[4].

5.2 Measures

We began observing each project six months after it registered on SourceForge in order to give peripheral contributors time to become involved in it. We then observe the project for the subsequent six-month period. Given that prior work has shown typical SourceForge projects to remain active for approximately one year (Stewart et al., 2006), we chose this period to capture an active period in most projects' life. Because OSS projects in the sample started on different days, the six months we observed do not necessarily correspond to the same calendar days for each project.

5.2.1 Dependent Variable

SourceForge allows projects to track not only the total number of task requests but also how many of them are "open" (i.e., not completed), which allows one to calculate how many "closed" tasks (i.e., completed) they contain. Researchers have considered closed tasks an important way to measure OSS projects' success (Crowston, Annabi, & Howison, 2003). Following Stewart and Gosain (2006), we operationalized our dependent variable, project performance, as the percentage of (percent tasks closed = (closed task requests / total task requests) x 100) or zero if projects did not have any requests. The proportion of closed tasks represents the degree to which the group addresses tasks that contributors bring to its attention and measures how well the group can garner developer resources to address project's needs, an important success indicator for OSS projects whose developers do not receive pay. This operationalization also concurs with other software development in the distributed context (Herbsleb & Mockus, 2003; Mockus, Fielding, & Herbsleb, 2002).

5.2.2 Independent Variables

In order to calculate measures for the independent variables, we differentiated identified contributions from anonymous contributions using contributors' user IDs. Although one can think of anonymity as a continuum, in this study, we focus on one specific aspect of anonymity on this spectrum: whether a user ID is associated with a contribution or not. Contributors can achieve a relatively high anonymity level if they do not include a user ID when they make a contribution. This approach concurs with the one that Forman, Ghose, and Wiesenfeld (2008) followed in studying anonymous reviews on Amazon and online sales. User IDs represent one of the most important cues in the OSS environment since they serve as the primary mechanism for reputation building because members can associate them with prior actions. If a person does not use a specific user ID, SourceForge associates the action with the tag "nobody", and we deem these contributions as coming from anonymous contributors (Crowston & Howison, 2003, 2005; Howison & Crowston, 2004; Yan, 2013). A contribution could be associated with the tag "nobody" because the contributor does not have a user ID or because they have chosen to not log in to maintain anonymity (Yan, 2013).

We calculated the anonymous to identified TR contribution ratio (anonymous TR ratio) by counting the number of tasks requests that the user ID "nobody" made and dividing that by the number of tasks requests that contributors with user IDs made (i.e., anonymous TR ratio = anonymous TR / identified TR). To

[2] http://spring-rich-c.sourceforge.net/1.1.0/index.html
[3] https://sourceforge.net/projects/heroarena/
[4] https://sourceforge.net/projects/transfog/

operationalize the anonymous to identified FDP ratio (anonymous FDP ratio), we summed the number of FDP that the user ID “nobody” made and divided that by the number of FDP that identified users made (i.e., anonymous FDP ratio = anonymous FDP / identified FDP). A post refers to a message that an OSS project participant wrote and that anyone can see. One or more posts make up a thread, and one or more threads make up public discussion forums.

To measure the application type, we used the intended audience field that the projects highlight based on the project’s goal on SourceForge. We coded projects focused on end users as 1 and 0 otherwise (Setia et al., forthcoming). Finally, we calculated measures for two additional control variables: we included 1) the number of developers since a larger overall number of participants may be associated with more activity and 2)the date the project registered on SourceForge in case a difference between projects that started at an earlier versus later date existed.

5.3 Descriptive Statistics

Table 1 presents descriptive statistics and intercorrelations for all research variables based on data about 611 projects, 15,766 FDP, and 7,458 TR. To provide some insight into the sample’s likely representativeness, we compared the descriptive statistics to the descriptive statistics in prior work. In our sample, projects had 7.62 developers on average (mean). The mean average represents a key statistic for OSS projects because developers constitute their main resource. Stewart and Gosain (2006) examined a smaller sample of 67 SourceForge projects in the communications or multimedia categories that had at least four developers and exhibited development activity in the last week. With these restrictions, they found that these projects had 8.25 developers on average (mean). Likewise, Krishnamurthy (2002) observed a restricted sample of 100 mature SourceForge projects that displayed the most activity. They found that these projects had 6.6 developers on average (mean). Thus, when considering the restrictions that we used to gather our sample compared to restrictions that prior studies used, we can see we found a similar number of developers per project.

We also considered the number of contributions from anonymous participants compared to the number of contributions from identified participants as a key statistic. In our sample, anonymous users submitted 18.3 percent of feature requests, 16.9 percent of defect reports, and 20.2 percent of FDP. Crowston and Howison (2003) reported that, in the projects they examined, anonymous submissions made up 15 percent of all messages on average (as low as 0% and as high as 50% for a few projects). We found similar findings to theirs. Further, our findings concur with findings for Wikipedia in that we found that registered users participated more actively than anonymous users (Kolbitsch, 2006).

Table 1. Descriptive Statistics and Intercorrelations

Variable	Mean	SD	1	2	3	4	5	6	7
1. Project performance (DV)	0.13	0.27	1						
2. Anonymous TR ratio	0.85	0.47	-0.35**	1					
3. Anonymous FDP ratio	0.84	0.4	0.18**	0.22**	1				
4. Application type	0.45	0.5	0.04	0	-0.10**	1			
5. Number of tasks open	11.38	38.26	0.32	-.29**	-0.18**	0.02	1		
6. Number of developers	7.62	5.68	0.15**	-0.11**	-0.07	0.03	.13*	1	
7. Register time (days)	11-27-04	107	-0.11**	0.14**	0.08*	-0.07	-.09*	-0.08	1
Note: * p < .10; ** p < 0.05; *** p < 0.01									

We used multiple moderated regression analysis (MMR) to test the research hypotheses. To ensure that the data satisfied the statistical technique’s underlying assumptions, we performed various analyses. We reduced skewness in the dependent variable, percentage of tasks closed, to the recommended level 1 through the square-root transformation. We centered all variables to reduce the possibility of multi-collinearity resulting from our including interaction terms to test the moderation hypotheses. The model variance inflation factors (all below 4) and the correlations between the independent variables suggest that the model did not have a problem with multi-collinearity. The residuals also suggest that the errors had a normal distribution. Our analytical approach concurs with Haans et al.’s (2016) recommendations and prior studies that have hypothesized curvilinear relationships (e.g., Mudambi & Schuff, 2010). Following Haans et al. (2016), we used a cross-sectional dataset to test curvilinear hypotheses that we developed using the between-theorization approach and accounted for individual heterogeneity using various control variables. Moreover, we tested the deepening effect specified as the moderation hypotheses using interaction terms (H3 and H4).

We present the MMR results in Table 2. Model 1 included only control variables. Model 2 included both linear effects and controls. Model 3 included the controls and linear and quadratic variables. Finally, Model 4 included the moderation effects. Because Model 4 produced the best results among the cohort, we rely on it when discussing our results.

Table 2. MMR Results

	Model 1	Model 2	Model 3	Model 4
Independent variables				
Anonymous TR ratio		-0.29**	-0.84**	-0.84***
Anonymous FDP ratio		-0.09**	-0.14*	-0.13**
H1: (anonymous TR ratio)^2			0.64**	0.58***
H2: (anonymous FDP ratio)^2			0.15*	0.16***
H3: application type * (anonymous TR ratio)^2				0.10**
H4: application type * (anonymous FDP ratio)^2				-0.06
Control variables				
Register time	-0.07	-0.03	-0.05	-0.06*
Application type	0.03	0.03	0.02	0.01
Number of open tasks	0.38**	0.28**	0.17***	0.17***
Number of developers	0.1**	0.08*	0.08**	0.08**
Model statistics				
R^2	0.17	0.27	0.42	0.42
Adjusted R^2	0.17	0.26	0.41	0.41
F	31.93**	36.77**	53.35**	43.38**
Note: * p < .10; ** p < 0.05; *** p < 0.01				

All coefficients related to hypotheses were significant except for the interaction between anonymous FDP ratio and application type. The main, quadratic, and interaction effects related to anonymous TR ratio were all significant. The results support both H1 and H2 and suggest that both anonymous TR ratio and anonymous FDP ratio have a curvilinear relationship with project performance.

We also found that application type altered the quadratic effect associated with anonymous TR ratio even though application type did not have a significant main effect. This result means that, while application type itself had no overall impact on project-performance levels, it did play a role in amplifying the curvilinear relationship between anonymous TR ratio and project performance (Szklo & Nieto, 2014). This finding supports H3. However, we did not find support for H4. To further highlight the significant interaction effect of H3, we graphically depict this relationship in Figure 2, which shows that projects that focused on developer-oriented applications had lower performance than projects that focused on end user applications at the turning point where the anonymous TR ratio neared balance (i.e., closer to one) and shifted slightly to the right (i.e., toward identified contributions). Thus, the developer-oriented applications had a deeper curvilinear relationship between anonymous TR ratio and project performance.

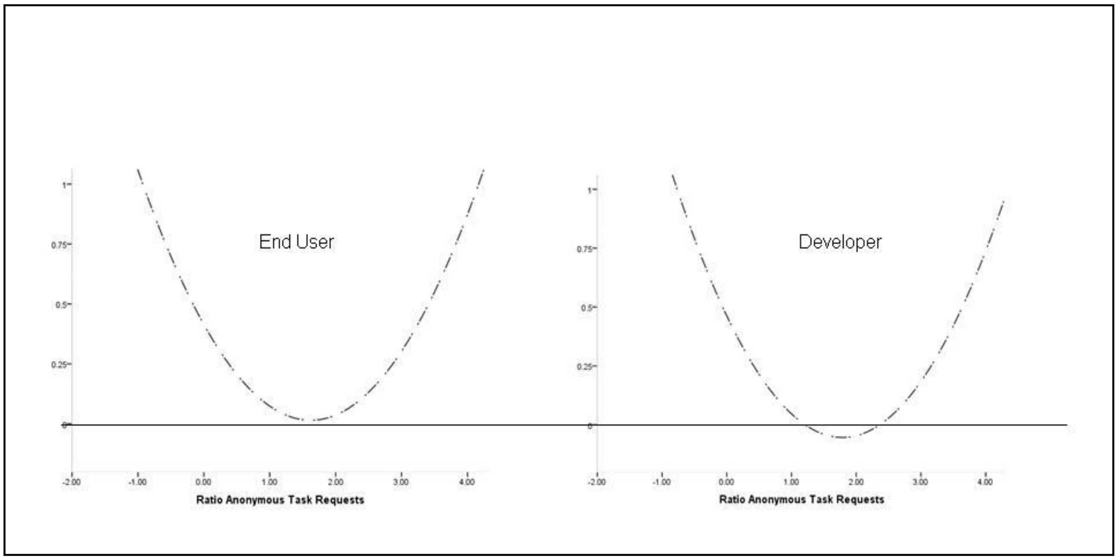

Figure 2. Interaction Effects

6 Discussion

Research that examines factors that lead to successful innovation has (until recently) overlooked the impact that APC has in group work because project contributors have typically been identifiable whether in traditional or virtual organizations. Although prior research has examined groups in which anonymous participants make all contributions, we do not clearly know how anonymity in OSS context affects outcomes. In this study, we examine the implications that APC have for peer production projects. To do so, we leverage the SIDE model to understand open, distributed innovation. We pay particular attention to contribution task and application types because software development represents knowledge-intensive work that requires individuals to coordinate to perform various tasks (Kraut & Streeter, 1995) and have the necessary expertise (Faraj & Sproull, 2000); thus, it differs from the tasks in typical SIDE studies based on lab experiments that place few interdependencies among group members (Postmes & Lea, 2000; Postmes & Spears, 2002; Reicher et al., 1995; Sassenberg, 2002). We expand the SIDE model to understand the impact of anonymity in the software-production process where developers and users can choose to contribute anonymously while converting ideas into a software application product through diverse tasks.

Our results indicate that, consistent with the SIDE model's basic premise, APC can enhance OSS project performance but that anonymity and performance have a complex relationship. In particular, we found that the ratio between APC and IPC had a curvilinear relationship with project performance, which the application type moderated. We found that positive project outcomes when a project had either a high number of APC or a lower number of APC across tasks requests and forum discussion posts. However, we found lower project performance when a project had a similar number of APC and IPC.

Further, our study suggests that the impact of anonymity depends on the type of innovation that serves as the basis for an innovation group's identity. A common goal to build a specific type of software application drives OSS communities. As such, the application an OSS community develops represents an integral part of its identity, and different application types can lead to different kinds of project identities. The classic SIDE model (Reicher et al., 1995), however, says little about how the social influence process may differ depending on the community's identity type, particularly in a knowledge-intensive environment. When a project has a knowledge-intensive identity, such as in software development, the tendency to identify more strongly with the group's identity due to social influence may be necessary but insufficient for the individual group member to act in a way that benefits the group's identity or common goal.

The findings concur with our argument that, in knowledge-intensive projects, the extent to which anonymity increases social influence depends on the common group identity's nature. Furthermore, we found that application type did not alter the curvilinear relationship between the proportion of anonymous to identified FDP (i.e., application type * (anonymous FDP ratio)^2 was not significant) possibly because forum discussions lack formality and strong ties to development action. Contributors who want to build their reputation may not think participating in forums will help build their identity, while they may think that making quality defect reports or feature requests could. For this reason, we surmise that developers may not act differently from other users when interacting on public forums.

6.1 Limitations and Future Research

We recognize this study's limitations and, consequently, its implications' boundaries. First, we focused on one cue about a contributor's identity: the contributor's user ID. However, one can use other cues such as language choice or communication style to infer participant identity as well (Anonymous, 1998; Pisonneault & Heppel, 1997; Rains, 2007a, 2007b; Rains & Scott, 2007). Furthermore, one can reveal someone's identity through other technical traces, such as IP addresses (Jackson et al., 2018; Kolbitsch, 2006; Forte et al., 2017). Therefore, the lack of user ID does not necessarily guarantee complete anonymity, although it does create a significant hurdle in revealing identity that one can overcome only with specialized methods. For OSS participants, a user ID represents the most transparent and practical way to reveal their identity. The user ID provides information about contributors' past behaviors and how those behaviors have impacted projects, their geographical location, and so on. It also likely represents the most obvious and easiest indicator of identity to individuals with whom they interact. Most importantly, one can compromise perceived anonymity when one links personal demographic information with publicly available records (Sweeney, Abu, & Winn, 2013).

Second, we largely focused on activities outside core development (e.g., defect reports, feature requests, and forum posts). Whether our findings extend to core development contributions such as patch submissions, code reviews, and commits needs additional research. Although focusing on peripheral activities limits our findings' applicability with respect to tasks related to creating source code, we focused on these activities because developers care more about building their reputation and may be less likely than end users to contribute code anonymously. The end user community, therefore, provides a more appropriate setting to observe APC and study their impact on project performance. Moreover, while development and peripheral activities certainly do not mutually exclude each other, they display distinct behavioral patterns and serve unique purposes (von Hippel, 2001). Peripheral activities often contribute unique knowledge that complements a developer's coding activities. By focusing on the impact of anonymity in peripheral contributions, we could draw specific conclusions that researchers can test in the development community in the future.

Third, we focus on projects that SourceForge supported and, therefore, our results apply more to typical projects hosted on similar websites. While SourceForge hosts a vast number of OSS projects, it does not host the largest projects. For example, it does not host Linux and Apache, and whether our results extend to these projects remains a topic for future research.

Fourth, we relied on the between-theorization method to test our hypotheses due to our data's cross-sectional nature. However, if one used panel data and fixed-effects models, one could conduct analyses based on the within-theorization approach to assess how performance varies as projects adopt strategies to alter the ratio between anonymous and identified contributions over time (Haans et al., 2016). Such an approach could provide stronger evidence regarding how projects may achieve the optimal level of anonymous contributions. Future research should use panel data and fixed-effect models to investigate these issues more deeply and obtain stronger conclusions about the long-term effects of peripheral contributions than our study's cross-sectional nature allows.

Fifth, while focused only on GNU-licensed projects to ensure that we limited the variation in project performance caused due to license choice (Stewart et al., 2006), we leave it to future research to assess whether our results generalize to other more permissive licenses.

Sixth, while we relied on the widely used cutoff of four developers for our sampled projects to ensure group dynamics (e.g., Hansen et al., 2011; Stewart & Gosain, 2006), it may be interesting to explore if the effects we observed differ significantly among projects with a different number of developers.

Seventh, while we hypothesized curvilinear effects, we need more research to determine the relationship's exact shape (i.e., whether it is U-shaped, logarithmic, exponential etc.) and how the turning point shifts when considering a broader set of factors such as project license, size, sponsorship, and development stage. Moreover, in our analysis, we focused on projects with volunteer developers. The OSS framework has evolved significantly in the last few years due to corporate interests. Many companies (e.g., Google, Microsoft) now pay developers to work on OSS projects alongside volunteer developers. Paid developers may change the nature of anonymous contributions because their work contracts may require them to use formal user IDs to make contributions. Thus, paid developers may choose to make anonymous contributions if they feel that their contributions violate employer contracts (Baskerville & Dulipovici, 2006). In addition, privacy concerns have magnified in recent years in the online domain. We believe that work that investigates factors that affect why developers choose to contribute anonymously in more detail could reveal whether the relationships we uncovered generalize to the new dynamics that characterize OSS.

Finally, our study also highlights other pressing questions. For instance, allowing APC could facilitate security threats in the form of malicious code, which could become a part of software applications. Issues around intellectual property and enforcing licenses are also complex and possibly intractable with anonymous contributors' participation. We leave it to future research to address these issues in more detail.

6.2 Research Implications

Studies that examine open, distributed innovation projects often exclude APC in their analyses (Crowston & Howison, 2003) and assume that APC lack reliability or relevance. Contrary to these prior assumptions, we found that APC can play a critical role in such projects. Our work offers multiple implications to that research area. In addition, our work has implications for the research on innovation management. We provide our study's implications for those two areas in Sections 6.2.1 and 6.2.2.

6.2.1 SIDE Model Implications

With this study, we make several theoretical contributions. First, we extend the SIDE model so that researchers can use it to explain the impact that APC have on innovation tasks in an open context in which contributors can freely decide whether they should remain anonymous when making a contribution. SIDE studies often focus on tasks in which the sole purpose concerns exchanging information to come to a consensus such as selecting a candidate for a job (Postmes & Spears, 1997). In typical experiments that researchers have designed to study the SIDE model, all contributors who interacted together have usually had the same anonymity level (Postmes & Spears, 1997). However, in many real-world contexts, individual contributors have the ability to determine whether they should remain anonymous (e.g., Wikipedia, GitHub, and SourceForge.) To connect the SIDE model to these increasingly common situations, we have to consider the impact of both individuals who remain anonymous and individuals who identify themselves when making contributions. By exploring many projects that have a different ratio between anonymous and identified contributors, we could leverage the SIDE model to explain performance across different conditions and connect it to these real-world contexts.

6.2.2 Implications for OSS Research

Our results indicate that one needs to understand participants beyond core developers to understand the various activities that developers perform. Prior research has focused on development groups' characteristics in trying to identify and describe the antecedents of developer activity (Daniel, Agarwal, & Stewart, 2013; Daniel et al., 2018a, 2018b; Daniel & Stewart, 2016). For instance, some studies have explored developer groups' relationships, license choice, and ideology (Stewart et al., 2006, Grewal, Lilien, & Mallapragada, 2006; Stewart & Gosain, 2006). In line with Setia et al. (2012), our results suggest that participants other than the core developers could also influence whether a project succeeds.

Future research should examine the impact of APC beyond individual OSS projects. OSS projects increasingly participate in what Feller, Finnegan, Fitzgerald, and Hayes (2008) refer to as "open source service networks" where various projects and firms collaborate to service customer needs with respect to OSS solutions. We need new theoretical development and empirical research to understand whether APC at various levels across different projects would influence the effectiveness of such service networks.

6.2.3 Managerial Implications

Our research has significant implications for managers who either oversee OSS projects or consider taking some projects to the OSS development style. Many managers feel hesitant about allowing APC as the following quote from SourceForge[5] illustrates:

[5] Note that the source no longer exists; hence, we cannot formally reference it.

> *The most common reasons for [disallowing anonymous contributions] are that the administrator feels an authenticated user community helps to strengthen the bond between the active users of their software (further helping to improve that software and its standing); or that project resources have been abused, in the past, and the administrator wishes to ensure that users of project resources are accountable for their postings.*

Our work suggests that, although many view anonymous group contributions as presenting new challenges, they can also present new opportunities for project managers.

Managers may also fear that anonymous contributors work for their competitors (Shaikh & Levina, 2019). Our research indicates that common fears about online anonymity's negative impacts may have their foundation in theories that do not necessarily pertain to the OSS-development context. First, although bonding and social attachments can add positive benefits to project members, they may not always translate into direct benefits towards a group's common goal. OSS projects thrive on group members' commitment to the project's common identity and goal to build software applications. However, OSS projects can obtain such commitment even if contributors have few cues about the identity of other contributors who make peripheral contributions.

Fears about vandalism and resource abuse (Davenport, 2002) concur with traditional deindividuation theories (Reicher et al., 1995). With our empirical findings, managers should feel more confident that, if they make sure that either identified or anonymous contributors make peripheral contributions, they can expect positive outcomes as long as most contributions come from either identified or anonymous contributors. However, performance can suffer if a project attracts a more balanced number of APC and IPC. If managers want to keep barriers to entry low for certain kinds of activities that benefit from the Internet's reach, it might be best to encourage a high proportion of anonymous peripheral contributions.

The decision to allow anonymous contributions can have broader impacts. As more industries consider adopting open source innovation (Wagner & Mahchrzak, 2007), organizations must carefully weigh the pros and cons of allowing APC (Wheeler, 2004). Our research makes the case for allowing APC strictly based on project performance. Institutional policies on anonymity, however, can have significant legal implications. For example, legal researchers have recommended making tools available for anonymous contributions based on amendment right to free speech (Bronco, 2004; Ford & Strauss, 2008). If an organization must accept APC by law, then our research suggests that its managers should make sure that it attracts either mostly identified contributions or mostly anonymous contributions.

7 Conclusion

In this study, we extended the SIDE model to better understand the impact that anonymity has on projects that seek to innovate in an open, distributed context. Specifically, we examined the impact that the ratio between anonymous and identified peripheral contributions has on OSS-development projects' performance. To do so, we developed hypotheses based on the unique aspects of the OSS-development context and the SIDE literature. We found that OSS projects had the lowest performance when they contain close to the same number of APC and IPC. However, project performance improved as the ratio became skewed such that most peripheral contributions came from either identified or anonymous contributors.

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