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The Impact and Evolution of Group Diversity in Online Open Collaboration

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Online open collaboration efforts, such as Wikipedia articles and open source software development, often involve a large crowd with diverse experiences and interests. Diversity, on the one hand, facilitates the access to and integration of a wide variety of information; on the other hand, it may cause conflict and hurt group performance. Although diversity's effects have been the subject of many studies in offline work groups (with the results remaining inconclusive), its effects in online self-organizing groups are underexplored. In this paper, we examine 648 WikiProjects to understand (1) how tenure disparity and interest variety affect group productivity and member withdrawal and (2) how the two types of diversity evolve over time. Our results show a curvilinear effect of tenure disparity, which increases productivity and decreases member withdrawal, up to a point. Beyond that point, productivity slightly decreases, and members are more likely to withdraw. In comparison, our results show a positive effect of interest variety on productivity and no significant effects on withdrawal. We also find that, over a project's life cycle, tenure disparity decreases and interest variety increases, with both converging toward the level that is optimal for group performance. Overall, our study highlights the importance of having diverse experiences and perspectives in online open collaboration and the power of self-organizing that helps groups evolve toward their high-performing zones. It also has practical implications on the design of collaboration tools and new forms of organizing work in traditional organizations.

Keywords: online open collaboration; self-organizing groups; diversity; group performance; Wikipedia
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1. Introduction

Computer technologies have enabled new forms of open collaboration in self-organizing groups on the Internet, as with Wikipedia and open source software projects. More recently, people have initiated online groups in many other domains to support collaborative creation of artifacts such as books (Open BookProject.net), maps (OpenStreetMap.org), teaching materials (cnx.org), and classification of galaxies (galaxyzoo.org). These online self-organizing groups perform a wide range of activities such as writing software, editing Wikipedia articles, creating teaching modules, providing user support, and designing innovative products and solutions (e.g., Lee and Cole 2003, Lih 2009, Nambisan and Baron 2010). Their success demonstrates the power of organizing collaborative work without traditional organizational structures (Shirky 2008). Existing research on online collaboration projects, such as open source software development and Wikipedia articles, highlights many factors that are crucial to the success of online self-organizing groups. These factors include motivation (Bryant et al. 2005, Roberts et al. 2006), governance structure (Butler et al. 2008, Markus 2007, Shah 2006), culture and ideology (Stewart and Gosain 2006), social structure and network ties (Daniel and Diamant 2008, Grewal et al. 2006, Hahn et al. 2008), and social identity and socialization (Bagozzi and Dholakia 2006, Ducheneaut 2005). These studies provide valuable insights into why individuals participate in online self-organizing groups and how individual efforts are organized and coordinated to accomplish group goals.

In the meantime, there has been limited research on the characteristics of the people who comprise the groups and how member attributes affect group performance (for exceptions, see Daniel et al. 2013, Giuri et al. 2010). Member attributes matter because they

affect how members work with one another and the effectiveness of their collaboration efforts (Mathieu et al. 2008). A key factor to consider is group diversity, which reflects the extent to which group members share similar or different attributes. Research in traditional organizations has linked group diversity to performance (Horwitz and Horwitz 2007, Williams and O'Reilly 1998), and recent work in open source projects suggests that it plays an equally important role in the success of online collaboration efforts (Daniel et al. 2013, Giuri et al. 2010). For example, Giuri et al. (2010) found a positive relationship between skill diversity and the performance of open source projects. Daniel et al. (2013) studied three types of group diversity respectively in contribution, languages spoken, and roles and found positive effects of role-based diversity on community engagement and market success of open source projects.

Despite recent progress, more work is needed to advance our knowledge of the effects of group diversity in online self-organizing groups, which may differ from those in offline work groups. For instance, Carte and Chidambaram (2004) suggested that the negative effects of diversity may be curtailed in teams mediated by collaborative technologies because of reductive capabilities such as visual anonymity and equality of participation. Similarly, the positive effects of diversity in these teams may be enhanced because of additive capabilities such as coordination support and electronic trial. Another distinctive feature of online groups is their self-organizing nature. Unlike work groups or virtual teams in organizations whose memberships are determined by organizational design and managerial oversight, diversity in online self-organizing groups is driven by members' voluntary participation. As a group grows and members of different experiences and interests join and leave the group, group diversity changes as well. Hence, we need to understand not only the effects of diversity, but also how diversity naturally evolves in these groups.

In practice, online self-organizing groups such as Wikipedia and open source projects provide platforms for groups of people to collaborate online to create artifacts of lasting value (Cosley et al. 2006) to the society or to a large community. The artifacts are being relied on for a wide variety of activities, including commercial activities, such as running major websites, and noncommercial activities, such as education and research from grade school through graduate school (Kane and Fichman 2009). Insights from our study will advance knowledge of conditions under which the "crowd" thrives in online collaboration to produce useful artifacts. In this article, we explore two research questions:

1. *How does group diversity affect the performance of online self-organizing groups*?

2. *How does diversity evolve over time in online self-organizing groups*?

We examine the two questions in the context of Wikipedia projects (referred to as WikiProjects hereafter). A WikiProject is an entity created within Wikipedia to help to coordinate and organize the writing and editing of a collection of pages devoted to a specific topic or family of topics[1] such as business, computer science, or Internet culture. We investigate the effects of two types of group diversity—tenure disparity and interest variety—on collaboration outcomes of 648 WikiProjects. We construct a longitudinal data set by quarter using the January 2008 full dump of English Wikipedia. At the beginning of each project quarter, we measure the extent to which members of a WikiProject differ in their time and experience as Wikipedia editors (tenure disparity) and the extent to which members differ in their domains of interest (interest variety). We then examine how the two types of diversity evolve over time and how they affect the amount of work that a project accomplishes and members' willingness to stay and contribute to the project in the quarter.

We find tenure disparity has curvilinear effects on productivity and withdrawal. Increased tenure disparity increases group productivity and decreases member withdrawal, up to a point beyond which productivity begins to decrease and withdrawal begins to increase. In comparison, we find only a positive, significant effect of interest variety on productivity. We also find that, over a project's life cycle, both types of diversity tend to converge toward the level that is optimal for group performance, with tenure disparity converging toward a moderate level and interest diversity converging toward a high level.

Our study makes several contributions to the management and information systems literature. First, the impact of diversity in online open collaboration is an important yet underexplored question (Daniel et al. 2013), and our study helps to fill this gap in the literature. Our findings, on one hand, confirm the importance of diversity in harvesting the "wisdom of crowds" in online collaboration and, on the other hand, suggest that the impact of diversity depends upon member attributes and the degree to which an attribute is accessible and salient online. More accessible attributes such as tenure tend to suffer a "ceiling" effect beyond which project productivity and member retention deteriorate, whereas less accessible attributes such as interests or expertise are immune to such effect. Second, our study of diversity in Wikipedia expands the diversity literature to a new context that is beyond traditional organizations and virtual teams. We test and confirm Carte and

[1] https://en.wikipedia.org/wiki/Wikipedia:WikiProject.

Chidambaram's (2004) theoretical propositions of the effects of diversity in computer-mediated groups. Our findings have design implications for the tools and processes through which member attributes become accessible or salient in online groups. Third, our findings on the dynamic evolution of diversity advance our understanding of the power of voluntary self-organizing. Although scholars and practitioners have written extensively about the power of online self-organizing groups, our study is among the first to show how the voluntary joining and leaving of members can move a project toward composition zones that are conducive to high performance. We also hope our findings will inspire new thinking in how project teams are managed in traditional organizations, especially regarding employee autonomy in joining and leaving project teams.

2. Literature Review

2.1. Diversity in Work Groups

Diversity in work groups is commonly defined as differences among individual attributes that will lead to the perception that others are different from the self (Van Knippenberg et al. 2004). The attributes can range from social demographic attributes such as age, gender, race, and nationality (Bayazit and Mannix 2003); to informational attributes such as tenure (O'Reilly et al. 1989), education (Dahlin et al. 2005), and functional areas (Van Der Vegt and Bunderson 2005); to deeper-level individual differences such as personality, values, and beliefs (Harrison et al. 1998). The extent to which a particular type of diversity affects performance often depends on two factors: visibility, the extent to which a difference is easily observable to group members, and job-relatedness, the extent to which a difference shapes perspectives or skills needed to perform cognitive tasks (Pelled 1996).

In spite of decades of research, the main effects of diversity in work groups remain largely controversial and inconclusive (see Van Knippenberg and Schippers 2007 and Williams and O'Reilly 1998 for reviews). Recent reviews have reached consensus that diversity tends to increase affective conflict and thus turnover and absenteeism (Milliken and Martins 1996, Williams and O'Reilly 1998). Individual differences in age, gender, race and ethnicity, and tenure have all been linked to increases in turnover. In comparison, the effects of diversity on cognitive task performance are less clear or, at best, mixed. Various studies of tenure or functional diversity have found positive, negative, or no effects on performance (Horwitz and Horwitz 2007, Milliken and Martins 1996, Williams and O'Reilly 1998).

The literature has agreed, however, upon two mechanisms through which diversity affects group performance and member satisfaction: the informational or decision-making perspective and the social categorization perspective (Van Knippenberg et al. 2004, Williams and O'Reilly 1998). According to the informational or decision-making perspective, heterogeneous groups should outperform homogeneous groups because the former have access to a broader range of knowledge, skills, abilities, and opinions and are thus able to consider more distinct information related to the task to come up with better decisions or creative solutions. According to the social categorization perspective, homogeneous groups should outperform heterogeneous groups because people use differences in social attributes as cues to categorize self and others into social groups and, as a result, they favor, feel more satisfied with, and have more positive evaluations when working with similar others than dissimilar others. This categorization process often results in subgroup dynamics (us versus them) and a high level of interpersonal conflict. The effects of diversity depend upon the interplay of the two mechanisms.

Recently, researchers have begun examining subgroup dynamics and possible moderators as ways to disentangle the puzzling effects of diversity on performance. Lau and Murnighan (1998) suggest that groups perform the worst not when every group member is unique, but rather when team members' differences create dividing lines, or "faultlines," that separate teams into distinct subgroups. Groups with moderate diversity experience more communication problems and relational conflicts and lower levels of team identity than groups with maximum diversity (e.g., Earley and Mosakowski 2000). Researchers have also examined moderators such as team processes, geographic distance, and team leader characteristics primarily in top management teams. Boone and Hendriks (2009) found functional background diversity to be beneficial to firm performance when collaborative behaviors, information exchange, and decentralization are high. Cannella et al. (2008) found that geographic separation impairs a team's ability to benefit from functional diversity when its members are located in different buildings.

2.2. Online Collaboration in Wikipedia Projects

Compared to offline work groups, online self-organizing groups such as Wikipedia and open source projects exemplify a different model of organizing work, i.e., a community-based one instead of a firm-based one (von Hippel and von Krogh 2003, Shah 2006). Most developers and editors contribute voluntarily. As a result, it is important to understand what motivates them and how they manage to coordinate the collective efforts. More than a decade of research has identified a wide array of factors that are crucial to their success. Interview and survey responses

reveal both intrinsic motivation, such as enjoyment, learning, and creativity (Lakhani and Wolf 2005), and extrinsic motivation, such as peer recognition, career concerns, personal use value, and money (Roberts et al. 2006). Other studies have examined factors like governance structure (Butler et al. 2008, Markus 2007, Shah 2006, Tiwana et al. 2014), social structure and networks (Grewal et al. 2006, Hahn et al. 2008, Kittur and Kraut 2008), and open source ideology or identification (Bryant et al. 2005, Stewart and Gosain 2006).

Few studies have examined the attributes of project participants and how group diversity affects project performance in online open collaboration such as Wikipedia and open source projects (see Chen et al. 2010, Daniel et al. 2013, Giuri et al. 2010 for exceptions). Insights from the Wikipedia and open source literature, however, illuminate the theoretical and practical value of understanding the impact of diversity in online collaboration. First, the open nature of online groups implies that projects can attract members with different levels of experience and interests. As a matter of fact, according to the "wisdom of crowds" argument, involving people with diverse backgrounds and perspectives is a necessary condition for the success of online open collaboration (Surowiecki 2004). Wikipedia article creation, similar to open source development, is a knowledge creation process where knowledge artifacts are continuously created, selected, and retained (Lee and Cole 2003, Ransbotham and Kane 2011, Kane et al. 2014). Diverse skills, interests, and experiences increase the spectrum of new content suggested, and the chance of finding and fixing errors through the critical review of many editors.

Second, although members with different perspectives and experiences are likely to fill different roles or perform different tasks, they are also likely to have different beliefs about project priorities and how work should be divided and coordinated. As a result, diversity poses challenges in online collaboration. Individual differences in experience and culture, when visible or accessible, can trigger perceptions of subgroups or "us" versus "them" (e.g., old-timers versus newcomers) that may cause conflict, delays in action, and member dissatisfaction. Research has shown that members with certain attributes such as newcomers (Suh et al. 2009) and women editors (Lam et al. 2011) are more likely to be "reverted"[2] in Wikipedia collaboration. Part of the reason may be that newcomers who join a project with a naive belief about the "egalitarian" nature of online collaboration are too eager to help and make changes that contradict or are inconsistent with the early work of old-timers. It may also be due to the fact that old-timers feel a strong sense of ownership that leads them to inappropriately exclude newcomers or discredit their edits (Suh et al. 2009, Thom-Santelli et al. 2009).

Third, existing literature also sheds light on the value of studying project growth and evolution over time. Only a few studies have examined the dynamic evolution of online collaboration efforts, exemplified by Darcy et al. (2010) who identified different patterns of evolution in project size and structural complexity in open source projects. Studies have also shown that, as open source communities grow in size, their code structure becomes more modularized and group structure becomes more decentralized (Crowston and Howison 2005). Analysis of open source developers' email suffixes shows that the demographic distribution of the community becomes more diverse over time, as measured by the dimensions of nationality and institutional affiliation (Lee and Cole 2003). These observations raise a number of interesting questions: does diversity always increase as projects grow? Is there an optimal level of diversity? How does the self-organizing nature of online groups affect their ability to benefit from and coordinate a diverse crowd? Our work takes the first step to begin to address these questions.

2.3. Diversity in Online Self-Organizing Groups

Although most research on diversity focuses on work groups in organizations or ad hoc groups in laboratories, the effects of diversity may differ in online groups supported by collaborative technologies (Carte and Chidambaram 2004). Three differences are worth noting: face-to-face versus computer-mediated communication, organizational hierarchy versus meritocracy, and closed and static versus open and fluid group membership (Martins et al. 2004).

First, members of online self-organizing groups are geographically dispersed and rarely meet in person. Due to visual anonymity (Carte and Chidambaram 2004), social cues such as a person's age, gender, and race may be less visible online than offline. So is information about tenure, education, and personal interests.[3] For example, tenure can often be inferred from an individual's physical appearance (e.g., gray hair), whereas such cues are not readily observable in online

[2] On Wikipedia, "Reverting means undoing or otherwise negating the effects of one or more edits, which results in the page being restored to a previous version" (http://en.wikipedia.org/wiki/Help:Reverting). To revert a change, an editor first clicks the history page to find an earlier version to which to revert. The editor can then edit this page and save it, and all changes made after the earlier version will be removed. A high percentage of reverts indicates a high level of controversy because editors cannot agree on the appropriate content for a page.

[3] Wikipedia includes unstructured user profile pages. Only approximately 20% of user profiles are populated. Of the populated user profiles, approximately 17% provided gender information, 29% listed birthday, and 25% listed interests (Le et al. 2010). The information is at least one click away if others are interested in learning more about a user.

environments. At the same time, visibility is not the only way in which individual differences can surface. Technology provides new ways for members to learn about one another, e.g., by checking one's user profile or work history (Carte and Chidambaram 2004). As a result, individual differences may not be readily visible but can still be accessed upon search or inquiry. These mixed effects make it difficult to extrapolate how individual differences will manifest and affect group outcomes in online collaboration. In general, the visibility of individual differences has a greater impact on the social categorization process than the information/decision-making process because the latter does not necessarily depend upon visibility to take effect (Pelled 1996). The impact of diversity hence depends on the degree to which individual differences are visible or accessible. When individual differences are less visible or accessible, the negative effects of diversity on group outcomes through social categorization are likely to be curtailed.

Second, compared with traditional work groups, online self-organizing groups are embedded in the context of a meritocracy rather than an organizational hierarchy. Status originates from a strong record of valuable contribution and peer recognition (Burke and Kraut 2008, Stewart 2005), instead of occupying hierarchical roles. Vertical authority over people gets replaced by lateral authority over tasks (Dahlander and O'Mahony 2011). Although core members—often a small set—may enjoy certain privileges (e.g., Wikipedia administrators), most members participate on an equal footing (Carte and Chidambaram 2004, Martins et al. 2004) and are less likely to be discouraged from sharing their unique perspectives for fear of losing their jobs or promotion opportunities. In addition, the asynchronous nature of online collaboration and the use of collaboration technologies can help members better coordinate their effort. For example, computer technologies enable members to engage in parallel processing so that more information can be generated and shared (Carte and Chidambaram 2004). Additive capabilities such as coordination support and electronic trial also enable members to track project progress and develop a collective memory of group norms, all of which should help the group tap into the diverse information possessed by its members. We thus expect that the positive effects of diversity on group outcomes through information/decision making are likely to be amplified in online open collaboration.

Third, compared to face-to-face work groups, online self-organizing groups have more fluid membership and lower entry and exit barriers (Faraj et al. 2011). Anyone who has the good will and interest to contribute can edit a Wikipedia article or join a WikiProject (unless there is evidence of vandalism). This difference should facilitate information/decision making by allowing new knowledge and perspectives to join group efforts, whereas its effects on social categorization are less clear. At the same time, fluid membership and computer-mediated communication make it hard for members to establish common ground or mutual knowledge (Cramton 2001, 2002). When conflict arises, members are more likely to make dispositional, rather than situational, attributions and blame one another. The low exit barrier makes it relatively easy for members to leave or stop contributing to the group effort when they are frustrated.

3. Research Hypotheses

3.1. Impact of Tenure and Interest Diversity on Performance

We examine group diversity along two dimensions: *tenure* in terms of the time that members have been with an online group and members' domains of *interest*. Tenure reflects the experience of being a group member and working on group tasks, and interests reflect the breadth of information and knowledge one brings to group efforts, both of which are crucial to making valuable contributions to group efforts. Both tenure and interests, when they become visible, can be used as social cues to interpret human behaviors (Pelled 1996, Williams and O'Reilly 1998).

Harrison and Klein (2007) classify diversity into three categories: *separation* captures differences among members in positions along a continuum, *disparity* captures differences among group members in their possession of valuable resources such as power or status, and *variety* captures differences among group members in different categories such as functional areas or domains of interest. Correctly categorizing a type of diversity is important, because it determines how the construct should be measured and interpreted. We choose to study *tenure disparity* because it considers both individual differences in tenure and the direction of the differences. Consider two five-person groups, one consisting of an old-timer with four newcomers (group A) and the other consisting of a newcomer and four old-timers (group B). If we ignore the direction of the differences and examine *separation* (as standard deviation), the two groups have the same level of separation. If we consider the direction of differences and examine *disparity* (as coefficient of variation or standard deviation over mean), group A has greater disparity than group B because the old-timer in group A is likely to have a greater impact on group dynamics than the newcomer in group B. We chose to study *interest variety* because interests, similar to educational and functional areas,

are categorical and each category reflects a unique source of information or perspectives.

We examined two group outcomes: group cognitive performance, measured as the amount of work accomplished, and group affective performance, measured as member withdrawal from contributing to group effort. Both measures have been widely used in offline work groups (Williams and O'Reilly 1998) and are meaningful in online self-organizing groups.

3.1.1. Effects of Tenure Disparity on Productivity and Withdrawal. High tenure disparity means high variability among group members in the time they have spent working on group tasks and in the experience they have accumulated as group members (Daniel et al. 2006, Pfeffer 1983). Reviews of the effects of tenure disparity on group cognitive performance have been mixed (Milliken and Martins 1996) although a recent review shows positive effects on the quantity and quality of team production (Horwitz and Horwitz 2007). There is also evidence suggesting that tenure disparity improves team processes in defining goals, developing work plans, and prioritizing work, which in turn improves team performance (Ancona and Caldwell 1992).

Evidence from traditional organizations and Wikipedia collaboration has shown that, although old-timers have the experience and skills to contribute, their effort or motivation is generally lower than that of newcomers (Pfeffer 1983, Wang et al. 2012). Having a mixture of newcomers and old-timers in online self-organizing groups thus ensures that the group has sufficient experience to establish and maintain task structure, yet enough new perspectives and information to complete the task. The creation of Wikipedia articles requires inputs at different levels, from high-level structuring (article structure) and administration work (fighting vandalism, resolving disputes) to low-level mundane tasks (editing, formatting, fixing typos). Newcomers often start with low-level, mundane tasks to learn about the community and to build their skill sets (Bryant et al. 2005, Ducheneaut 2005) and later move on to more challenging tasks. Kittur and Kraut (2008) show that Wikipedia articles benefit from having a subset of (experienced) editors structure the work before the large crowd joins to fill in the content and improve its quality. Similarly, Daniel et al. (2006) propose a synergistic effect that arises from the collaboration between newcomers and old-timers and a positive effect of tenure disparity on open source project performance.

At the same time, tenure disparity has been linked to reduced communication and social integration and increased conflict (Williams and O'Reilly 1998). When tenure disparity becomes extremely high, old-timers and newcomers may have drastically different views of the collaborative work, such as the scope or structure of an article. They may also differ in their familiarity with community policies (Bryant et al. 2005). Take Wikipedia as an example. Butler et al. (2008) found 44 pages under the category of "Wikipedia Official Policy" and 248 pages under "Wikipedia guidelines." It takes time for a newcomer to learn the policies and apply them properly. Ambiguities in the policies can lead to different interpretations and power play. Conflict between newcomers and old-timers often occurs as a result of disagreements on article scope and interpretations of Wikipedia policies. In high-conflict situations, old-timers may engage in defensive actions to vet or ignore the new information or perspectives that newcomers bring (Thom-Santelli et al. 2009). These defensive behaviors may deter newcomers from participating, and group productivity suffers. We thus posit the following.

Hypothesis 1. *There is a curvilinear relationship between tenure disparity and group productivity. Increases in tenure disparity lead to increasing group productivity, but with diminishing returns. Increasing tenure disparity beyond certain levels will decrease group productivity.*

There is consensus in the diversity literature that tenure disparity reduces social integration and increases member turnover (O'Reilly et al. 1989). Pelled (1996) found that tenure disparity leads to high levels of task-based conflict. Some studies have also found that, even when unsatisfied members do not leave, they are less willing to contribute effort and ideas to the group (Milliken and Martins 1996). As we mentioned earlier, although tenure may not be readily visible in online groups because of the lack of face-to-face contact, it can surface as members begin interacting with one another or be inferred from profile pages or work histories. Because of their lack of familiarity with the history of an article and Wikipedia policies, newcomers may make changes that are inconsistent with prior decisions. When old-timers and newcomers disagree or get into an "edit war," tenure is often cited by the old-timers to attack or discredit the newcomers. Kriplean et al. (2007) described several disputes between Wikipedia newcomers and old-timers. In one case, an old-timer made the following comment to a newcomer: "We DID write an article just on the scientific theory of . . . before you showed up . . . You're obviously new here . . . arguing based on your reading of NPOV and Be bold is a bit ridiculous, like a kid just out of high school arguing points of constitutional law. . . . People who have been here for years understand them much better than you do. They won't prove effective weapons for you to wield in this argument" (p. 7). These negative responses, including having one's work reverted, can be very demotivating and can drive editors away. The effects

are stronger and longer-lasting on newcomers when their work is reverted by more experienced editors (Halfaker et al. 2011). We thus posit the following.

Hypothesis 2. *There is a curvilinear relationship between tenure disparity and member withdrawal. When tenure disparity is low, increasing it does not increase member withdrawal. When tenure disparity goes beyond certain levels, increasing it increases member withdrawal, at an accelerating rate.*

3.1.2. Effects of Interest Variety on Productivity and Withdrawal. Interest variety in online self-organizing groups is similar to educational or functional diversity in offline work groups. We define interest as topics or categories about which editors care and to which they have passion for contributing. Wikipedia organizes all articles under eight categories: *Arts*, *Geography*, *Health*, *History*, *Science*, *People*, *Philosophy*, and *Religion*. Writing many of the articles requires knowledge from more than one category. For example, an article about a city in the United States needs to cover the city's geography, history, people, etc. The creation of a high-quality article requires the search and acquisition of information from multiple sources as well as proper structuring and integration of the information. Collectively, members decide what information is relevant and how to integrate and organize the information. Having members with diverse interests increases the range and depth of information that the group can access and act upon (Dahlin et al. 2005).

The effects of expertise or functional diversity in offline work groups have been examined primarily within the context of management teams (Mathieu et al. 2008). Its effects are somewhat equivocal, with most studies finding a positive relationship between diversity and performance (Boone and Hendriks 2009, Cannella et al. 2008). Daniel et al. (2013) examined role-based diversity in open source projects, which approximated functional diversity in work groups, and found it to be positively related with project market success. Recent research suggests that the effects may be curvilinear (Dahlin et al. 2005, Earley and Mosakowski 2000). For instance, Van Der Vegt and Bunderson (2005) found an inverted U-shaped relationship between expertise diversity and team performance. We expect a similar relationship between interest variety and productivity in online collaboration. An initial increase in interest variety increases the breadth of information that members contribute to the collaboration effort and improves group productivity. When interest variety goes beyond certain levels, the many different interests or perspectives are likely to cause disagreement and conflict over article scopes or how to combine and reconcile the different perspectives. Group members may become overwhelmed by the amount of information and fail to integrate effectively (Williams and O'Reilly 1998) and, as a result, group productivity suffers.

Hypothesis 3. *There is a curvelinear relationship between interest variety and group productivity. Increases in interest variety lead to increasing group productivity, but with diminishing returns. Increasing interest variety beyond certain levels will decrease group productivity.*

Research on functional diversity has primarily focused on its cognitive impact and overlooked its effects on affective outcomes. Only a few studies have examined the effects of educational or functional diversity on member withdrawal. Some suggest being different from one's colleagues in terms of educational backgrounds increases turnover in top management teams (Milliken and Martins 1996). Others show that functional diversity reduces group cohesion and increases conflict in traditional work groups (Williams and O'Reilly 1998) and in global virtual teams (Kankanhalli et al. 2007). In the context of online open collaboration, we suspect that the impact of interest variety on member withdrawal is similar to the impact of tenure disparity. When interest variety is low, individual differences are not readily visible and less likely to become salient, because of the extra effort required to retrieve the information. When interest variety becomes high, there is a greater chance for it to cause disagreement and conflict. According to Kriplean et al. (2007), arguments over article scopes can originate from both differences in experience and differences in interest. Members whose work or perspective gets discredited by other editors are likely to stop contributing. We thus posit the following.

Hypothesis 4. *There is a curvilinear relationship between interest variety and member withdrawal. When interest variety is low, increasing it does not increase member withdrawal. When interest variety goes beyond certain levels, increasing it increases member withdrawal, at an accelerating rate.*

3.2. Evolution of Tenure Disparity and Interest Variety Over Time

Two streams of research shed light on how diversity may evolve over time in online self-organizing groups. The first stream is organizational demography theory. Pfeffer (1983) argues that demographic distributions in organizations are determined by growth in employment and personnel policies related to the selection and retention of employees. Hiring, voluntary quitting, and forced resignations can all affect the distribution of tenure and other attributes in organizations. The second stream is the attraction-selection-attrition (ASA) framework (Schneider et al. 2006). Its general proposition is that over time organizations become relatively homogeneous with regard

to the kinds of people in them as a result of three processes: the *attraction* of people whose attributes are congruent with the culture of the organization, the *selection* of people with attributes the organization desires, and the *attrition* process during which people who do not fit the organization leave. All three processes occur in online self-organizing groups (Butler et al. 2014). An online group tends to attract members who have similar goals or interests. Prospective members can observe community activities (e.g., project goals, member list on the project page) to determine whether there is a good fit between their interests and the group's goals before they join (Preece and Shneiderman 2009). After a member joins a group, there is mutual selection between the group and the member as to whether the membership shall continue. Attrition happens when members who do not fit in the group or who perceive a mismatch between their goals and what the group provides leave. Although members may leave a group for various reasons, research has shown that members who are dissimilar from others are more likely to leave (Wang et al. 2012). Diversity is therefore shaped by the joint working of the three processes, and we expect it to decrease over time.

Hypothesis 5. *Tenure disparity and interest variety in online self-organizing groups decrease over time.*

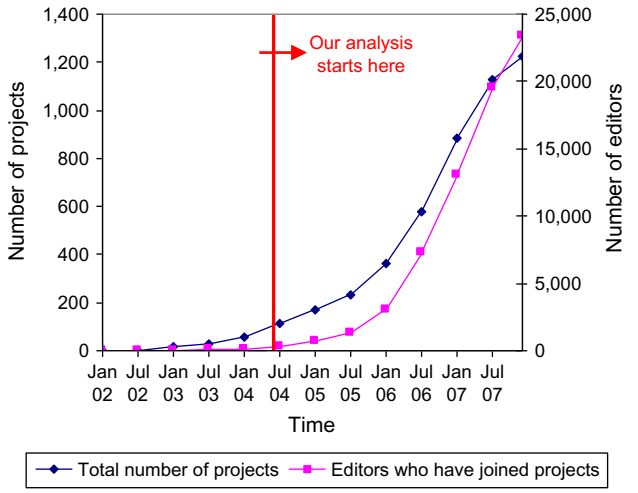
4. Methods

4.1. Research Setting: WikiProjects

A WikiProject is a collection of pages devoted to the management of a specific topic or family of topics within Wikipedia and, simultaneously, a group of editors who use those pages to collaborate on encyclopedic work. Figure 1 shows that since 2002 more than 20,000 Wikipedia editors have joined more than 1,000 projects. In this study, we focus on topical WikiProjects,[4] which are created to improve articles within a topic area (e.g., Business, Computer Science, or Internet Culture). Topical WikiProjects play an important role in coordinating the writing of articles by identifying missing articles or articles that need work, by providing peer review to improve article quality, and by aligning articles in the same topic areas to the same style of writing. We focus on topical projects because they share similar goals and it is meaningful to compare them in terms of diversity and productivity.

WikiProjects provide a good setting for our study of diversity in online open collaboration for several reasons. First, most WikiProjects manage their membership using a member list where members can sign or remove their names, which allows us to identify members of a WikiProject. Second, WikiProjects are analogous to work groups in terms of having clear goals and organized activities to meet those goals. They are analogous to other online collaboration efforts, such as open source projects, in terms of voluntary participation and self-organization, so that our findings can be generalized. Third, Wikipedia archives provide rich historical data that we can analyze to measure individual tenure and interests, membership changes, and project performance over time.

Figure 1 (Color online) Timeline of WikiProjects in Wikipedia



Notes. The *x* axis is the time from the beginning of WikiProjects to the time when the dump used in this research ends. The left *y* axis is the number of projects in Wikipedia. The right *y* axis is the number of editors who have joined WikiProjects.

The activities of a WikiProject center on its main page. Figure 2 shows the main page of "WikiProject Internet Culture'' as an example. It states the scope and goals of the project; a list of the members of the project; a list of tasks to be done; and templates, tools, and other resources for members.

4.2. Data Collection

The data set we use in this study is extracted from the January 2008 dump[5] of English Wikipedia. To gather our sample of projects, we traversed from the main directory page of WikiProjects and excluded projects that are not topical. We also excluded projects that never grow to have at least three members (the minimal size of a group), projects that do not have a member list, and projects whose scope cannot be estimated

[4] Other, nontopical projects are created to organize internal Wikipedia processes, such as categories, help systems, and portals, or to perform maintenance work such as citation and grammar cleanup, user recognition, and improvement of policy and guideline pages.

[5] The people who run Wikipedia produce periodic dumps that include the complete text of all articles and talk pages, including their complete edit history, from the beginning of Wikipedia. The English-language dumps are available from http://download.wikimedia.org/enwiki/.

Figure 2 (Color online) Screenshot of the Main Page of WikiProject on Internet Culture

Source. https://en.wikipedia.org/wiki/Wikipedia:WikiProject_Internet_culture.

using categories. In the first two years of Wikipedia, the level of activity in WikiProjects was very different from more recent years, with a small number of projects and editors involved (see Figure 1). We therefore excluded projects created before June 2004. Further analysis excluded 33 projects with missing data or outlying performance. Our final data set has 648 WikiProjects.

We created a longitudinal data set in which each observation records the characteristics, composition, and performance of a project for each quarter in its life span. The level of analysis is *project quarter*.[6] Each project quarter is a 90-day period in a project's life span with the first quarter beginning after its creation date. Take WikiProject *Internet Culture* as an example. Its first record is the first 90-day period following its date of creation, the second measures the second 90-day period, and so on, until the end of the dump at the end of 2007. Our final data set includes 3,619 project quarters from 648 projects.

We estimated the scope of a WikiProject (i.e., what articles fall under the project) by finding the Wikipedia category that matches its title (like category *Science* for *WikiProject Computer Science*) and finding all articles that fall under that category.[7] We traversed through all subcategories of the matched category down to the fourth level and considered all articles in those categories to be within the scope of the WikiProject.[8] We used historical edits of a project's member list ("Members" as shown in Figure 2) to identify members of each WikiProject. In Wikipedia, any editor can join a project by adding his or her username to the member list, and later leave the project by removing the username. Occasionally members who

[6] We chose quarter as the time period because it is small enough to capture major changes in behaviors such as withdrawal from project efforts yet large enough to filter out noise. Our sensitivity analysis showed that members who were inactive for 90 days would rarely return, meaning it provides a reliable measure of member withdrawal.

[7] We also considered an alternative measure, *claimed scope*, by including articles whose talk pages link to the WikiProject, a way for projects to claim articles in their scope. Because claiming articles is a manual process, the claimed scope grows inconsistently over time for different projects, and projects frequently work on articles that they do not bother to claim. Overall, claimed articles appear to be a serious underestimate of scope. Hence we estimated the scope of projects using categories, which seemed a more reliable measure to compare scope across projects.

[8] We only traverse to the fourth level because the Wikipedia subcategory structure is not a hierarchy, but a more general graph structure. Through experimentation we discovered that traversing four levels covers most meaningful subcategories without reaching many problematic links.

are considered inactive are removed from the list by other members.

4.3. Dependent Variables

Group Productivity ($PRODUCTIVITY_{it}$): We measured group productivity by the amount of work—total number of edits—done by the members of a WikiProject on articles within the scope of the project in the current quarter. We repeated our analyses with an alternative measure—the number of words added by members to articles within the scope—and our main results remain qualitatively the same.

Member Withdrawal ($WITHDRAWAL_{it}$): We measured member withdrawal by the number of people who were active members in the previous quarter but removed their names from the member list or stopped contributing in the current quarter. We considered a member to be active for a quarter if the person had at least one edit to an article within the project scope, the talk page of such an article, any of the project organization pages, or the user pages or user talk page of any other project member during that quarter.

4.4. Independent Variables

Tenure Disparity ($TENURE_{it}$): We measured tenure disparity using the coefficient of variation of the tenure of all project members. Coefficient of variation is a widely used measure of tenure disparity in past research (Bedeian and Mossholder 2000, Harrison and Klein 2007). If we denote each member's tenure as T_i and the mean tenure over n members as T_{mean}, the coefficient of variation can be calculated using the following formula (Harrison and Klein 2007):

$$\left[\sum (T_i - T_{mean})^2 \Big/ n\right]^{1/2} \Big/ T_{mean}.$$

Table 1 shows six scenario projects of five members with various levels of tenure disparity. The highest level of tenure disparity occurs when a project has a highly experienced old-timer working with some brand-new members (scenario 6), i.e., when the project has one member at the highest endpoint of the tenure continuum and others at the lowest. The lowest level of tenure disparity occurs when all members cluster at the middle of the continuum (scenario 1). A moderate level of tenure disparity occurs when a project has its members evenly distributed across the tenure continuum—a balanced mixture of members with low, medium, and high levels of experience with the site (scenarios 3 and 4).

We measured tenure as the number of days elapsed from a member's first edit in Wikipedia to the end of a quarter (*Wikipedia Tenure*). We explored two alternative measures: how long an editor has been a member of a specific WikiProject (*WikiProject Tenure*) and how many edits an editor has performed (*Total Edits*). We preferred *Wikipedia Tenure* over *WikiProject Tenure* because *Wikipedia Tenure* is more visible to other editors than *WikiProject Tenure*. Experience with Wikipedia as a whole transfers readily to work on individual projects. For instance, editors who have learned how Wikipedia policies work can apply those policies in discussions within any WikiProject. We preferred *Days Since Joining* over *Total Edits* because it captures both experience from editing articles and experience from observing the work and interactions of other editors (Ducheneaut 2005). It is a common measure of tenure in open source research (Dahlander and O'Mahony 2011) and Wikipedia (Zhang and Zhu 2011) research. Our results remained qualitatively the same using the alternative measures. We report our findings using *Wikipedia Tenure*.

Table 1 Scenario Projects with Various Levels of Tenure Disparity (Tenure Measured as Days)

	Member 1	Member 2	Member 3	Member 4	Member 5	Tenure disparity
Scenario 1	699	750	830	790	900	0.10
Scenario 2	200	300	320	378	400	0.28
Scenario 3	90	200	300	450	500	0.55
Scenario 4	90	120	400	600	720	0.73
Scenario 5	90	300	400	600	1,200	0.82
Scenario 6	90	120	180	200	1,200	1.32

Interest Variety ($INTEREST_{it}$): We measured interest variety using Blau's index because interest is a categorical variable (Harrison and Klein 2007). We first composed eight top-level interest areas from the categorical index portal of Wikipedia: *Arts*, *Geography*, *Health*, *History*, *Science*, *People*, *Philosophy*, and *Religion*. Then, following a procedure similar to Kittur et al. (2009), we assigned a Wikipedia article to an interest area if the article was closest to the top-level category of the interest area in the subcategory structure. For example, article *Computer Science* is in category *Computer science*, which is a third-level subcategory of *Science* (through *Science*, *Scientific disciplines*, *Applied sciences* to *Computer science*), closer than all other top-level categories, and was thus assigned to be in the area of *Science*. An article can be assigned to more than one interest area if it is equally close to several top-level categories. In these cases, we split the number of edits of an editor equally to the multiple interest areas. For example, if an editor had done 10 edits of an article (e.g., *Manhattan Project*) that falls in the categories of *Science* and *History* we considered the editor has done 5 edits in *Science* and 5 edits in *History*.

We classified a Wikipedia editor as being interested in an area if that editor had done more than 10 edits on articles in that area and those edits comprised at least 25% of all edits that editor had made in Wikipedia. Using these criteria, we assigned 24.25%

of the editors in our data set to no interest area, 51.45% to one interest area, 23.48% to two interest areas, and only 0.83% to three or more areas. Our results remained qualitatively the same using 20 edits or 20% as the cutoff. For a particular project quarter, we calculated interest variety by counting the number of project members in each interest area. If we denote the percentage of members in an area as P_i, Blau's index can be calculated as follows (Harrison and Klein 2007):

$$1 - \sum P_i^2.$$

The highest level of interest variety occurs when a project has members with interests evenly distributed in all categories (Harrison and Klein 2007). The lowest level of interest variety occurs when all members share the same interest in one area. A moderate level of interest variety occurs when a project has its members with interests in some of the categories—some unique and some overlaps.

4.5. Control Variables

Quarter Index ($QUARTER_{it}$): We measured time in quarters (90-day periods), starting with quarter 0 from the moment the project was created, until the last full quarter before the end of 2007.

Project Size ($SIZE_{it}$): We measured the size of the project as the number of project members during the current quarter.

Project Scope ($SCOPE_{it}$): We measured the scope of the project as the number of articles falling under the project scope during the current quarter. Scope, determined by the structure of the category hierarchy in Wikipedia, changed slowly. Most changes involved new articles being added to the project's scope.

Project Creation Quarter ($CREATION_i$): We measured the creation quarter of the project as the number of quarters (90-day periods) from January 2002 to the date the project was created. A larger number means the project was created later. Because of the sheer increase in the number of projects and participating editors over time, we suspect that projects created later may face a different environment than projects created earlier.

Level of Controversy ($CONTROVERSY_{it}$): We measured the level of controversy as the percentage of reverts[9] in all edits on articles within the project scope during the current quarter, normalized by the overall percentage of reverts in Wikipedia over the same period of time. Reverting other editors' edits is a common expression of conflict and controversy within Wikipedia (Kittur et al. 2007). This measure counts reverts done by all editors working on the articles within the scope of a project, instead of only project members (a small portion of all editors). It controls for effects caused by controversy that is inherent in the project's subject matter.

[9] For a definition of "revert," see Footnote 1. A high percentage of reverts indicates a high level of controversy, because editors cannot agree on the appropriate content for a page.

4.6. Hierarchical Linear Model (HLM) Analysis

Our data are nested in nature—quarters nested within projects—so we analyzed the data using HLMs (Bryk and Raudenbush 1992). We first specified an unconditional linear growth model with only intercept and the quarter index. We then added project-level control variables such as size, creation quarter, scope, and level of controversy. Finally, we added our independent variables, tenure disparity and interest variety, and their quadratic terms. Building the models incrementally enabled us to test whether adding more predictors leads to better model fit (Kreft and de Leeuw 1998). We specified the following equations to test our hypotheses:

$$PRODUCTIVITY_{it} = \pi_{0i} + \pi_{1i} * QUARTER_{it} + \gamma_{it},$$

$$\begin{aligned}\pi_{0i} = {} & \beta_{00} + \beta_{01} * SIZE_{it} + \beta_{02} * SCOPE_{it} \\ & + \beta_{03} * CREATION_i + \beta_{04} * CONTROVERSY_{it} \\ & + \beta_{05} * TENURE_{it} + \beta_{06} * INTEREST_{it} \\ & + \beta_{07} * (TENURE_{it})^2 + \beta_{08} * (INTEREST_{it})^2 + \mu_{0i},\end{aligned}$$

$$\pi_{1i} = \beta_{10} + \mu_{1i},$$

$$WITHDRAWAL_{it} = \pi_{0i} + \pi_{1i} * QUARTER_{it} + \gamma_{it},$$

$$\begin{aligned}\pi_{0i} = {} & \beta_{00} + \beta_{01} * SIZE_{it} + \beta_{02} * SCOPE_{it} \\ & + \beta_{03} * CREATION_i + \beta_{04} * CONTROVERSY_{it} \\ & + \beta_{05} * TENURE_{it} + \beta_{06} * INTEREST_{it} \\ & + \beta_{07} * (TENURE_{it})^2 + \beta_{08} * (INTEREST_{it})^2 + \mu_{0i},\end{aligned}$$

$$\pi_{1i} = \beta_{10} + \mu_{1i}.$$

Table 2 presents the main statistics of variables used in the analysis before grand mean centering and log-transformation. We log-transformed (base 2) our dependent variables and two independent variables—project size and project scope—because they were all highly skewed to the right. For ease of interpretation, we performed grand mean centering for all predictor variables except creation quarter. Grand mean centering also reduced multicollinearity between main effects and quadratic terms. We fit the models using PROC MIXED in SAS (Littell et al. 1996).

We conducted a number of diagnostic analyses (Belsley et al. 1980) to check for homoscedasticity, normality, multicollinearity, and outliers. Influence analysis identified 33 projects as potential outliers and we excluded them from our data. Residual analysis showed signs of autocorrelation and heteroscedasticity. We adjusted model specification to estimate different variances over time and different variances

Table 2 Descriptive Statistics and Correlations

	Mean	SD	1	2	3	4	5	6	7	8
1. Group productivity	1,210	1,658								
2. Member withdrawal	3.681	4.741	0.469***							
3. Quarter	3.109	2.743	0.167***	0.210***						
4. Project size	21.40	27.18	0.520***	0.852***	0.405***					
5. Project scope	18,622	65,126	0.148***	−0.044*	0.092***	−0.023				
6. Project creation	16.66	3.121	0.045**	0.009	0.568***	0.126***	−0.057***			
7. Level of controversy	1.104	0.414	0.001	0.033+	0.035*	0.048**	0.031+	0.085***		
8. Tenure disparity	0.554	0.189	0.25***	0.284***	−0.099***	0.164***	−0.016***	0.129***	−0.005	
9. Interest variety	0.591	0.197	0.259***	0.322***	0.128***	0.327***	−0.016	0.136*	−0.055***	0.343***

Note. $N = 2{,}971$ for withdrawal and $N = 3{,}619$ for all other variables.
$^{+}p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

and covariances across projects. Our results remained unchanged after the adjustments. Even after grand mean centering, the inclusion of both the linear and quadratic terms of interest variety pushed the variance inflation factor (VIF) over 4 and tolerance below 0.25, together with changes in the sign and significance of the predictors (Belsley et al. 1980). Further analysis showed that adding the quadratic term did not significantly improve model fit for interest variety. We therefore excluded the quadratic term of interest variety from further analysis. Multicollinearity analysis revealed no issues with other variables.

5. Results

5.1. The Impact of Diversity in Online Open Collaboration

Table 3 presents the four models predicting group productivity. We assessed model fit using two indices. For each pair of models, we first examined the differences between the deviance statistics (Δdev), which is twice the negative log-likelihood and has a chi-square distribution with the number of parameters between models as the degree of freedom (Kreft and de Leeuw 1998). Due to the large sample size, we also examined the Bayesian information criterion (BIC), which punishes models with a large number of parameters (Burnham and Anderson 2004). Smaller values suggest a better model fit, and a difference of −10 or greater strongly favors the more complex model over the simpler one.

Model comparisons suggest that model 4 had a better fit than the simpler models, so we interpreted its results to test our hypotheses. The intercept suggests that members of an average project performed $2 \wedge 9.788 = 884$ edits in its first quarter. All control variables had significant effects on project productivity. On average, projects earlier in their life span, with more members, of a larger scope, or dealing with a less controversial topic were more productive. The positive coefficient 0.771 of project size suggests that a 10% increase in project size resulted in $1.10 \wedge 0.771 = 1.076$ times or a 7.6% increase in productivity. The negative coefficient of quarters suggests that the total number of edits became $2 \wedge -0.256 = 83.7\%$ of the previous quarter, or that project productivity decreased by approximately 16.3% each quarter over time.

Hypothesis 1 posits that high tenure disparity leads to high productivity with diminishing returns. Our results supported the hypothesis. Model 4 revealed a positive effect of tenure disparity ($\beta = 2.009$, $p < 0.001$) and a negative effect of its quadratic term ($\beta = -3.537$, $p < 0.001$). The signs of the two coefficients suggest a curvilinear relationship, as depicted in Figure 3. When tenure disparity was low, it was

Table 3 HLM Results Predicting Group Productivity (Log2 Transformation)

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	8.429*** (0.105)	9.669*** (0.418)	9.559*** (0.421)	9.788*** (0.421)
Quarter	0.08*** (0.02)	−0.347*** (0.024)	−0.247*** (0.024)	−0.256*** (0.024)
Project size (log2)		1.061*** (0.044)	0.799*** (0.048)	0.771*** (0.048)
Project scope (log2)		0.396*** (0.021)	0.385*** (0.021)	0.387*** (0.02)
Project creation quarter		−0.074** (0.024)	−0.071** (0.024)	−0.078*** (0.023)
Level of controversy		−0.451*** (0.109)	−0.41*** (0.107)	−0.401*** (0.106)
Tenure disparity			2.205*** (0.243)	2.009*** (0.245)
Interest variety			1.723*** (0.309)	1.536*** (0.31)
Tenure disparity squared				−3.537*** (0.665)
Interest variety squared				
−2 log-likelihood	13,980.9	13,282.7	13,060.3	13,032.4
Deviation (ΔDev)		−698.2***	−222.4***	−27.9***
BIC	14,110.3	13,438.1	13,228.6	13,207.2
ΔBIC		−672.2	−209.5	−21.4
N	3,619	3,619	3,619	3,619

$^{**}p < 0.01$; $^{***}p < 0.001$.

Figure 3 (Color online) Effects of Tenure Disparity on Project Productivity and Member Withdrawal

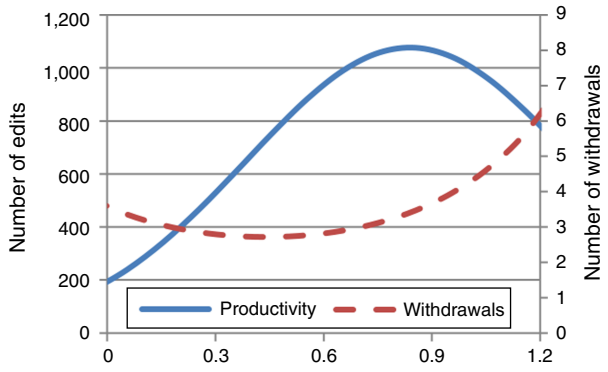
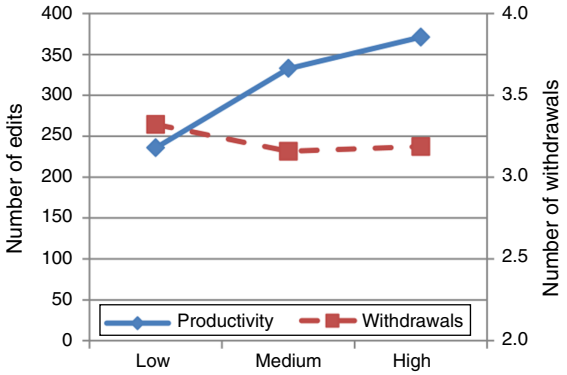


Figure 4 (Color online) Effects of Interest Variety on Productivity and Withdrawal



positively related to productivity. An increase of 0.1 in tenure disparity led to a 14.9% increase in productivity. After tenure disparity went above 0.8, further increases decreased productivity.

Hypothesis 3 posits that high interest variety leads to high productivity with diminishing returns. Model 4 revealed a positive effect of interest variety ($\beta = 1.536$, $p < 0.001$). An increase of 0.1 in interest variety led to an 11.2% increase in project productivity. The quadratic term of interest diversity was excluded because of multicollinearity concerns. So, we recoded interest variety into a categorical variable to examine the hypothesized nonlinear effects. We classified projects with interest variety below 0.33 as low interest variety, between 0.33 and 0.66 as medium interest variety, and above 0.66 as high interest variety.[10] Compared to projects with low interest variety, projects with medium interest variety performed 41% more edits ($\beta = 0.496$, $p < 0.001$), and projects with high interest variety performed 57.4% more edits ($\beta = 0.654$, $p < 0.001$). There was no significant difference between projects with medium and high interest variety ($p = 0.09$). Overall, the results suggest a ceiling effect, as shown in Figure 4. Increasing interest variety from low to medium significantly increased group productivity, yet increasing interest variety from medium to high caused group productivity to level off. Hypothesis 3 was supported.

Table 4 presents the four models that predict member withdrawal. The models are parallel to the four models in Table 3. Again, Model 4 had a better fit than the simpler models. In general, projects earlier in their life span, with more members, or of a smaller scope, had higher member withdrawal. Interestingly, level of controversy did not have any significant effects on withdrawal. The positive coefficient 0.747 of project size suggests that a 10% increase in project size resulted in $1.10 \wedge 0.747 = 1.074$ times or a 7.4% increase in the number of members who stopped contributing to the project. The negative coefficient of quarters suggests that the number of members who stopped contributing became $2 \wedge -0.073 = 95\%$ of the previous quarter or decreased by 5% each quarter over time.

Hypothesis 2 posits a curvilinear relationship between tenure disparity and member withdrawal in the sense that tenure disparity beyond certain levels increases member withdrawal. Model 4 in Table 4 revealed a positive effect of tenure disparity ($\beta = 0.47$, $p < 0.001$) and a positive effect of its quadratic term ($\beta = 2.051$, $p < 0.001$). The results supported Hypothesis 2. The curvilinear effect is shown in Figure 3. Projects with a low to moderate level of tenure disparity, between 0 and 0.8, had relatively low levels of member withdrawal. When tenure disparity went above 0.8, the number of members who withdrew from group activities increased substantially.

Hypothesis 4 posits a similar curvilinear relationship between interest variety and member withdrawal. Model 4 revealed no significant effects of interest variety on withdrawal ($\beta = -0.11$, $p = 0.18$). Again, we recoded interest variety to three levels to examine its nonlinear effect. The results are shown in Figure 4. Compared to projects with low interest variety, projects with medium interest variety had 4.8% less withdrawal ($\beta = -0.07$, $p = 0.13$), and projects with high interest variety had 4.1% less withdrawal ($\beta = -0.06$, $p = 0.28$). Neither difference was statistically significant, meaning that interest variety had no effects on withdrawal. Hypothesis 4 was not supported.

5.2. The Evolution of Diversity in Online Open Collaboration

Hypothesis 5 posits that tenure disparity and interest variety decrease over time. We analyzed tenure disparity and interest variety as a function of time,

[10] We chose 0.33 and 0.66 because they divide the projects into low, medium, and high at the theoretical level. We repeated the analysis with mean ± standard deviation and our results remained qualitatively the same.

Table 4 HLM Results Predicting Member Withdrawal (Log2 Transformation)

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	1.855*** (0.044)	1.652*** (0.107)	1.614*** (0.109)	1.469*** (0.107)
Quarter	0.176*** (0.01)	−0.089*** (0.008)	−0.08*** (0.008)	−0.073*** (0.008)
Project size (log2)		0.734*** (0.012)	0.727*** (0.014)	0.747*** (0.014)
Project scope (log2)		−0.02*** (0.005)	−0.02*** (0.005)	−0.02*** (0.005)
Project creation quarter		0.005 (0.006)	0.007 (0.007)	0.011+ (0.006)
Level of controversy		0.019 (0.032)	0.014 (0.031)	0.014 (0.029)
Tenure disparity			0.365*** (0.077)	0.47*** (0.075)
Interest variety			−0.199* (0.088)	−0.11 (0.082)
Tenure disparity squared				2.051*** (0.214)
Interest variety squared				
−2 log-likelihood	7,753.4	6,371	6,319.1	6,247.4
Deviation (ΔDev)		−1,382.4***	−51.9***	−71.7***
BIC	7,798.7	6,442.2	6,403.3	6,338
ΔBIC		−1,356.5	−38.9	−65.3
N	2,971	2,971	2,958	2,958

$^{+}p < 0.1$; $^{*}p < 0.05$; $^{***}p < 0.001$.

project size, scope, and level of controversy to test the hypothesis. The variables were operationalized in similar ways as in the previous section. The data are nested so we ran another set of HL Ms as follows:

$$TENURE_{it} = \pi_{0i} + \pi_{1i} * QUARTER_{it} + \gamma_{it},$$

$$\pi_{0i} = \beta_{00} + \beta_{01} * SIZE_{it} + \beta_{02} * (SIZE_{it})^2 + \beta_{03} * SCOPE_{it} + \beta_{04} * CREATION_i + \beta_{05} * CONTROVERSY_{it} + \mu_{0i},$$

$$\pi_{1i} = \beta_{10} + \mu_{1i},$$

$$INTEREST_{it} = \pi_{0j} + \pi_{1i} * QUARTER_{it} + \gamma_{it},$$

$$\pi_{0i} = \beta_{00} + \beta_{01} * SIZE_{it} + \beta_{02} * (SIZE_{it})^2 + \beta_{03} * SCOPE_{it} + \beta_{04} * CREATION_i + \beta_{05} * CONTROVERSY_{it} + \mu_{0i}$$

$$\pi_{1i} = \beta_{10} + \mu_{1i}.$$

Hypothesis 5 was supported for tenure disparity but not for interest variety. The full model in Table 5 had a better fit than the null model and revealed a negative effect of time on tenure disparity ($\beta = -0.037$, $p < 0.001$). In addition, tenure disparity increased as projects grew bigger ($\beta = 0.052$, $p < 0.001$) with diminishing margins ($\beta = -0.013$, $p < 0.001$). Projects created earlier or of a larger scope had slightly higher tenure disparity. Level of controversy had no significant effects on tenure disparity.

Table 5 HLM Results Predicting Tenure Disparity and Interest Variety

	Tenure disparity		Interest variety	
Variables	Null model	Full model	Null model	Full model
Intercept	0.544*** (0.006)	0.794*** (0.033)	0.6*** (0.007)	0.436*** (0.04)
Quarter	−0.012*** (0.002)	−0.037*** (0.002)	0.017*** (0.001)	0.006*** (0.001)
Project size (log2)		0.052*** (0.004)		0.028*** (0.002)
Project size squared		−0.013*** (0.001)		−0.006*** (0.001)
Project scope (log2)		0.004** (0.002)		0.006*** (0.002)
Project creation quarter		−0.012*** (0.002)		0.01*** (0.002)
Level of controversy		−0.011 (0.007)		−0.004 (0.005)
−2 loglikelihood	−6,574.3	−7,147.5	−9,017.3	−9,411.6
Deviation (ΔDev)		−573***		−394.3***
BIC	−6,529	−7,069.8	−8,972	−9,333.9
ΔBIC		−540.8		−361.9
N	3,619	3,619	3,619	3,619

$^{**}p < 0.01$; $^{***}p < 0.001$.

In comparison, the model revealed a positive effect of time on interest variety ($\beta = 0.006$, $p < 0.001$). In addition, interest variety increased as projects grew bigger ($\beta = 0.028$, $p < 0.001$) with diminishing margins ($\beta = -0.006$, $p < 0.001$). Projects created later or of a larger scope had higher interest variety. Level of controversy, again, had no significant effect on interest variety.

Figure 5 shows the evolution of tenure disparity over time. Two patterns are worth noting. The average level of tenure disparity decreased over time, and the dispersion of tenure disparity across projects decreased over time as well. Additional analysis shows that from quarter 0 to quarter 5, the mean of tenure disparity decreased from 0.58 to 0.53 ($p < 0.001$), and the standard deviation decreased from 0.246 to 0.147 ($p < 0.001$). These results suggest a "convergence-toward-the-middle" effect. Although the initial level of tenure disparity ranged between 0 and 1.2, by their 10th quarter most projects' tenure

Figure 5 (Color online) Evolution of Tenure Disparity Over Time

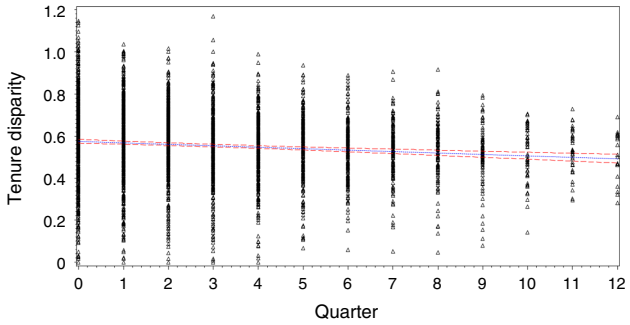
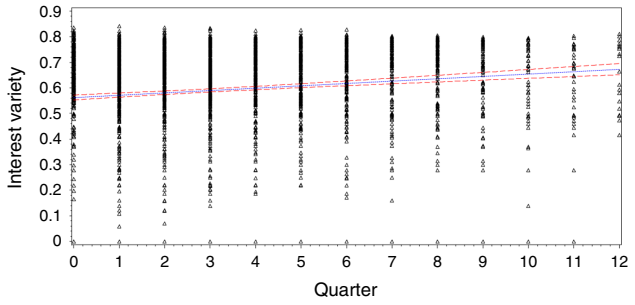


Figure 6 (Color online) Evolution of Interest Variety Over Time



disparity ranged between 0.3 and 0.8. This range, if matched back to the x-axis in Figure 3, is the range during which projects experienced high productivity with relatively low member withdrawal. Hence, the projects seemed to self-organize and evolve toward an optimal level of tenure disparity for performance.

Figure 6 shows the evolution of interest variety, and we observed two different patterns. First, the average level of interest variety slightly increased over time. From quarter 0 to quarter 5, the mean of interest variety across projects increased from 0.55 to 0.62 ($p < 0.001$). It continued to increase beyond quarter 5, although the difference is no longer significant ($p = 0.55$). Second, although a small set of projects maintained low interest variety, the majority of projects moved above 0.4 by their 10th quarter. Our analysis of productivity suggests that projects with interest variety above 0.33 outperformed those with interest variety below 0.33. The projects' interest variety seemed to be moving toward their optimal level of performance over time as well.

6. General Discussion

We draw insights from decades of diversity research to understand the impact and evolution of diversity in online collaboration. Analysis of 648 WikiProjects suggests that (1) tenure disparity has an inverted U-shape effect on group productivity and a *U*-shape effect on member withdrawal; (2) interest variety has a positive effect on productivity and no effects on withdrawal; and (3) over a project's life cycle, tenure disparity decreases and interest variety slightly increases, both of which move toward their optimal levels for project performance. Below, we briefly discuss these findings, speculate on the causal mechanisms, and highlight the theoretical and practical contributions of our work and directions for future work.

6.1. Discussion of Main Findings

Our first finding is the curvilinear effects of tenure disparity on productivity and withdrawal. Projects with a moderate level of tenure disparity outperform projects with a low or high level of tenure disparity. According to Harrison and Klein (2007), moderate tenure disparity occurs when project members are evenly distributed across the tenure continuum—a balanced mixture of members with all levels of experience—as illustrated in scenarios 3 and 4 in Table 1. We speculate that the result is driven by the interplay of the positive and negative effects of tenure disparity. On the positive side, old-timers and newcomers tend to focus on different kinds of tasks (Bryant et al. 2005). Newcomers often start with tasks such as adding content to an article, adding references, and fixing typos, whereas old-timers have the experience to work on high-level administrative tasks such as scoping or structuring articles and fighting vandalism. On the negative side, newcomers and old-timers may have different views of the history and scope of an article that need to be reconciled. A moderate level of tenure disparity implies, on one hand, that the project has the resources to successfully complete a wide range of tasks; on the other hand, differences between old-timers and newcomers are blurred, making tenure a less salient cue for drawing social boundaries. When disagreements happen, members with a moderate level of experience can help to bridge between the brand-new or long-time members to help resolve the disagreements. In contrast, low tenure disparity occurs when all members cluster in the middle of the continuum (scenario 1 in Table 1) meaning that the project may lack old-timers' experiences or newcomers' novel perspectives to perform certain tasks. High tenure disparity occurs when a project has a highly experienced old-timer working with some brand-new members (scenario 6 in Table 1) with distinctive faultlines and little common ground. Consequently, differences in tenure and perceptions of group tasks may quickly become salient and hard to reconcile.

Our second finding is the positive effect of interest variety on productivity. This effect can be explained by the information/decision-making process, because members with different interests contribute unique information to the project. The absence of any negative effects of interest variety is puzzling. A possible reason is that, compared to tenure, interests are either less accessible or less likely to be used as a cue for social categorization. We drew a random sample of 100 editors from 100 WikiProjects and manually coded their tenure and interests based on information on the project or editors' profile pages. We found information about tenure for 22 editors and information about interests for 10 editors. Although the accessibility of tenure and interests are both low, we speculate that tenure is more salient than interests in the context of Wikipedia collaboration. Salience is

different from visibility or accessibility. In group settings, multiple attributes may be visible, but not all of them will trigger social categorization. Only attributes that become salient will be used as cues to classify individuals into categories (Hogg and Abrams 1988). We speculate that tenure is more salient than interests for several reasons. First, information about tenure is simpler and easier to parse than information about interests. Editors often indicate their tenure with their join date (e.g., January 13, 2009) or length of being an editor (e.g., 5 years 9 months). In contrast, editors often indicate their interests by listing articles they have edited or occasionally groups of which they are a member. Second and more importantly, tenure is a simple number, whereas interests are distributed across multiple categories and likely to overlap across individuals. Compared to interests, tenure leads to a simpler categorization of editors (newcomers versus old-timers) and makes it easier to associate or attribute traits to the two groups (e.g., newcomers are less experienced than old-timers) (Hogg and Abrams 1988). In addition, when disagreements happen, editors are more likely to refer to tenure as a way to justify their position because tenure implies experience and ownership of articles (Thom-Santelli et al. 2009). Differences in tenure are more salient than differences in interest and thus more likely to trigger social categorization. Hence, we observed more negative effects of tenure disparity than interest variety.

Our third finding is the dynamic evolution of tenure disparity and interest variety toward an optimal range for high productivity and low withdrawal. The pattern may be the result of multiple factors: project growth over time, membership change, and members gaining experience over time. The evolutionary outcomes are likely to be the consequence of all these processes intertwining and interacting with one another. Additional analysis suggests that the evolution of tenure disparity is not simply an artifact of project aging. Instead, it is largely driven by the attraction-selection-attrition (ASA) processes, during which newcomers join and old-timers who do not fit with the group leave. We observed membership change in 75% of project quarters in our data set. In a typical project quarter, on average, 5.78 new members joined and 3.68 members left. The joining of newcomers decreased over time and the leaving of old-timers demonstrated an inverted U-shape, first increasing and then decreasing. These patterns correspond to our finding that major changes of tenure disparity and interest variety occurred in the early quarters of a project because that was when most membership changes happened. They also support our speculation that the evolution of diversity is primarily driven by the self-organizing nature of online collaboration and the open, fluid boundaries of the projects.

6.2. Theoretical Contributions to Online Open Collaboration

Our study makes several contributions to the information systems and management science literature. First, we show the importance of studying group composition and diversity in online open collaboration. Although most existing research on online collaboration has focused on motivation, governance, and social structure, our results suggest that the attributes of group members are another important factor that influences the success of these groups. Our findings, on one hand, confirm the importance of diversity in harvesting the "wisdom of crowds" in online collaboration and, on the other hand, suggest that the impact of diversity depends upon member attributes and the degree to which an attribute is accessible and salient online. More accessible attributes, such as tenure, tend to suffer a "ceiling" effect beyond which project productivity and member retention deteriorate, whereas less accessible attributes, such as interests, are immune to such effect. We believe the findings generalize to other online open collaboration efforts.

Second, our study of diversity in Wikipedia expands the diversity literature to a new context that is beyond traditional organizations and virtual teams. We test and confirm much of Carte and Chidambaram's (2004) theoretical proposition of the effects of diversity in computer-mediated groups. Our results suggest that similar processes—information/decision making and social categorization—are at work in online open groups, although the degree to which they are activated differs from that of offline work groups. As Carte and Chidambaram (2004) proposed, visual anonymity and the lack of copresence reduces the salience of individual differences and their likelihood to trigger social categorization. Our study suggests that the notion of visibility needs to be revisited in online groups because technology provides new ways for members to learn about one another. Future research should delve deeper to understand the distinction and relationships among visibility, accessibility, and salience and what factors affect the degree to which individual differences become visible, accessible, or salient online. Our findings also have important implications on the design of profile tools to support online collaboration. For example, what are the pros and cons of making individual attributes salient? How can we improve the design of user profile pages to achieve the optimal level of visibility or accessibility of individual attributes?

Third, our findings on the dynamic evolution of diversity demonstrate and advance our understanding of the power of voluntary self-organizing. Although scholars and practitioners have written extensively about the power of online self-organizing

groups, our study is among the first to show how the voluntary joining and leaving of members can move a project toward composition zones that are conducive to high performance. This finding has both theoretical and practical implications on how project teams are formed and managed in traditional organizations. Work groups in organizations are often created by managerial agency, and, once a group is formed, it is difficult or uncommon to add or drop members even when they do not work well together. Instead, our study suggests a promising alternative by letting members self-select into projects, collectively define goals and plan tasks, and self-manage to deliver work products. This self-organizing approach may be particularly suitable for complex, nonroutine tasks that require a diverse set of experiences and expertise and large-scale projects in which members participate with different levels of involvement. Recent developments in enterprise social software such as wikis, blogs, and online social networks have equipped organizations and their employees with the right tools to transform organizational hierarchies to be more decentralized, connected, fluid, and participative (Majchrzak et al. 2009). Organizational cultures and policies need to adapt to support these new practices (e.g., creative ways of connecting and rewarding individuals and allocating resources to different business units). We strongly believe that this is the future direction of organizing work both within and outside organizations.

6.3. Limitations and Future Work

There are several rich directions for future research. First, although we have demonstrated strong associations between diversity and group performance across a number of years, we analyzed archived data in a natural environment, rather than manipulated conditions in a controlled environment. Future studies could use interventions to manipulate group diversity and observe its effects on group processes and outcomes to demonstrate causality more directly. Second, we chose to focus on tenure disparity and interest variety because both attributes are relevant and important to tasks in online self-organizing groups (Williams and O'Reilly 1998). Other dimensions of diversity, such as gender, age, race, and values and beliefs, may surface in the process of collaboration and are relevant to its tasks as well (Lam et al. 2011). Perhaps data on these measures could be gathered or inferred to give a fuller picture of the effects of diversity in online self-organizing groups. Third, future studies should examine collaboration processes and the effects of diversity on individual members to gain a deeper understanding of why and how diversity has the effects we found in this paper. For example, edits and interactions on the talk pages could be analyzed to measure group communication and conflict and how they mediate between diversity and group outcomes. Theory predicts that members who are most different are most likely to leave the group. Is that what happens in online self-organizing groups? How is the effect mediated by which members of the group a particular member interacts with? Answers to these questions will provide valuable insights to continuously harvest the "wisdom of crowds," further enhancing the performance of online self-organizing groups.

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