All Talk: How Increasing Interpersonal Communication on Wikis May Not Enhance Productivity

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Prior research suggests that facilitating easier communication in social computing systems will increase both interpersonal interactions as well as group productivity. This study tests these claims by examining the impact of a new communication feature called "message walls" that allows for faster and more intuitive interpersonal communication in wikis. Using panel data from a sample of 275 wiki communities that migrated to message walls and a method inspired by regression discontinuity designs, we analyze these transitions and estimate the impact of the system's introduction. Although the adoption of message walls was associated with increased communication among all editors and newcomers, it had little effect on productivity, and was further associated with a decrease in article contributions from new editors. Our results imply that design changes that make communication easier in a social computing system may not translate to increased participation along other dimensions.

CCS Concepts: • **Human-centered computing → Wikis**; **Empirical studies in collaborative and social computing**; *Empirical studies in interaction design.*

Additional Key Words and Phrases: wikis; newcomers; peer production; interpersonal communication

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1 INTRODUCTION

Online communities engaged in the co-creation of public information goods rely on extensive collaboration. Although Wikipedia is the most well-known example of a community that produces in this way, the model of production that Wikipedia popularized has been emulated in millions of smaller wikis and in numerous other types of online communities. Communication between participants seems to enable collaboration in these settings. As collaborative projects mature, members increasingly devote time to coordination through interpersonal communication to better organize their own efforts and to assign tasks [21, 24]. Interpersonal communication also plays a central role

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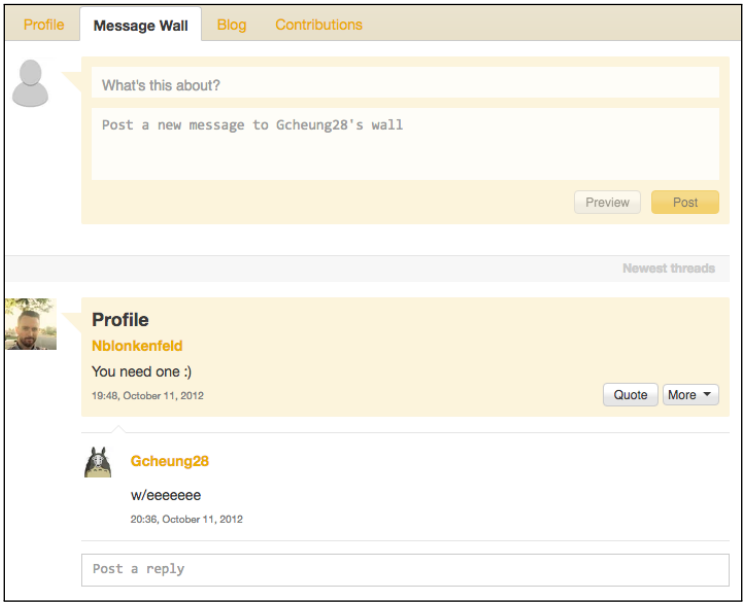

Fig. 1. Example of a "message wall" page in the *Recipes* wiki. The top half shows the interface for starting a new discussion thread by entering both subject and body text. The bottom shows an existing thread consisting of a message and a reply.

in welcoming and initiating new members into communities by facilitating information-seeking and mentorship, which enables newcomers to become better integrated and participate more effectively in the organization [1, 7, 26]. This prior work suggests that better support for interpersonal communication should lead to both increased communication and increased productivity, particularly among newcomers.

Driven by these ideas, community managers and systems designers have invested heavily in supporting interpersonal communication. For example, the Wikimedia Foundation has spent many years building a system called "Flow" which aims to improve the ease of interpersonal communication in Wikipedia.[1] Despite such investments, little evidence directly evaluates whether easier interpersonal communication translates into increased productivity in these settings.

In this paper, we provide a large-scale empirical test of whether easier interpersonal communication leads to enhanced productivity and newcomer participation in peer production communities. To do so, we examine a population of 275 wikis hosted by Wikia that made interpersonal communication easier by introducing an interface called "message walls" (shown in Figure 1). We estimate the impact of the new design by analyzing panel data on participation before and after wikis transitioned to the message wall interface.

We find that the move to message walls is associated with increases in communication overall and among new contributors. However, we do not find evidence of changes in article editing activity beyond a short-lived initial increase. Contrary to our expectations and prior theory, we find evidence that the transition is associated with *lower* rates of contribution to articles from new editors. Our research contributes to human-computer interaction, social computing, and organizational research

[1] https://www.mediawiki.org/wiki/Structured_Discussions *archived at* https://perma.cc/SU4T-D5X3

by suggesting that socio-technical systems facilitating easier communication may not necessarily increase productivity.

2 BACKGROUND

Prior research on "peer production" communities [5] points to several closely linked reasons why interpersonal communication may play a central role in successful projects of this nature. First, more communication may lead to more efficient work. The lack of top-down decision-making in peer production projects means that volunteers must define collective goals, develop and enforce social norms, and create organizational structures and workflows [6]. Frequent interpersonal communication may make it possible, or at least easier, to do so.

In particular, interpersonal communication frequently underpins effective coordination, which a large body of social computing and organizational research links to greater collaborative productivity [23, 24, 28]. In prior studies of peer production in both Wikipedia and Wikia wikis, higher levels of coordination explain variation in content quality [21, 22]. One prior study estimates that Wikipedia articles with non-empty talk pages have 5.8 times more edits and 4.8 more contributors on average than those with empty talk pages [42]. Among work groups and virtual teams, a similar pattern occurs whereby collaborators with more integrated communication network structures perform better at complex information seeking and problem solving tasks [4, 10].

Interpersonal communication may also elicit more participation in peer production projects. Researchers and participants frequently define success in peer production in terms of communities' ability to marshal the volunteer resources needed to sustain production [9, 13, 39]. Prior research suggests several pathways by which interpersonal communication might increase participation. The mere presence of other contributors to a collective endeavor can sustain participation [44] and communicating and interacting with other volunteers motivates many peer production participants [7, 25]. Higher levels of social interaction also support group identification, commitment, and socialization, all of which can increase participation in online communities [23]. Spaces for interaction provide opportunities for feedback, which can elicit additional contributions and increase contribution quality [8, 45].

Interaction also facilitates the formation of collective identities that sustain participants' commitment to communities. For example, sustained engagement with other volunteers lead Wikipedia editors to transition from seeing the project as simply a repository of articles to a collection of people working together to maintain a public good [7]. This process of social integration through communication can build a cohesive "organizational culture" that sustains collaboration [20], and deeper social bonds that encourage commitment to the project [36, 37].

Given this prior work, if a community made it easier for members to communicate with one another, we would expect to see an *increase in the number of messages (H1a)* that occurs within that community. We would also expect to see an *increase in the number of communicators (H1b).* Additionally, the literature in this area suggests that increased communication among participants in peer production communities will result in an *increased number of contributions (H2a)* to the project made by a *greater number of contributors (H2b).*

2.1 Interpersonal communication and newcomers

Interpersonal communication supports another critical process in peer production: the socialization of new contributors through legitimate peripheral participation [23, 26]. Although peer production projects have experimented with formal and structured forms of socialization [33], newcomers to peer production projects are almost exclusively oriented through unstructured and individualized processes. In these processes, newcomers typically begin as lurkers [2], and may become occasional and then more active contributors [3, 35]. Interpersonal communication enables newcomers

to learn norms, routines, and cultures of groups through conversations with more experienced contributors [7, 35].

Engaging in discussion can elicit newcomers to pursue sustained participation in peer production projects in several ways. First, newcomers may seek information from veteran volunteers with questions about contributing to the project [1]. Asking questions and receiving answers also helps newcomers acquire the skills to effectively contribute [29]. Indeed, connecting newcomers to experienced community members is one of the few interventions demonstrated to increase newcomer retention over time [30]. The success of question-and-answer interventions also demonstrate the existence of distributed mentorship in a community, signaling a community's overall investment in newcomers [27, 45]. Additionally, veteran volunteers often approach newcomers personally in order to connect them with tasks that they might like or be well-suited to perform. These overtures help provide role clarity and encourage newcomers to take on more challenges and responsibility [32].

Interpersonal communication in peer production is typically archived and visible to other participants. As a result, new volunteers can read existing discussion threads to learn more about the project they are joining and its community norms. Past discussions may also help newcomers gain a sense of what kind of community they are joining and how they may or may not fit into it [2, 43].

Finally, interpersonal communication is the cornerstone for building affective bonds of camaraderie among volunteers. Through conversations (both on and off topic) and discussions of the project's history and vision, volunteers transition from viewing the project as a static information repository to a dynamic collective that is created and maintained by people like them [7].

If a community makes it easier for people to communicate with one another, we would expect *newcomers to increase the number of messages (H3a)* they engage in. We would also expect that easier interpersonal communication would enable more people to interact with one another leading to a *greater number of new communicators (H3b)* in each community. Since communication is an important facet of socialization within a community, we would expect that making it easier for newcomers to communicate with other members would help them navigate the community better, and more clearly understand what tasks need to be done and how to do them. We anticipate this will lead to an *increase in the number of newcomer contributions (H4a)* as well as an *increase in the number of new contributors (H4b)*.

3 EMPIRICAL SETTING

To test the hypotheses derived above, we examine the introduction of a new interpersonal communication interface in a large population of wiki communities engaged in peer production. The wikis are all publicly editable and are hosted by Wikia, a for-profit company that allows anyone to start a wiki on any subject. The wikis span many different topics, though many of the largest relate to fan culture about gaming, comic book franchises, popular TV shows, and science fiction lore. On October 4, 2016, Wikia partially rebranded itself as Fandom, to highlight the prevalence of entertainment and fan communities on its site.

Each Wikia wiki is a community of its own, though members may participate in multiple communities. All wikis on Wikia use the MediaWiki software popularized by Wikipedia. As is the case with Wikipedia, content produced on Wikia is distributed freely and released under a Creative Commons Attribution-ShareAlike license.

3.1 Intervention: From user talk pages to message walls

In general, wikis created using MediaWiki have discussion pages associated with every page on the site. Discussion pages for articles are called 'talk pages' and those for user profiles are called

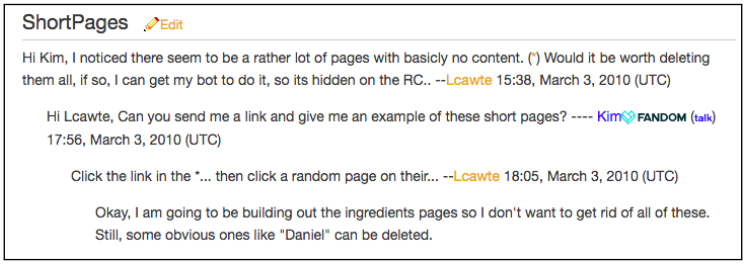

Fig. 2. A user talk page on *Recipes* wiki

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== ShortPages ==

Hi Kim, I noticed there seem to be a rather lot of pages with basicly no content.
([[Special:ShortPages|*]]) Would it be worth deleting them all, if so, I can get my bot to do
it, so its hidden on the RC.. --[[User:Lcawte|Lcawte]] 15:38, March 3, 2010 (UTC)
:Hi Lcawte, Can you send me a link and give me an example of these short pages? ----
[[User:Kimberly McCollister|<font color="Blue">Kim</font>]]<staff /> ([[User talk:Kimberly
McCollister|<font color="Blue" size="1">talk</font>]]) 17:56, March 3, 2010 (UTC)
::Click the link in the *... then click a random page on their... --[[User:Lcawte|Lcawte]]
18:05, March 3, 2010 (UTC)
:::Okay, I am going to be building out the ingredients pages so I don't want to get rid of all
of these. Still, some obvious ones like "Daniel" can be deleted.
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Fig. 3. Source code editor for text in Figure 2

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'user talk pages.' While talk pages are used for discussion of particular articles, user talk pages are typically used for informal conversations between editors, making introductions, asking questions, and giving feedback. The default MediaWiki interface for all pages (whether articles, policies, or discussion) is exactly the same: pages, no matter their purpose, start blank and are editable through a "wiki markup" text editor such as the one shown in Figure 3.

The freedom to edit any page in any way is both a hallmark of MediaWiki and a source of confusion. Starting a discussion on a blank page puts the onus on participants to organize their conversation (e.g., label distinct topics, indent or otherwise represent relationships between comments), sign their messages with their name as they go along, and so on. All of this requires additional time, skill using wiki markup, and knowledge of community norms and routines. User evaluation studies of the MediaWiki talk page have shown that new editors can take up to four or five minutes to understand and figure out how to edit a talk page [38]—a long period of time in comparison to many similar messaging interfaces. Additionally, the default MediaWiki notification system makes it a challenge to keep track of which conversations have received responses.

In September 2011, Wikia announced plans for a new feature—the "message wall"—to replace user talk pages.[2] Message walls resembled the discussion threads that are commonly seen on other social media, forums, and blogs (see Figure 1), and were designed to make interpersonal conversations among editors easier. Wikia staff identified several drawbacks of the default MediaWiki talk page system, including missed notifications, inconsistent norms around where to post, and frequent

[2]See: https://community.fandom.com/wiki/User_blog:Dopp/Communicate_Easily_with_Message_Wall *archived at* https://perma.cc/CV7S-EMNS

user error around signing names[3], which provided the impetus to develop a new interpersonal messaging system.

Message walls introduced a number of new features that changed and clarified how editors communicate with each other. First, message walls moved away from the standard markup editor and introduced a text box that an editor could directly type into when they landed on a different editor's page (see Figure 1). This shortened the time it took to communicate with others, since editors no longer had to load a new page or use wiki markup to write their message.

The message walls interface also automatically performed a number of operations that user talk pages previously required editors to do by hand. For instance, all messages left on user talk pages needed to be deliberately signed with four tildes ("~~~~") in order to have the editor's account name show up next to their messages. In Figure 2, drawn from a real conversation that occurred on the same *Recipes* wiki shown in Figure 1, editors signed the first three messages in the thread, but the fourth one was left unsigned (a common oversight). Furthermore, the indentations visible in Figure 2 must be manually inserted (represented by colons (":") in the wiki markup in Figure 3). Message walls automatically associate usernames with posts, provide subject headers, and indent conversations. Since user talk pages require conversations to be threaded manually, the visual organization of user talk pages can vary across communities. For example, some wikis use a convention of displaying more recent comments on top, while others do the opposite. Message walls provided a uniform interface that meant that communicating in a new wiki was a much smoother process for any editor.

Message walls also included a revamped notification system. Previously, an editor would need to choose to follow an entire page in order to know when their message received a response, meaning that any new post on that page would generate a notification. Instead, the message walls notification system automatically notified editors when they received a response on their specific thread. Editors accessed message walls by clicking on the same link that they used to access user talk pages in the past. All other article and talk pages were unaffected by the introduction of message walls.

A beta version of message walls was first released October 5, 2011 on five Wikia wikis. After a period of testing and debugging, it was introduced to five more wikis in November 2011. In January 2012, after adding a few new features (such as the notification system), it was made available to administrators as a wiki-level setting they could change in a dashboard present on all Wikia wikis. By 2015, message walls became the default user discussion option for newly created Wikia wikis, and almost all Wikia wikis were transitioned over to the new system. As a result, the feature was rolled out to wikis at different points in time and at different points in wikis' life cycles.

4 METHODS, DATA, AND MEASURES

To understand the impact of message walls, we built and analyzed an exhaustive longitudinal dataset of interpersonal communication and contribution activity that occurred on all wikis that experienced the intervention. We identified our study population of wikis using records provided by Wikia. The company provided the exact date and time of 6,189 events where wikis enabled message walls during the initial period when the feature became available between January 2012 and October 2, 2012. We then used publicly available database "dump" files (posted by an archival group called WikiTeam to the Internet Archive)[4] to generate exhaustive longitudinal trace data

[3]See: https://community.fandom.com/wiki/User_blog:Ohmyn0/Let%27s_Talk_About_Talk_Pages *archived at* https://perma.cc/KD7R-A4JB

[4]A list of archives is available at: https://archive.org/details/wikiteam *archived at* https://perma.cc/V5G4-EREF

for 4,380 of these wikis. Data for the remaining 1,809 wikis was not available in the WikiTeam archives.

Since message walls could be turned on and off by administrators, it was not always the case that wikis would transition to message walls permanently. To ensure the comparability of the transitions in our analysis we consider only the *first* time that each wiki in our sample transitioned. We also limit our analysis to wikis that adopted message walls for at least two months after their first migration.

We apply several other exclusion criteria. In order to compare only wikis that adopted the new feature for a sustained period, we drop 86 wikis that turned off message walls for more than 10 minutes during the eight weeks after it was first turned on. We also excluded 1,256 wikis from our analysis that had no edits or that had not existed for at least four weeks prior to their migration to message walls. This ensured that communities had some period of exposure to user talk pages against which we could draw a comparison. We also exclude 563 inactive wikis by requiring wikis to have at least one edit in at least three quarters of the weeks of the study period in our analysis. Applying all of these exclusion criteria left us with a dataset of 275 wikis in our training set and 275 in our test set (see the section on split sample analysis in §4.3 below).

We analyze activity occurring 8 weeks before and 8 weeks after each wiki moved to the new message walls interface. We believe that this is long enough to allow us to model underlying trends in contribution activity while short enough that factors unrelated to the message walls transition are less likely to impact the results. Within the 16 week analytic window, our unit of analysis is the *wiki week*, meaning that for every measure we aggregate observations from each wiki into week-long bins.

We only include activity from registered editors (user accounts) on Wikia. While unregistered users may edit wikis with attribution made to their IP address, we choose to exclude them in this case. IP addresses are not reliable identifiers, and dropping unregistered users avoids double-counting editors who may both edit from a registered account and edit anonymously [34]. Additionally, the benefits of message walls are lower for unregistered users because they are unable to receive notifications from responses. We describe the individual measures in detail below.

4.1 Outcome measures

Number of messages. Our first dependent variable is the aggregate amount of interpersonal communication on the wiki. In the first 8 weeks of our study, editors communicated by editing user talk pages, then they abruptly transitioned to message walls, which they used for the second 8 weeks. Edits to user talk pages and posts to message walls leave different kinds of traces in the data recorded by Wikia. For example, multiple edits may be made to a user talk page to create text that appears as a single comment while a single edit to a message wall is more likely to reflect a single comment. In order to make a single commensurate measure, we collapsed edits to user talk pages into strings of sequential edits by treating a series of consecutive edits by the same editor to a given user talk page or message wall as a single communicative act. Our aggregate measure of interpersonal communication is the number of strings of sequential edits to user talk pages per week in the period before the transition, and the number of strings of sequential message walls posts per week in the period after.

Number of communicators. The count of unique editors who made edits to either a user talk page or a message wall in a given week.

Number of contributions. The total number of edit sessions made on article pages in each week. Following prior work on participation on wikis [15, 17, 33, 34], we define an edit session to be a string of edits made by an editor to an article page with less than an hour elapsing between any

two edits in the sequence. Given that edits made to articles can take a long amount of time [17], and that editors may save intermittently save and preview their progress [34], we believe that collapsing such edit sequences would provide a metric that allows us better quantify participation in article editing across different editors. We use this metric as a way to operationalize the extent to which editors are making contributions to an online public good.

Number of contributors. The number of unique editors who made edits to a wiki's article pages in each week.

Impact on newcomers. Since we were interested in the extent to which newcomers in particular were affected by the transition to message walls, we generated measures for each of the above outcomes separately for newcomers. We define an editor to be a *newcomer* at time t if they had created their account less than 3 months before and had made fewer than 20 total edits at t. We define a *newcomer edit* as any edit made by a newcomer. We use this definition to aggregate the total number of newcomer edits made to articles, user talk pages, or message walls during a week to construct newcomer versions of each of the previously introduced dependent variables. For example, in addition to the total number of messages in a particular week, we had a corresponding measure for the *number of messages by newcomers* for that week. In this vein, we also constructed dependent variables for *number of newcomer communicators*, *number of newcomer contributions*, and *number of newcomer contributors*.

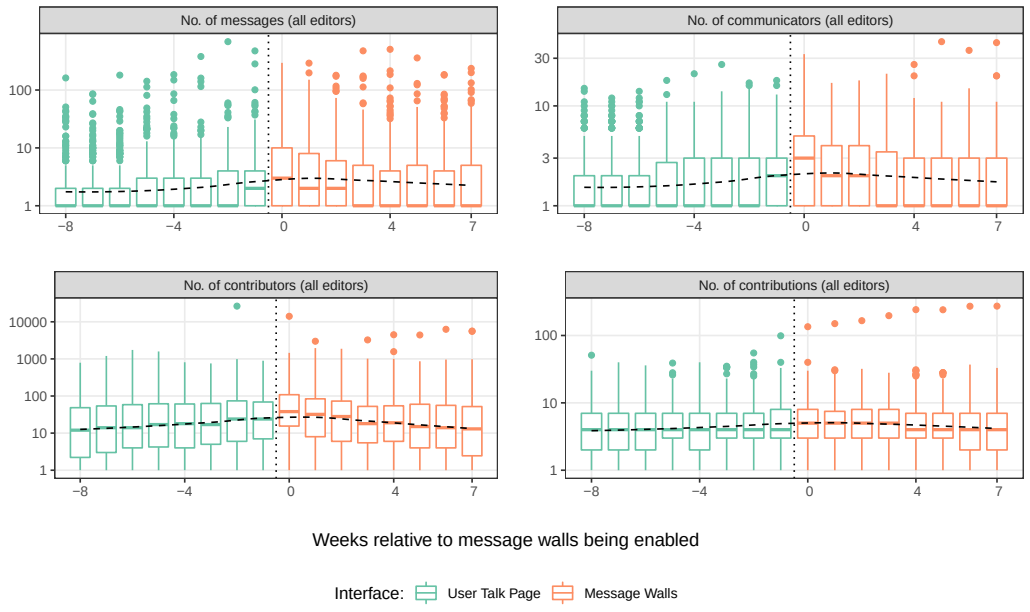

Fig. 4. The distribution of each of our dependent variables for all editors across all wikis eight weeks before and after the adoption of message walls. The center of the boxplots shows the median over all wikis, the boxes show the interquartile range (IQR, the 25^{th}-75^{th} percentiles), the whiskers extend to $1.5 * \text{IQR}$, and draw values beyond that range as points.

4.2 Analysis plan and models

We constructed longitudinal regression models to compare participation in wikis immediately before and after the introduction of message walls. We adapt the panel regression discontinuity approach introduced by Fé and Hollingsworth [12] and previously used in social computing research by Hill and Shaw [18]. The sudden switch to the message walls feature in software allows us to draw within-wiki comparisons immediately around the intervention and estimate its impact on the outcome variables. In doing so, we adapt the methods and concepts of quasi-experimental techniques of observational causal inference [31].

In quasi-experimental regression discontinuity designs (RDDs), analysts make a strong claim to causal identification by assuming (and providing credible evidence) that an intervention occurred at an "as-if random" point along the distribution of an otherwise smooth and continuous "forcing variable," resulting in a well-defined treatment and control group similar to those created in researcher-designed experiments [31]. We make an analogous, but much weaker claim: the introduction of message walls occurred at a precise moment for the wikis in our sample, allowing us to approximate an RDD by comparing each wiki to itself immediately before and after the intervention. By modeling the relationships between our dependent and independent variables around the intervention, we observe whether and how they changed in the weeks afterwards.

We refrain from making strong causal claims because the way the intervention took place leaves room for confounding factors that may have shaped the outcomes we observe. For every wiki in our study, at least one of the community administrators requested the intervention and, in some cases, the change was discussed among community members prior to implementation. Wikia had also publicly announced their goals for the system in terms of its impact on communities. This means that even though our estimates capture any shift in each outcome variable that occurred

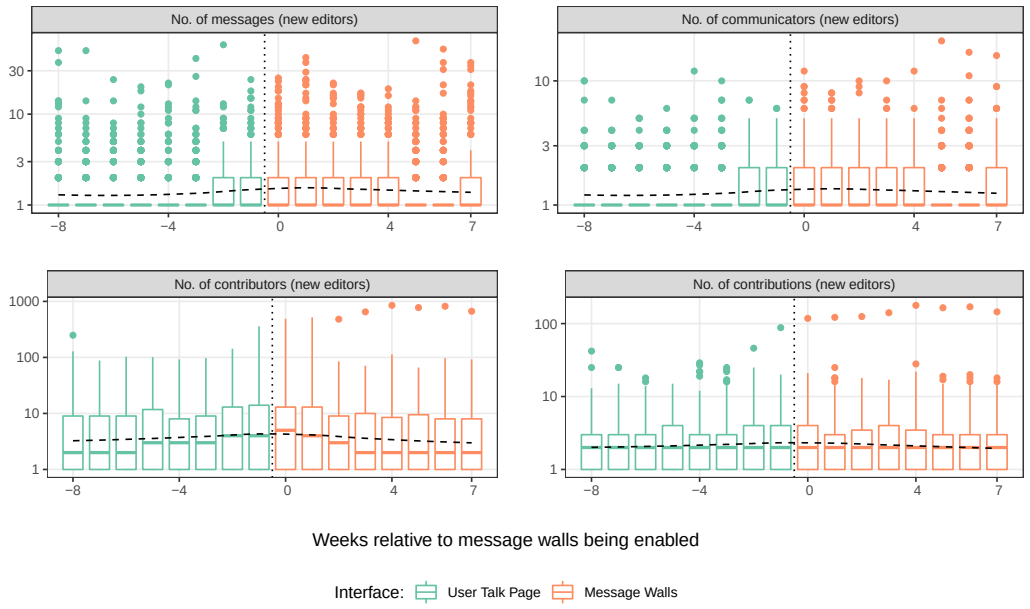

Fig. 5. The distribution of our dependent variables for new editors across all wikis eight weeks before and after the adoption of message walls. As in Figure 4 above, we plot the median, mean, IQR, 1.5 ∗ IQR, and extreme values over the wikis for each week in the study period.

after the migration to message walls, the shifts we observe can not be attributed to the effect of message walls alone.

Our dependent variables are over-dispersed counts, so we used negative binomial regression. Our models all take the general form

$$Y = \beta_0 + \beta_1 msgwall + \beta_2 \mathbf{wiki} + \beta_3 \mathbf{wiki} \times week + \epsilon. \quad (1)$$

For each model, Y is an outcome measure, *week* is the wiki week in the study period relative to the intervention, and *msgwall* is a dichotomous variable indicating whether message walls are present or absent. We also include ***wiki***, a vector of wiki-level fixed effects, to fit individual trend lines for each wiki.

When plotting our dependent variables, we observed that the outcomes measuring number of edits to articles and number of article editors exhibited spikes around the week that wikis turned on message walls (see Figures 4 and 5). This brief spike led us to adopt two empirical strategies. First, we report the means for all of our outcome variables in the week immediately before the transition and the two weeks immediately after. Second, we decided to drop the week immediately after the transition ($week = 0$ or "week zero") from the datasets that was used to estimate the regression models reported in our main results. We drop week zero because our hypotheses and prior work suggested that message walls would lead to substantial and sustained shifts, and because doing so results in a more conservative estimate of the change after the intervention.[5]

Preliminary visual exploration of the data also led us to expect that underlying trends in wiki activity might be moderated by the size of the editor community. In response, we estimated models that interacted the *msgwall* indicator with a measure of wiki size, taken as the natural logarithm of the number of editors who had ever edited the wiki at time of the transition. The interaction term did not help explain variation in any of our outcomes so we report models without it.

4.3 Split-sample analysis

Recent work has demonstrated that "researcher degrees of freedom" in variable selection, hypothesis testing, and revision can bias statistical evidence in the empirical social sciences [14, 16, 19, 40]. To mitigate these risks in the context of this project, we adopted the split-sample approach proposed by Fafchamps and Labonne [11] through the following steps. First, prior to the development of the inclusion criteria, measures, and models described above, we randomly divided our full sample (i.e. the population of wikis that adopted the message walls feature) into a *training* set containing 2196 wikis and a *test* set containing 2184 wikis. We then used the *training* set to define, build, debug, and refine our measures, inclusion criteria and models prior to the submission of our paper for peer review. Upon applying the inclusion criteria described in section 4 to the 2196 wikis in our training set, we ended up with a sample of 275 wikis, which we used in conducting the analyses presented in this paper.

During peer review, we responded to all reviewer comments and completed further revisions and refinements using only the *training* set of wikis. These results and figures are presented in this manuscript in §5.1. After our paper was accepted, an anonymous member of the CSCW program committee was designated to shepherd our manuscript to publication. Only at this point did we conduct our analysis using our *test* set. After sharing results from the test set with the shepherd, we added the results of our analysis and a brief discussion of these results to a new subsection included

[5]We report the results of the same models estimated on a dataset including week zero in our online supplement (see the final section of this paper for more details). As expected, these alternative specifications produce substantially different estimates of the impact of the intervention. We elaborate on this difference and the implications for our findings in §6.

Outcome	Week -1	Week 0	Week 1
All Editors			
No. of messages	7.41	11.42	9.30
No. of communicators	1.76	2.84	2.18
No. of contributions	76.27	105.49	73.47
No. of contributors	6.12	6.87	6.31
New Editors			
No. of messages	0.89	1.87	1.50
No. of communicators	0.58	0.86	0.68
No. of contributions	10.40	13.45	10.01
No. of contributors	2.73	3.08	2.65

Table 1. Mean outcomes across all wikis for the weeks immediately around the transition.

in §5.2. Our discussion is limited to describing differences between the training and test sets. The shepherd worked with us to ensure that this was the only substantive change to our manuscript.

A split-sample design of this sort adapts the principle of cross-validation for an observational study. It provides several benefits over a more typical approach using all data in a single analysis reported in a paper. First, the test set analysis provides a direct evaluation of the robustness of the findings from the training set by estimating the same models on out-of-sample data. If the results deviate, this would threaten the validity of the findings reported in the paper and would indicate that the findings do not generalize beyond the training set. Any such deviation would be due to either random sampling variability or inadvertent model over-fitting. By reporting everything, we gain additional insights into the estimates reported in the paper as well as confidence that the work has not been subject to publication bias pressures in the review process. In the event that our test set results diverged substantially from our training set results, we would have revised our interpretation of the results accordingly. If the discrepancies led us to find a clear error in the way we performed our analysis that may have invalidated our work, we would have considered withdrawing the submission entirely. In any case, we would have coordinated with the shepherd to ensure that changes to the paper were minimal enough that they did not require a new round of external review.

A more detailed discussion of the rationale, logistics, and implications of split-sample designs for observational studies are provided in the article by Fafchamps and Labonne [11]. We are not aware of prior studies that have employed split-sample tests with observational data in social computing research, but note the parallels with cross-validation techniques commonly applied in machine learning studies.

5 RESULTS

5.1 Results from training set

Our training set results suggest that the transition to message walls is associated with an increase in communication—especially among newcomers—but very little evidence of sustained change in contribution activity. We observe some evidence of a decline in contributions among newcomers.

Table 1 shows the means of each dependent variable over a three week period around the intervention. This captures the short-term impact of message walls and entails neither parametric assumptions nor adjustments for other potential sources of variation. Although the differences between the weeks varies enormously in magnitude across the outcome variables, the pattern is consistent. In every case, there is an increase from week -1 (before the intervention) to week 0

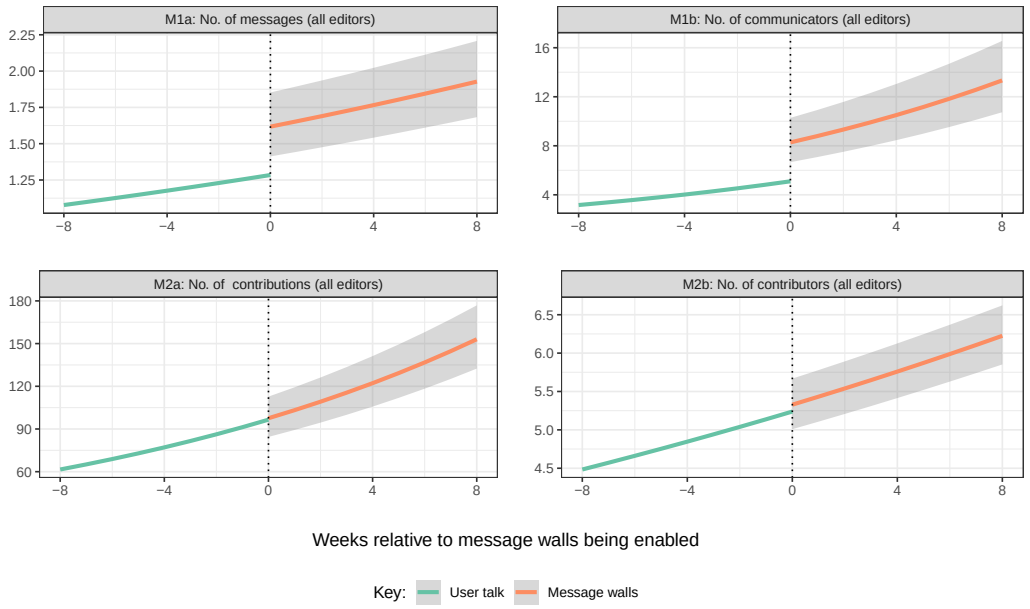

Fig. 6. Visualizations of hypothesis tests for outcomes including all editors. We show model predicted values for each outcome variable in a prototypical wiki over time; before and after the change to message walls. The ribbons in the post-intervention period represent 95% confidence intervals in the estimate of the model coefficient for message wall.

(immediately following it). Then, in almost every case, the values revert back to lower levels one week later.

Table 2 reports parameter estimates and standard errors for the *msgwall* term in each of our negative binomial regression models. To aid interpretation, Figures 6 and 7 visualize the estimates by plotting model predicted values for a prototypical wiki across all editors and new editors respectively. We generate the trend lines for these plots by fitting a regression model on the predicted values from each of the models reported in Table 2. Our estimates are represented by the magnitude of the discontinuous vertical jump (if any) seen at week 0 in each of the plots in Figures 6 and 7, with the grey ribbons in the post-intervention period representing the 95% confidence intervals for the change associated with *msgwall*.

We find evidence to support H1a and H1b, that making communication easier increases the number of messages between editors in general, as well as the number of people communicating. M1a estimates that the number of messages by all editors rose 62% from 5.1 to 8.3 messages per week in a prototypical wiki at the point they introduced message walls ($\beta = 0.48, \sigma = 0.11$). Similarly the number of editors who communicated in the prototypical wiki increased 26% from 1.3 to 1.6 according to M1b ($\beta = 0.23, \sigma = 0.07$). Aggregating over the eight weeks in the study period following the change, our models predict a total of 162% as many messages sent by 126% as many communicators. We do not find evidence to support H2a or H2b, which proposed that the number of contributions and the number of people contributing would increase with message walls. Table 2 and Figure 6 show that the estimates for both of these dependent variables are not distinguishable from zero.

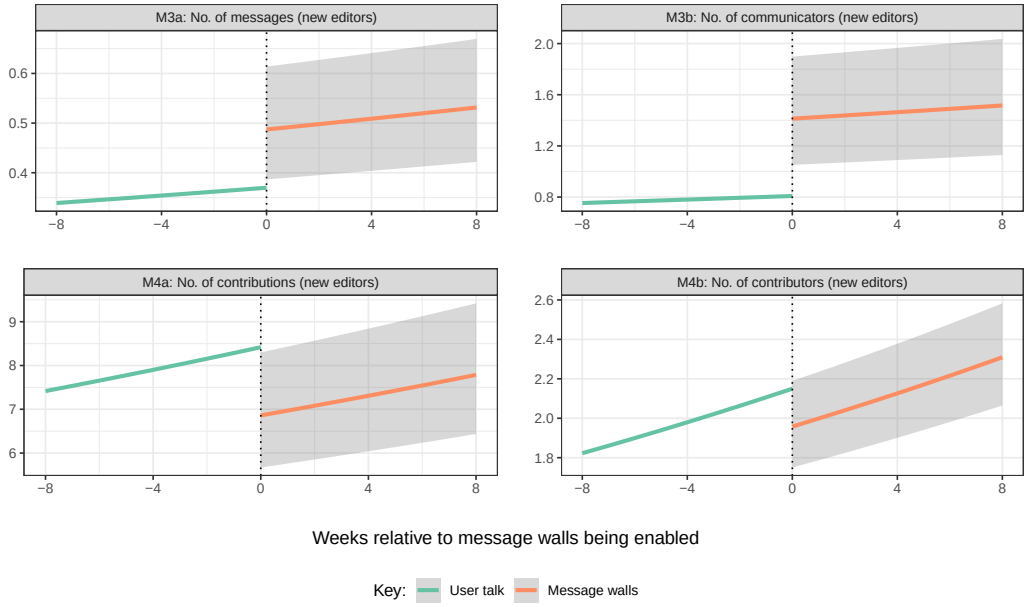

Fig. 7. Visualizations of hypothesis tests for outcomes including new editors only. As in Figure 7 above, we show model predicted values for each outcome variable in a prototypical wiki over time; before and after the change to message walls. The ribbons in the post-intervention period represent 95% confidence intervals in the estimate of the model coefficient for message wall.

	Outcome	Est.	SE
All Users	M1a: No. of messages	0.48 ***	(0.11)
	M1b: No. of communicators	0.23 ***	(0.07)
	M2a: No. of contributions	0.01	(0.07)
	M2b: No. of contributors	0.02	(0.03)
New Users	M3a: No. of messages	0.56 ***	(0.15)
	M3b: No. of communicators	0.28 *	(0.12)
	M4a: No. of contributions	-0.2 *	(0.1)
	M4b: No. of contributors	-0.09	(0.06)

Table 2. Estimates from our training set (with standard errors in parentheses) of the impact of the transition to message walls for all dependent variables.

For the newcomer-related hypotheses, we find evidence to support H3a and H3b, indicating that the transition to message walls led to increases in messages sent by newcomers and in the number of newcomers sending messages. M3a estimates that messages sent by newcomers increased by 75% in the prototypical wiki from 0.81 to 1.4 messages per week ($\beta = 0.56, \sigma = 0.15$) as the number of communicating newcomers each week increased by 32% from 0.37 to 0.49 ($\beta = 0.28, \sigma = 0.12$). Over the eight weeks in the study period following the change, our models predict a total of 175% as many messages sent by 132% as many newcomers.

With respect to H4a, we find that the transition to message walls was associated with a decrease in the number of article contributions by newcomers. This outcome contradicted our expectations. M4a estimates that the number of article contributions made by newcomers declined 18% from 8.4 to 6.9 edits per week in the prototypical wiki shown in Figure 7 at the point they introduced message walls ($\beta = -0.2, \sigma = 0.1$). We note some uncertainty around this estimate as the standard error is fairly large relative to the value of β. We found no evidence to support H4b, which stated that the transition to message walls would lead to an increase the number of new article editors.

5.2 Results of test set analysis

Results from the analysis of the test set are provided in Table 3. Like our training set, results from our test set suggest that message walls increase communication, but not productivity. This was true both for newcomers and overall. Despite similar patterns of results, differences between the results from our test set of holdout wikis suggest that some specific claims about the feature's effects on newcomers might not be robust.

We find that for the All Editors models, results from our test set of holdout wikis are similar to those from the training set. One difference is in M2, which models the number of article contributions and contributors. Our estimates on the training set were positive, but on the test set they are negative. Since in both cases our results are not statistically significant, we do not consider this a substantive difference.

We find some variation between the training set and the test set in the New Editors models. In particular, the estimate for M3b (number of newcomer communicators) is insignificant in the test set but positive and significant in the training set. Additionally, the estimate for M4b (number of newcomer editors) is insignificant in the training set, but is negative and significant in the test set. Thus, we find that in the test set—unlike in the training set—message walls do not produce a significant effect on the number of newcomer communicators and may lower the number of newcomers contributing to articles. Because both our training and test sets contain relatively few newcomers, random variations in newcomer activity between the datasets may explain the different results.

	Outcome	Est.	SE
All Users	M1a: No. of messages	0.47 ***	(0.11)
	M1b: No. of communicators	0.17 **	(0.07)
	M2a: No. of contributions	-0.03	(0.07)
	M2b: No. of contributors	-0.03	(0.03)
New Users	M3a: No. of messages	0.34 *	(0.14)
	M3b: No. of communicators	0.11	(0.11)
	M4a: No. of contributions	-0.33 ***	(0.1)
	M4b: No. of contributors	-0.14 **	(0.05)

Table 3. Estimates from our held-back test set (with standard errors in parentheses) of the impact of the transition to message walls for all dependent variables.

5.3 Robustness to threats to validity

We evaluated the sensitivity of our results to several potential threats to validity by conducting a number of robustness checks and estimating alternative model specifications. We explain several of these sensitivity analyses below. More detailed descriptions and full results can be found in the

online supplement to our study described at the end of this paper. Because they were part of the manuscript that was reviewed, the robustness checks reported here were conducted on the training set.

Several threats stem from decisions we made in the design of our study's variable construction and analytic plan. The main results report findings from an analysis of 8 weeks of activity before and after the moves to message walls, we also ran our models on versions of the dataset with 6 and 12 weeks of data around on either side of the transition. These alternate specifications did not substantively alter our results. Furthermore, we tested the sensitivity of our results to the use of 7 day time intervals. Our results were not substantively different when we aggregated our dependent variables in 4-day or 10-day 'weeks.' We also varied the parameters that defined newcomers in this study (i.e. time and number of edits made since account creation). We shifted these thresholds to 2 and 4 months since account creation and 10 and 30 edits made since account creation respectively. Changing the measure in this way did not substantively alter our findings.

An additional concern common to RDDs is that results might be driven by underlying stochastic variation in the dependent variables. This is typically tested by conducting "placebo" tests on datasets with an incorrect or "dummy" transition threshold. To do so, we selected 14 different dummy dates either before or after the actual transitions for each wiki.[6] We ran our eight models on 14 different dummy datasets and found that ~90% of the models produced no significant effects at these alternative cutoffs.

The inconsistency of some of our measures across the transition to message walls also poses a threat to the validity of our results. We have chosen to compare the number of edit sessions on user talk pages made before the transition directly with edit sessions on message walls made after. While we argued earlier that these two measures of communication are comparable, we acknowledge that they capture editors interacting with different interfaces. For example, editors frequently organize and edit conversations on talk pages after discussions to clean up threads that are poorly formatted. However, since we hypothesize that message walls would elicit more interpersonal communication in general, any resulting inflation of our measure of communication on user talk pages means that our estimates would be conservative with respect to our hypotheses. We find evidence of an increase despite this potential inflation in the measure of communication on user talk pages.

6 DISCUSSION

Our results provide evidence that the message walls intervention was associated with more communication among all editors and among newcomers in particular. This suggests that the user talk page system limited communication on Wikia wikis (as indicated by previous research on Wikipedia [38]) and that message walls succeeded in making communication easier. In this important sense, our analysis suggests that message walls appears to have achieved its purpose.

However, the intervention did not change rates of article editing overall and may have even reduced article editing among newcomers. We believe that the most likely explanation is a substitution effect where the increased ease of communication led editors to converse more and edit articles less. This substitution effect has been observed in similar contexts, such as when the introduction of a new tutorial system on Wikipedia led to a short-term drop in contributions from newcomers [33]. It is possible that the negative impact on newcomer contribution we find in M4a is a short-term effect of the introduction of message walls. In additional analyses of our results included in the supplementary materials described at the end of this paper, we find that newcomers exhibit a

[6]We constructed these dummy dates by selecting the maximum number of non-overlapping 16-week analytic windows before and after the actual cutoff dates that we could use while still having sufficient data to allow our models to converge.

dip in article contributions when considering their behavior six weeks and eight weeks after the introduction of message walls, but this effect is no longer present twelve weeks after the transition.

Alternatively, making it easier to communicate on these wikis might have empowered lurkers who had no intention of editing articles to begin chatting with other editors. This could also explain how the message walls transition increased newcomer communication without a corresponding increase in article production. Finally, the introduction of message walls may have shifted the purpose for participation among some editors. Prior work on communication in wikis has emphasized the use of talk pages and user talk pages for engaging in coordination [42] and conflict resolution [41] in the service of developing articles. However, the introduction of message walls may have led some participants to focus more on social interactions. For example, as many wikis in our sample are fan communities, the transition to message walls may have increased general discussions of fan culture, rather than supporting collaboration on article development.

These results underscore that communication and collaborative production are distinct activities. While prior research, theory, and intuition led us to expect that increased communication would bring about corresponding increases in productivity, we find little evidence to suggest that these expectations would be justified. As we have indicated, the absence of such evidence may reflect aspects of our research design. It is also possible that our measures do not capture other changes brought about by the migration to message walls, such as shifts in the tone of interpersonal communication, in the perceptions of participants, or in their organizational culture. In both respects, alternative analysis methods, measurement, or modeling strategies might yield results more consistent with the expectation that more communication leads to enhanced collaboration.

Our results may also reflect elements of the message walls transition itself. As we suggested, some administrators and editors of the wikis that adopted message walls were likely aware that the change was coming and may have altered their behavior preemptively. It is also possible that the outcomes we observe are not due to the effect of message walls alone.

We find the short-lived spikes observed in some of the dependent variables immediately after the transition to message walls—visible in Table 1 and Figures 4 and 5—difficult to explain conclusively. The spikes could be due to the novelty of message walls, an increase in administrator activity, or some other, unobserved attribute that led these wikis to adopt message walls in the first place. Alternately, they might be due to the bursty nature of activity on many wikis. As Table 1 suggests, models run on the training set without dropping the week immediately after the transition provide notably different estimates. In particular, the week 0 bump leads to significant positive estimates for number of article contributions and number of article editors (H2a and H2b), and positive (but insignificant) estimates for number of newcomer article contributions and number of newcomer article editors (H4a and H4b).[7]

These estimates are dependent on the burst of activity in the first week when message walls were in use. It is possible that this burst was, in fact, the immediate effect of message walls. Nevertheless, a short-lived effect is inconsistent with both the theory that motivated our study and the goals articulated by Wikia in implementing the new feature. Despite some evidence that the design change may have produced a short-lived flurry of activity, we conclude that the easier interpersonal communication made possible by message walls and the more frequent communication associated with its deployment did not result in corresponding increases in productivity.

Our findings suggest several possible avenues for future research. While these results report the overall impact of message walls on our population of wikis, we encountered enormous variation in our dataset. Conducting analyses of subgroups of wikis (based on factors like age or topic of the

[7]Full results of these models are included separately in our online supplement described at the end of this paper.

wiki) could shed light on whether and how various kinds of communities respond to such feature changes differently.

Additionally, further study on the message walls deployment could identify more granular effects of the intervention by analyzing whether certain kinds of communication are more likely before or after the transition (e.g., by seeing if editors ask more questions, or whether they are likely to reach out to new editors, and so on). While we have shown that message walls bring about a higher volume of communication, analyzing the content of the messages sent before and after the transition could help us identify whether and how the nature of communication might differ with the implementation of the new system.

7 CONCLUSION

This study contributes a large-scale observational test of prior work that connected ease of interpersonal communication with increased productivity and newcomer participation. The results contradict previous findings and challenge an important set of long-standing assumptions in the design of social computing systems. Message walls seem to have increased interpersonal communication with no apparent impact on production overall. Among newcomers, the adoption of message walls may have even decreased production. Our results suggest the need for more fine-grained and empirically-tested theories of any link between interpersonal communication and collaborative production.

Both Wikia and Wikipedia have now invested resources in revamping interfaces for communication on their platforms. This study evaluates the impact of one such system on communication and productivity. While many projects might consider implementing systems like message walls to facilitate easier communication on their platforms, they might not be sufficient to encourage productivity among the editor base or to increase participation by newcomers.

Finally, this work contributes a new process for conducting split-sample observational research for HCI and social computing. This approach allows us to ensure greater reliability and reproducibility of our analyses, and reduces the risk that our findings reflect spurious relationships, p-hacking, researcher and reviewer degrees of freedom, and other pitfalls of statistical inference common in the analysis of behavioral data. We recommend that future attempts at split-sample analysis continue to iterate on the process we have outlined in this manuscript and we urge the CSCW community to take steps to encourage and more fully accommodate this kind of procedure in its review cycle.

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SUPPLEMENTARY MATERIAL AND DATA

An online supplement was published alongside the paper and is available in the ACM Digital Library. We have placed an archival copy of this supplement, as well as code and data useful for replicating our analyses, in the Harvard Dataverse at the following URL: https://doi.org/10.7910/DVN/CZCRSI

REFERENCES

[1] Ahuja, M. K., and Galvin, J. E. Socialization in Virtual Groups. *Journal of Management 29*, 2 (2003), 161–185.

[2] Antin, J., and Cheshire, C. Readers are not free-riders: Reading as a form of participation on Wikipedia. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* (New York, NY, USA, 2010), CSCW '10, ACM, pp. 127–130.

[3] Antin, J., Cheshire, C., and Nov, O. Technology-mediated contributions: Editing behaviors among new Wikipedians. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work* (New York, NY, USA, 2012), CSCW '12, ACM, pp. 373–382.

[4] Balkundi, P., and Harrison, D. A. Ties, leaders, and time in teams: Strong inference about network structure's effects on team viability and performance. *Academy of Management Journal 49*, 1 (2006), 49–68.

[5] Benkler, Y. Coase's Penguin, or, Linux and "The Nature of the Firm". *The Yale Law Journal 112*, 3 (Dec. 2002), 369.

[6] Benkler, Y., Shaw, A., and Hill, B. M. Peer production: a form of collective intelligence. In *Handbook of Collective Intelligence*, T. W. Malone and M. S. Bernstein, Eds. MIT Press, Cambridge, MA, 2015, pp. 175–204.

[7] Bryant, S. L., Forte, A., and Bruckman, A. Becoming Wikipedian: transformation of participation in a collaborative online encyclopedia. In *Proceedings of the 2005 International ACM SIGGROUP Conference on Supporting Group Work* (New York, NY, 2005), GROUP '05, ACM, pp. 1–10.

[8] Cheshire, C., and Antin, J. The social psychological effects of feedback on the production of Internet information pools. *Journal of Computer-Mediated Communication 13*, 3 (2008), 705–727.

[9] Crowston, K., Annabi, H., and Howison, J. Defining Open Source Software Project Success. In *ICIS 2003 Proceedings* (Seattle, Washington, USA, 2003), pp. 327–340.

[10] Cummings, J. N., and Cross, R. Structural properties of work groups and their consequences for performance. *Social Networks 25*, 3 (2003), 197–210.

[11] Fafchamps, M., and Labonne, J. Using split samples to improve inference on causal effects. *Political Analysis 25*, 4 (2017), 465–482.

[12] Fé, E., and Hollingsworth, B. Short- and long-run estimates of the local effects of retirement on health. *Journal of the Royal Statistical Society: Series A (Statistics in Society) 179*, 4 (2016), 1051–1067.

[13] Foote, J., Gergle, D., and Shaw, A. Starting online communities: motivations and goals of wiki founders. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)* (New York, NY, 2017), ACM, pp. 6376–6380.

[14] Freedman, D. A. A note on screening regression equations. *The American Statistician 37*, 2 (1983), 152–155.

[15] Geiger, R. S., and Halfaker, A. Using edit sessions to measure participation in Wikipedia. In *Proceedings of the 2013 conference on Computer supported cooperative work* (2013), ACM, pp. 861–870.

[16] Gelman, A., and Loken, E. The statistical crisis in science. *American Scientist 102*, 6 (2014), 460–465.

[17] Halfaker, A., Geiger, R. S., Morgan, J. T., and Riedl, J. The rise and decline of an open collaboration system: how Wikipedia's reaction to popularity is causing its decline. *American Behavioral Scientist 57*, 5 (May 2013), 664–688.

[18] Hill, B. M., and Shaw, A. The hidden costs of requiring accounts online: Quasi-experimental evidence from peer production. *Unpublished manuscript Under review*.

[19] Ioannidis, J. P. A. Why most published research findings are false. *PLOS Medicine 2*, 8 (2005), e124.

[20] Kiene, C., Shaw, A., and Hill, B. M. Managing organizational culture in online group mergers. *Proceedings of the ACM on Human-Computer Interaction 2*, CSCW (2018), 89:1–89–21.

[21] Kittur, A., and Kraut, R. E. Harnessing the Wisdom of Crowds in Wikipedia: Quality Through Coordination. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (New York, NY, USA, 2008), CSCW '08, ACM, pp. 37–46.

[22] Kittur, A., and Kraut, R. E. Beyond Wikipedia: Coordination and conflict in online production groups. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work (CSCW '10)* (New York, NY, 2010), ACM, pp. 215–224.

[23] Kraut, R. E., Resnick, P., and Kiesler, S. *Building successful online communities: evidence-based social design.* MIT Press, Cambridge, MA, 2012.

[24] Kraut, R. E., and Streeter, L. A. Coordination in Software Development. *Communications of the ACM 38*, 3 (1995), 69–81.

[25] Lakhani, K., and Wolf, B. Why hackers do what they do: Understanding motivation and effort in free/open source software projects. In *Perspectives on Free and Open Source Software*, J. Feller, B. Fitzgerald, S. A. Hissam, and K. R. Lakhani, Eds. MIT Press, 2005, pp. 3–22.

[26] Lave, J., and Wenger, E. Legitimate peripheral participation in communities of practice. In *Supporting Lifelong Learning: Perspectives on learning*, vol. 1. Routledge, 2002.

[27] Luther, K., Fiesler, C., and Bruckman, A. Redistributing leadership in online creative collaboration. In *Proceedings*

of the 2013 Conference on Computer Supported Cooperative Work (New York, NY, USA, 2013), CSCW '13, ACM, pp. 1007–1022.

[28] Malone, T. W., and Crowston, K. What is Coordination Theory and How Can It Help Design Cooperative Work Systems? In *Proceedings of the 1990 ACM Conference on Computer-supported Cooperative Work* (New York, NY, USA, 1990), CSCW '90, ACM, pp. 357–370.

[29] Morgan, J. T., Bouterse, S., Walls, H., and Stierch, S. Tea and sympathy: crafting positive new user experiences on wikipedia. In *Proceedings of the 2013 conference on Computer supported cooperative work* (New York, NY, USA, 2013), CSCW '13, ACM, pp. 839–848.

[30] Morgan, J. T., and Halfaker, A. Evaluating the impact of the wikipedia teahouse on newcomer socialization and retention. In *Proceedings of the 14th International Symposium on Open Collaboration* (New York, NY, USA, 2018), OpenSym '18, ACM, pp. 20:1–20:7. event-place: Paris, France.

[31] Murnane, R. J., and Willett, J. B. *Methods matter: Improving causal inference in educational and social science research.* Oxford University Press, New York, NY, 2011.

[32] Musicant, D. R., Ren, Y., Johnson, J. A., and Riedl, J. Mentoring in Wikipedia: a clash of cultures. In *Proceedings of the 7th International Symposium on Wikis and Open Collaboration* (New York, NY, USA, 2011), WikiSym '11, ACM, pp. 173–182.

[33] Narayan, S., Orlowitz, J., Morgan, J., Hill, B. M., and Shaw, A. The Wikipedia Adventure: field evaluation of an interactive tutorial for new users. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (New York, NY, USA, 2017), CSCW '17, ACM, pp. 1785–1799.

[34] Panciera, K., Halfaker, A., and Terveen, L. Wikipedians Are Born, Not Made: A Study of Power Editors on Wikipedia. In *Proceedings of the ACM 2009 International Conference on Supporting Group Work* (New York, NY, USA, 2009), GROUP '09, ACM, pp. 51–60. event-place: Sanibel Island, Florida, USA.

[35] Preece, J., and Shneiderman, B. The reader-to-leader framework: motivating technology-mediated social participation. *AIS Transactions on Human-Computer Interaction 1*, 1 (2009), 13–32.

[36] Ren, Y., Harper, F., Drenner, S., Terveen, L., Kiesler, S., Riedl, J., and Kraut, R. Building member attachment in online communities: Applying theories of group identity and interpersonal bonds. *Management Information Systems Quarterly 36*, 3 (2012), 841–864.

[37] Ren, Y., Kraut, R., and Kiesler, S. Applying common identity and bond theory to design of online communities. *Organization Studies 28*, 3 (2007), 377–408.

[38] Schneider, J., Passant, A., and Breslin, J. G. Understanding and improving Wikipedia article discussion spaces. In *Proceedings of the 2011 ACM Symposium on Applied Computing* (New York, NY, USA, 2011), SAC '11, ACM, pp. 808–813.

[39] Schweik, C. M., and English, R. C. *Internet success: A study of open-source software commons.* MIT Press, Cambridge, MA, 2012.

[40] Simmons, J. P., Nelson, L. D., and Simonsohn, U. False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant. *Psychological Science 22*, 11 (2011), 1359–1366.

[41] Viégas, F. B., Wattenberg, M., and Dave, K. Studying Cooperation and Conflict Between Authors with History Flow Visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2004), CHI '04, ACM, pp. 575–582. event-place: Vienna, Austria.

[42] Viégas, F. B., Wattenberg, M., Kriss, J., and Ham, F. V. Talk Before You Type: Coordination in Wikipedia. In *2007 40th Annual Hawaii International Conference on System Sciences (HICSS'07)* (Jan. 2007), pp. 78–78.

[43] Yeow, A., Johnson, S., and Faraj, S. Lurking: Legitimate or Illegitimate Peripheral Participation? *ICIS 2006 Proceedings 62* (2006).

[44] Zhang, X., and Zhu, F. Group size and incentives to contribute: A natural experiment at Chinese Wikipedia. *The American Economic Review 101*, 4 (2011), 1601–1615.

[45] Zhu, H., Zhang, A., He, J., Kraut, R. E., and Kittur, A. Effects of peer feedback on contribution: a field experiment in Wikipedia. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2013), CHI '13, ACM, pp. 2253–2262.

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