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Motivations to Use Multifunctional Public Goods in Organizations: Using Agent-Based Modeling to Explore Differential Uses of Enterprise Social Media

Abstract: This work conceptualizes enterprise social media (ESM) as a multifunctional public good that both supports communication that connects users directly and allows users to contribute or access communal information. We show how differing motivations to use an ESM—connective or communal goals—interact with individuals' perceptions of activity on a platform, and the consequences this has for individual participation decisions and the viability of the digital space. We begin with a case study of the adoption of an ESM platform within a single organization. We then apply findings from this case study, combined with broader theories of technology adoption, to create agent-based simulations. We show that the connective and communal aspects of an ESM complement each other and can spur adoption; we also identify the importance of information decay as a variable influencing collective adoption. We end with a discussion of the theoretical and practical implications of our results.

Keywords: enterprise social media, public goods, agent-based modeling, connective, communal

Introduction

Scholars and practitioners alike have trumpeted the potential value organizations might gain through adopting collaborative technologies that mimic the features and affordances of social media platforms. These products provide workers with new means of sharing information, developing connections, and creating a more collaborative and participatory organizational culture (Laitinen & Sivunen, 2020; Treem & Leonardi, 2013). Yet, because the ways individuals use these technologies is often discretionary, ESMs are a new example of a problem organizations have long faced regarding shared digital spaces: how to encourage contributions and activity from organizational members (e.g., Razmerita, et al., 2016; Wasko & Faraj, 2005).

Understanding ESM adoption involves considerations of the different motives individuals have for using a digital tool in an organizational context (Kalman et al., 2002; Yuan et al., 2005), the ways that the material functionalities of digital tools shape communication patterns, and the ways that communicative behaviors of other organizational members influence choices regarding technology use (Fulk, 1993). In this research, we seek to put work on connective and communal aspects of digital information goods in conversation with recent scholarship on the management of visibilities in digital spaces. From an applied standpoint, our research provides insights into why—despite the laudatory rhetoric around the benefits of ESM—organizations find it difficult to motivate members to engage with ESM in a sustainable manner. The majority of attempts to launch ESMs follow a similar pattern: an initial burst of enthusiasm followed by a precipitous drop in activity, with rates of ongoing use under 15% (Li, 2015; Rode, 2016).

We look at ESM adoption and use from the perspective of user motivations and perceived critical mass. We argue that different uses of an ESM can produce different perceptions of how popular an ESM is and thus shape employees' motivations to use the technology. We begin with

a case study of workers' perceptions of an ESM and their plans for adoption at a single organization. We then take the primary findings from this case study, combined with broader theories of technology adoption and social behavior, to create a set of agent-based models: computational simulations where programmed agents act according to rules. Our simulations model people choosing whether and how to interact with an ESM system, based on their perceptions of how much it is being used. These agent-based models allow us to (a) explore how the connective and communal aspects of a combined public good interact and (b) explore how different approaches to seeding the platform or encouraging initial contributions influence outcomes.

Theoretical Background

ESM as a Multifunctional Public Good

In an influential paper, Fulk et al. (1996) argue that information technologies often act as public goods. These are goods that are non-excludable (anyone can use them) and non-rivalrous (use by one person does not diminish use by another). Canonical examples include clean air, public parks, and lighthouses (see Olson, 1965; Samuelson, 1954). Fulk et al. (1996) argue that different information technologies represent two distinct types of public goods: connective goods and communal goods. Connective goods allow users to get in contact with someone quickly and to share one-to-one information. Telephones, e-mail, and chat platforms all largely support connective functions. Communal goods are things like shared databases or wikis—when information is added by one person it becomes available to everyone.

A public goods framework provides one explanation for why an individual might not contribute to a shared organizational resource like an ESM (Fulk & Yuan, 2013). From a rational choice perspective, it makes sense for individuals to use public goods without contributing to them, potentially creating a *tragedy of the commons* in which the good eventually has little value

for anyone (Hardin, 1968). However, we also know that use of shared technology systems can provide benefits to those who contribute, such as social influence and increased status (Fulk et al., 1996). Thus, we can view a worker's decision of whether to contribute to an information public good as a social dilemma, in which individuals must weigh the potential benefits against the costs (material and social) of expending resources for the benefit of others (Cabrera & Cabrera, 2002). Connective and communal goods present different sets of costs and benefits, and different communication technologies present different dilemmas for users choosing whether to contribute (Kalman et al., 2002).

The diverse functionalities and uses of ESM mean that it does not fit neatly as either a connective or a communal information good. Leonardi et al. (2013) define ESM as:

> Web-based platforms that allow workers to (1) communicate messages with specific coworkers or broadcast messages to everyone in the organization; (2) explicitly indicate or implicitly reveal particular coworkers as communication partners; (3) post, edit, and sort text and files linked to themselves or others; and (4) view the messages, connections, text, and files communicated, posted, edited and sorted by anyone else in the organization at any time of their choosing. (p. 2)

As such, ESM supports interpersonal interactions *and* operates as a knowledge resource that persists over time (Rode, 2016).

In other words, we can view ESM technology as a multifunctional public good that can support both connective and communal activities. In part because previous information and communication technologies were not as robust or flexible as contemporary offerings, little work has directly theorized about the use of multifunctional public goods in organizations. For example, Fulk et al. (1996) conceptualized the personal computer as providing individuals access to multi-

ple public good functions but viewed functions as associated with different technologies: email providing connectivity and electronic bulletin boards providing communality. Similarly, Yuan et al.'s (2007) study of the interdependent relationship between information exchange through communal means and connective means looked at the two forms of communication as enacted through different technological systems. Unlike many previous technologies, ESM offers users the ability to engage in communal and connective communication within the same software. Fulk and Yuan (2013) argue that a public goods framework is valuable for the study of ESM use because its multifunctionality, and different levels of visibility associated with use, can produce varied motives for individuals to use the platforms. While some empirical work has explored how particular affordances influence ESM adoption (e.g., Leonardi, 2014; Pee, 2018; Sun et al., 2020; Van Zoonen et al., 2022), the specific role that multifunctionality and diverse motivations play in ESM adoption patterns is both undertheorized and understudied.

Motivations to Contribute to Digital Public Goods

In many respects the context of digital public goods is similar to other technology adoption decisions, and therefore can be informed by the literature examining what drives choices individuals make in other contexts (Davis, 1989; Venkatesh et al., 2003). Technology adoption studies argue that the primary factors predicting whether an individual will use a technology are (a) the perceived usefulness of the technology and (b) the perceived ease of use of the technology. This aligns with findings regarding what motivates contributions to digital public goods by positioning the decision as a weighing of the perceived benefits associated with engagement with the technology (i.e., usefulness) against the perceived costs (i.e., ease of use).

Perceived benefits and associated motivations may differ depending on the functionality of an information public good. One motivation to use a connective public good is the expectation

that a message will connect the user with other members of a network, termed *connective efficacy* (Kalman et al., 2002). In terms of communal goods, workers may have different motivations for seeking information, collecting information, or contributing information (Heinz & Rice, 2009). For instance, individuals are more motivated to contribute to an electronic knowledge repository if they have found useful information in the repository and if they feel that the information they are providing might be useful to others (Rice et al., 2017; Wasko & Faraj, 2005). On the other hand, some recent work looking specifically at ESM use found that workers' satisfaction in helping others was not significantly related to ESM participation (Rode, 2016).

Empirical research indicates that these motivations are influenced by what is visible on an ESM. One of the primary motivations for using an ESM is increased attention and reputation (DiMicco et. al., 2008). Visible signals that others have seen one's contributions, such as the presence of likes, comments, and view counts increase the motivation of individuals to use an ESM (Yardi et al, 2009). On the other hand, the potential visibility associated with communal uses of ESMs may deter participation when workers experience anxiety and uncertainty regarding who will view their communication and how it may be perceived (Treem, 2015; Van Zoonen et al., 2022). As a result, workers may decide to access content or observe others rather than more visible actions like contributing content or attempting to connect with others.

Communication visibility might be best viewed as neither positive nor negative, but something that individuals seek to manage based on situated motivations and goals (Flyverbom et al, 2016). Viewing ESM as a context for visibility management encourages us to attend more to assessing the ways that individuals perceive the communicative space and their possibilities for action, and less to the overall visibility of communication on the platform—which is often the focus of studies of organizational knowledge sharing. As discussed, connective and communal

uses of ESM are associated with different types of visibility in terms of who has access to communication and for how long. Visibility management in the context of public goods also requires that we attend to how use of the good by others alters the perceived costs and benefits of communication for any given individual. To understand how the multifunctional nature of ESM platforms relates to motivations, we ask:

RQ1: What are the connective and communal motivations to use ESM platforms?

Digital Information Goods, Perceived Critical Mass, and Communication Visibility

When technologies like an ESM are implemented as public goods—with broad availability and discretionary participation—the goal is to achieve a "critical mass" of use such that the collective good becomes viable and self-sustaining over time (Markus, 1987; Marwell & Oliver, 1993). Critical mass is possible because digital information public goods constitute a network of potential communicative relations (Rohlfs, 1974)—both between individuals as well as between individuals and communally available content. Network growth through engagement with the public good (either additional users or additional content contributions) constitutes a network externality, meaning that the value of the good changes as the number of users and amount of content changes (Tucker, 2008). While there are conditions in which adding more people to a network does not improve group communication—for example, when people or groups become cut off from the rest of the network (Rice, 1982)—in general, increased participation is a positive network externality in the sense that it creates more potential communication partners.

Similarly, contributions of content to a public good are often encouraged based on the logic that they provide incremental value to the network. However, research on information overload demonstrates that as repositories of communication grow they can become unwieldy, noisy, and make it harder for individuals to locate information (Eppler & Mengis, 2004; Karr-

Wisniewski & Lu, 2010). Additionally, when individuals experience overload they may retreat from a communicative environment as a coping mechanism (Bawden & Robinson, 2009). However, in general more content is seen as a positive determinant of critical mass.

Critical mass, as a specific threshold, is not easy to quantify objectively and varies widely across contexts of digital communication (Morris & Ogan, 1996). Given the operational variability of critical mass, some scholars advocate that when considering issues around technology use, *perceived critical mass* is a better lens to understand individuals' behaviors (Lou et al., 2000; Van Slyke et al., 2007). In the context of participation and communication on an ESM, perceived critical mass would reflect an organizational member's belief that a sufficient number of contacts can be reached (connectivity) or a sufficient collection of content can be accessed (communality). For example, an individual who searches for information and finds nothing may perceive a lack of critical mass and no value, may find exactly what they seek and perceive the ideal level of critical mass, or find a plethora of irrelevant information and perceive the public good as overloaded (Chen & Wei, 2019). Kraut et al. (1998) discuss how perceived critical mass reflects both material and social aspects of public goods use. As more individuals use a technology, it becomes more useful in a material sense as communication becomes possible with more people in the organization. This increase in users can also facilitate social and normative pressures favoring adoption. The utility of perceived critical mass as a mechanism for driving adoption and use of technologies has been demonstrated in the context of email (Rice et al., 1990), 3G mobile services (Cho, 2011) and social networking sites (Lee et al., 2013).

In the context of ESM, it is possible that perceived critical mass operates as one means for individuals to assess whether they are likely to achieve their goals related to communication visibility. Scholars have noted the need to further develop theory regarding how increased digi-

talization of behaviors through technologies changes how individuals perceive and pursue communication visibility (Fu & Cooper, 2022; Leonardi & Treem, 2020; Reischauer & Ringerl, 2023). If perceived critical mass is a product of the way users experience a digital information good, then it is important to consider in more detail how aspects of an ESM would be visible or known to workers. For example, an individual looking to send a message to another individual or group may expect to be able to find those individuals active on the platform. Alternatively, an individual seeking knowledge regarding a specific organizational policy may expect to find a discussion post related to that topic. Therefore, one way to view the relationship between workers' motivations and their evaluations of the usefulness of the ESM is to assess how their motivations relate to the communication visibility they experience when using the ESM. Different individuals using the ESM in different ways will experience different forms of communication visibility, which will shape the likelihood the ESM will be able to provide the benefits sought. Moreover, their use of the ESM itself will alter communication on the ESM in ways that are then potentially visible to other members, and may influence others' perceptions of whether the ESM has or will reach critical mass. Based on these dynamics, we pose the following questions:

RQ2: How do different motivations for use influence the way that organization members experience communication visibility and assess the perceived critical mass of an ESM platform?

RQ3: What experiences of communication visibility increase perceptions of critical mass in a manner that increases the likelihood of widespread ESM adoption?

We took a multi-method approach to address these questions. First, we conducted a case study of ESM adoption to gain a deep understanding of how people form perceptions of an ESM system and how they make decisions about whether or not to use it. In particular, the case study examined whether individuals had different motivations for using the ESM, and how initial expe-

riences using the platform related to decisions about ongoing use of the ESM. We then used these findings to build an agent-based model of ESM adoption, in which simulated users seek to (a) connect to others, (b) search for information from a shared information repository, and (c) add information to the information repository. Using this model, we ran a number of "virtual experiments" to explore various dynamics and conditions that might influence ESM adoption.

Empirical Case Study

Methods

To develop an empirically-grounded understanding of workers' motivations for use of an ESM platform, we conducted a case study examination at the Dutch branch of ATA (a pseudonym), a global financial company offering auditing, tax, and advisory services. Two months before our research began, ATA had implemented an ESM platform, which we will call "Gateway." Gateway was a tailored implementation of TIBCO's Tibbr enterprise social platform, hosted on the organization's servers and available to all ATA workers. In terms of both appearance and features, Gateway provided functionalities similar to most public-facing and enterprise social media platforms: personal profile pages, following of other users, a feed of recent content on individuals' pages, discussion threads, and the ability to post, search, like, and share content. Management noted that they intended to provide an ESM that was intuitive, and which would appear and operate similar to platforms like Facebook, LinkedIn, and Twitter. According to messages provided by management to workers at ATA, the goals in implementing the ESM were to "break down geographic and time barriers," "enable a mobile workforce," "foster open communication," and "connect people beyond existing networks." At the start of our study, 3,327 employees had access to the tool, 1,147 of whom had registered on the platform, and 365 (11%) were actively using it in terms of posting content, responding to posts, etc. These numbers fluctu-

ated throughout the course of our study but did not differ much from the initial values.

Data Collection

As the research objective was to identify the influence of perceived critical mass on the use of Gateway, only active users of the platform were included in the sampling frame. We were broadly inclusive of what constituted an active user and were open to including any worker who had experience with Gateway. Users were approached via e-mail and not via the tool, as it was known that not all active users (according to our definition) accessed the tool regularly. Participation was voluntary, and participants were not paid nor encouraged by management to respond to interview requests.

A total of 39 employees were interviewed, equally distributed across the three main departments within ATA: Audit (13 users), Advisory (13 users), and Shared Services (13 users). Interview questions were related to perceptions and use of Gateway. Additionally, 33 of our participants consented to be followed on the platform. We performed a content analysis of their activities, which served to provide a first indication of their use of the platform and was used as input for the interview guide for the specific participants. Interviews lasted between 20 and 60 minutes, and were transcribed as soon as possible after each interview, facilitating ongoing theoretical sampling in which insights emerging during early interviews were taken into account in subsequent interviews.

Data Analysis

For the analysis of the content that users shared on Gateway, we followed a deductive thematic analysis approach that was more "prior data or prior research driven" in the words of Boyatzis (1998, p. 29). Here, we used a coding scheme that we had developed, validated and applied in a previous study on the use of an ESM *(reference withheld for review purposes),* and that

was based on different kinds of activities that users deployed on such a platform. Our analysis was aimed at determining how many instances of each of these activities were found in the content generated by the respondent, but also what topics the users talked about, and if this was related to their daily tasks. The extent to which activities were related to one's job indicated whether the employee was still experimenting with use or was already extracting benefits in performing daily tasks. Furthermore, we analyzed the persistence of activities over time: repeated activities were an indication of continued use, whereas one-off questions or messages (without follow-up) indicated initial use. The findings from this content analysis were included in the interviews, where we validated our impressions from the content analysis and explored users' experiences with Gateway in more detail.

Our analysis of the interviews was based on thematic analysis, aimed at identifying, analyzing and reporting themes within the data. We followed a hybrid method of thematic analysis, combining the deductive template approach outlined by Crabtree and Miller (1999) with the data-driven inductive approach described by Boyatzis (1998). Further details about our analyses of both the content shared on Gateway and the interview data can be found in Appendix A1 in the online supplement.

Case Study Findings

We found that users of Gateway were at different stages of experience regarding use of the technology. Specifically, based on our interviews and observations of participants' behavior on Gateway, we identified a distinction between workers in a stage we labeled *initial use* (about one-third of our participants) and other workers (the remaining two-thirds) who we classified as having moved on to a stage labeled *continued use*—a distinction that echoes previous findings in the literature on CMC use (e.g., Hiltz & Turoff, 1981; Jung, 2011), as well as the IS literature on

post-adoption behavior (Jasperson et al., 2005) and continuance (Bhattacherjee, 2001). Workers in the *initial use* category described their goals as exploring the tool, becoming familiar with the technology, and experimenting with its functions to find out whether it would be valuable for work. Employees engaged in *continued use* referenced incorporating Gateway into their daily work and using it on a regular basis for communication, knowledge sharing, and task-based collaboration. Although, as we will discuss, perceived critical mass influenced both stages of ESM use, users' comments indicated it played the largest role in the transition from initial use to continued use.

From Initial Use to Continued Use

Initial Use. Comments by workers in the initial use phase indicated that they were still determining whether the technology was useful. Workers in this category noted they had yet to benefit from Gateway but had not dismissed the possibility of reaping future benefits should they continue use. Analysis of the activity of workers in the initial use phase showed that they did not use Gateway to post questions about daily work activities, but instead talked about general topics such as 3D printing or lunch breaks. Use of Gateway by workers at this stage did not have immediate relevance to work task completion.

Continued Use. Workers who had used Gateway over an extended period of time noted that they realized benefits from use of the technology that aided in their work. Specifically, content analysis of activity on Gateway showed that these users mostly asked and replied to questions that had immediate task relevance. Table A3 in the online supplement provides codes and exemplary quotes for both stages of use.

Perceived Critical Mass

The presence of one group of users who were active on the ESM and could potentially

contribute to the collective good (initial use), and the presence of another group that was already contributing to the collective good (continued use) allowed us to examine the role of perceived critical mass in the viability of the ESM as a collective good.

Respondents indicated that perceived critical mass was a key influence on decisions regarding whether to discontinue use of the ESM or transition into more sustained, continued use. For example, one participant said:

> But if I know that everyone is connected to [Gateway], and they pop up on a screen or something, or on their iPhone, then I would be more inclined to use [Gateway], because I know I [can] reach those people.

However, how respondents assessed perceived critical mass differed substantially depending on the motivations and goals users had when engaging with Gateway; specifically, whether workers were primarily interested in connecting with other workers (connective use) or providing and accessing content (communal use). How these two different usage types were influenced by perceived critical mass, and how different uses relate to the transition from initial to continued use, is addressed in the following sections.

Connectivity

For workers seeking to use Gateway to connect with other ATA employees, their priority was the ability to reach individuals or groups on the platform. Given this goal, perceived critical mass manifested through signals to a user that others were using Gateway—through others responding to one's post, answering a question, or accepting a request. Respondents noted that when they did not find evidence that others were present and able to be reached on Gateway the ESM had little value to them, as there were other ways to connect with coworkers. The possibility of connectivity required some signal to users that communication was being received; ideally

this would take the form of a communicative response from another user. Absent perceived critical mass, those prioritizing connectivity had little reason to move from initial to continued use.

Specifically, two dimensions of the relationship between critical mass and connectivity emerged in the interviews with workers: confirmation and network presence, both connecting to earlier work on the importance of reciprocity and visibility in ESM use (e.g., Leonardi, 2014; Rode, 2016). Confirmation refers to communication signals that provide the user the impression that others are using the ESM. This occurs through the confirmation of actions, inputs, and contributions (e.g., others responding to one's posts). Network presence concerns workers' aim to reach a broad network of other workers, which was seen as beneficial in cases where the user needed to spread news or needed input from many different people. Table A4 in the online supplement provides examples of comments reflective of these dimensions.

In general, for individuals seeking connectivity as the primary function of Gateway, a perceived critical mass of available others served as a clear criterion in the movement from the initial use stage to the continued use stage.

Communality

Workers at ATA motivated by communality were more concerned with whether a perceived critical mass of valuable content was available on Gateway. Specifically, our analysis revealed that communality had three dimensions: perceived usefulness, perceived relevance, and perceived information overload—echoing concepts identified in the literature on CMC use more broadly (e.g., Hiltz & Turoff, 1985; Liang & Fu, 2017). Whereas perceived usefulness refers to the extent to which the information found on Gateway would be useful in users' daily tasks, perceived relevance concerns users' perceptions of whether the content available on the platform was related to their work, even it was not directly useful for a task they were currently involved

in. Perceived information overload was seen as an important barrier to achieving communal goals: users expressed concern with the amount of information they were asked to confront or sort through on the platform, feeling that Gateway already presented more content in certain areas than any single worker could read or use. Table A5 in the online supplement shows examples of comments for each of these dimensions.

In general, respondents who perceived a critical mass in terms of useful content or relevant information were more likely to make the transition from initial to continued use of Gateway. However, because workers focused on communal use were interested in content, they were not dependent on active participation by any other user at the time of access. Once content was provided it could have repeated benefits for users needing that content in the future through individual-to-content relationships. Indeed, workers noted that the threshold for perceived critical mass was potentially lower related to content (i.e., communality) as they only needed to encounter some material that was personally relevant. Respondents also noted that unlike with connectivity, where users desired the maximum possible number of other users for potential communication, too much content could make it more difficult to find valuable information and could undermine communal goals.

Case Study Discussion and Limitations

With regards to Research Question 1, the comments from workers at ATA indicated that users of Gateway had distinct motivations when initially engaging with the ESM, and that most of these motivations could be categorized as taking advantage of the connective capabilities of the ESM, the communal capabilities, or both. Alone these results are neither surprising nor particularly novel, and are consistent with previous research on digital information public goods (i.e., Kalman et al., 2002; Yuan et al., 2007), but confirming this distinction between motivations

is necessary before exploring the relationships to perceived critical mass. Regarding Research Question 2, which looked at how different motivations are connected to perceived critical mass, our findings demonstrate that perceived critical mass, and the ways communicative visibility shapes perceptions, operate differently depending upon whether workers are engaging with an ESM to meet connective goals or communal goals. Those using the ESM for connection perceived critical mass based on being able to reach another user while those using it for information associated critical mass with the ability to access desired content.

Conceptually, the distinction between initial use and continued use is representative of, and consistent with, findings that individuals use communication technologies with particular goals in mind, determine whether the technology can meet those goals, and use those assessments to make decisions about ongoing adoption (Leonardi, 2011). Put differently, workers at ATA initially using Gateway were engaged in a process of learning if and how the technology might help them relative to their respective communicative goals. Similar to findings on how workers use ICTs for learning (e.g., Kane & Alavi, 2007), initial use of Gateway facilitated a form of exploration in which users tested the potential benefits of the ESM, while ongoing use operated as a form of exploitation in which workers sought to derive additional benefits over time. Perceived critical mass served to signal opportunities for ongoing exploitation due to expected positive network externalities. However, the differences in motivations among the users indicate that individuals approached Gateway seeking a particular form of communication, creating the possibility that individuals exploring for connective communication might encounter communal communication and choose not to exploit the communal possibilities (and vice versa). This indicates the need for alignment between the motivations for use of a public good and signals provided so individuals learn that opportunities for exploitation exist.

Regarding Research Question 3, which examined what contributed to the likelihood of ongoing adoption of an ESM, our case study findings identify a self-reinforcing cycle between ESM use and perceived critical mass: The continued use of Gateway by workers is influenced by the perception of a critical mass; in turn, the activities (or lack thereof) of each user influence others' ongoing perceptions of critical mass. This reciprocal pattern implies that mechanisms which increase perceptions of critical mass can lead to cascading changes in behavior (and future perceptions of critical mass) that build momentum over time.

This case study has several limitations that restrict our ability to theorize more broadly about the relationships between users' motivation for engaging with ESM, the communicative signals that might encourage ongoing use of an ESM, and how an ESM as a public good might thrive or die out over time. Most importantly, our research only looked at a limited sample of users in a single organization, at a single point in time, using a single (now somewhat outdated) ESM platform. While our approach gives a rich understanding of how workers decided whether to participate in this ESM we are limited in our ability to consider long-term dynamics or how differences in the attributes of an organization, features of ESM software, or a rollout strategy might influence adoption. The case study provides evidence that the adoption of ESM is a complicated, non-linear process which is dependent on local perceptions of critical mass and individual communicative goals. These perceptions are recursively influenced by the actions and inactions of others, which suggests the existence of complex feedback loops. In order to explore the implications of these findings, we turn to agent-based modeling.

Agent-Based Models

While we can build up intuitions about group-level behavior through understanding individuals, further knowledge regarding reciprocal, recursive interactions can be gained through

agent-based models (Lazer & Friedman, 2007; Smith & Rand, 2017). Agent-based models (ABMs) are computer programs that simulate computational agents acting according to well-defined rules and allow us to observe how different starting conditions and different rules produce different higher-level behaviors. Rather than seeking for universal rules, ABMs help to understand a system that is "complex, interactive, and conditional" (Marwell and Oliver, 1993, p. 25). In our case, for example, instead of looking at population-level patterns of adoption and deducing global rules about the size of the critical mass needed we conceive of perceived critical mass as an individual-level phenomenon. In ABMs, each individual agent has their own perception of the world and makes decisions based on local conditions and their past experiences.

Although using ABMs is not common in communication scholarship, this form of analysis has been used to study group and organizational communication processes (e.g., Garner, 2016; Palazzolo, 2005). Recently, Waldherr et al. (2021) argued that ABMs are an ideal tool for communication researchers studying interdependent processes. Like all models, the goal of ABMs is not to capture everything about the real world but to capture the essence of the situation being modeled and to show how changes to assumptions or parameters change outcomes (Lazer & Friedman, 2007). ABMs are particularly well-suited for exploring how higher-level behavior emerges from individual level decisions (Macy & Willer, 2002). A significant benefit of utilizing simulations is that they allow for the testing of processes across a variety of organizational conditions (e.g., group size or features of technology) that would be difficult to access or control otherwise (Smith & Conrey, 2007). Like other methods, ABMs come with a set of assumptions and limitations to their validity. Just as researchers using a regression-based design must justify their measurements of constructs and chosen statistical approach, researchers using ABMs must justify the structure of agent interactions and the algorithms and parameters used to determine

how agents make decisions (Macy & Willer, 2002; Smith & Rand, 2017). ABMs and mathematical modeling were important for the development of theories of critical mass in both the context of technology adoption and collective action (Bass, 1969; Marwell & Oliver, 1993). We use a similar approach to model not a single adoption decision, but how users perceive critical mass and continuously adjust their participation in a multifunctional context with both connective and communal functions, and how their decisions influence others.

Methods

We use our findings from the case study, combined with theories of online collaboration, to build up a conception of how people decide whether and in which ways to participate in an ESM. We then formalize this understanding by using the Python framework Mesa (Kazil et al., 2020) to create a set of agent-based models with computational agents that act according to rules based on our case study and theory. We observe the behavior of these agents with different starting parameters to make inferences and generate hypotheses about the features that influence whether an ESM will be adopted as a communal and/or connective public good.

In the case study, we found that people typically used Gateway to meet either connective or communal goals. When seeking to connect with others, critical mass was perceived based on whether others were responsive. When seeking information (i.e., communal goals), critical mass was perceived based on the ability to find the information sought. In each case, success in meeting one's goals led to a perception that the ESM was both useful and that it was at or would reach critical mass. Successes led participants to be more active on the ESM in the future.

We model the key aspects of this decision-making process by simulating a set of people (agents) who interact with each other and with an 'information space.' First, we describe how the general model works, and then explain our three key scenarios: a purely connective good, a

purely communal good, and a multifunctional good representing a modern ESM.

The information space is composed of a set of information 'locations' which represent items of information that might exist in an enterprise social media system. For example, one location might represent instructions for signing up for the company retirement plan while another represents the strategy for the coming year. We model information in each location in the information space as either existing or not. The *initial information proportion* is the amount of content in the information space when the simulation starts. In an ESM, new information is continuously being added, and much of the information quickly becomes outdated or difficult to find. In our case study, participants described this as information overload. Because participants not finding relevant information were unlikely to continue use of the ESM, a pattern consistent with extant research on technology use and overload (Bawden & Robinson, 2009; Eppler & Mengis, 2004), we model information as decaying over time. In the information space, each piece of information has a random chance of disappearing each day with a given probability which we call the *decay rate*. Although counterintuitive, decay is a useful means of modeling in a simple way both information becoming irrelevant and information overload because in both processes some pieces of information become more difficult to find. Of course, this simplicity comes at a cost and information decay fails to capture some aspects of information overload, such as search costs that increase with the amount of information.

The agents in our model act by either attempting to connect with other agents or by interacting with the information space. Each individual agent has a 'state' which is inspired by the findings from our case study and composed of four probabilities: the probability to be active (*activity probability*), to try to connect with someone (*connect probability*), to search for information (*search probability*), and to contribute information (*contribute probability*). Every 'day' they act

according to these probabilities and update them. At the beginning of each simulation, every agent has the same probabilities for taking each type of action as the other agents.

Each 'day' agents choose whether to log onto the ESM based on their *activity probability*. In the case study, we found a difference between initial use and continued use: For those who had moved to continued use, logging into the ESM simply became part of their daily work. As we describe below, agents who find evidence of critical mass increase their *activity probability*. If a user becomes active on a given day, they then decide which other actions to take: whether to try to connect, to search for information, and/or to contribute information. We learned from our case study that connective and communal behaviors are fairly independent, and so we model them as being separate: an agent could perform some of them, all of them, or none of them.

Connect probability represents the likelihood that an agent will try to use the ESM as a connective information good. When an agent tries to connect, they choose another random agent; if the other agent is active on that day, then their connection is successful. This reflects the findings regarding connectivity from the case study of Gateway users who, when they found signals that others were available and active on the platform, perceived it as having critical mass and being useful. Therefore, in terms of the model we assume that a successful connection is how agents assess whether to keep using the ESM to connect. If they are successful in connecting, they are more likely to try again—in other words, they increase their *activity probability* as well as their *connect probability*. On the other hand, if the agent they try to connect with is not active, they decrease both of these probabilities.

We model communal motivations using the *search probability* and *contribute probability.* Each day that an agent is active they choose whether to search for information. If they choose to search, the agent chooses a random location in the information space and checks whether the in-

formation they are searching for exists. A central finding from the case study was that when users had communal motivations, they perceived both the usefulness of the ESM and the existence of critical mass based on their ability to access content perceived as useful or relevant. Users who were successful were more likely to continue using the platform. Therefore, if the information an agent is looking for exists they increase their *activity probability* and their *search probability*. Conversely, if it does not exist they decrease both of these values. It is worth noting that this stylized version of information search neglects unintentional information collection that occurs when active ESM users are exposed to information that they didn't seek out (Heinz & Rice, 2009; Leonardi, 2014).

Agents undergo a similar process when deciding whether to contribute. If the coin flip based on *contribute probability* means that an agent attempts to contribute on a 'day,' then they choose a random location in the information space. If the information does not exist then they add it. Participants in our case study did not discuss their motivations to contribute to communal aspects of ESM, but previous research suggests that people feel generalized reciprocity when using electronic resources (Wasko & Faraj, 2005). Therefore, if a search for information is successful, then the agent also increases their *contribute probability.* Conversely, they lower their *contribute probability* if a search is unsuccessful. Theory is less clear about how success or failure in contributing to a good would change future intentions to contribute and intuitions could lead us in either direction. For example, if the information someone wants to add to an information resource already exists, then perhaps this would increase their sense that the information good is popular and valued and increase their likelihood of contributing in the future. On the other hand, if a piece of information already exists then the user might feel that their knowledge is not needed. Related arguments apply for when the information does not already exist. We therefore

simplify our model by assuming that these forces cancel each other out: whether an agent is successful in making a contribution does not change their probability to be active or to contribute in the future. *Contribute probability* therefore only changes based on how successful an agent is at finding information, as explained above. The function used to determine how quickly each probability changes is explained in Appendix A2 in the online supplement.

Outcome Measures

We use the ABM to perform a number of "virtual experiments" by varying the initial conditions of the agents and the system. The values that parameters take in the simulations are guided in two ways: first, we use the results from our case study and previous research to identify a set of feasible values. Parameters for an ABM can come directly from experiments or observations (Smith & Rand, 2017); in our case, we used our qualitative research to identify the key processes occurring but we did not directly measure things like the probability to try to connect or to add information. Our second guide for choosing parameters is to consider the types of interventions that an organization might make and to attempt to model those. Organizations that want their ESM to succeed could be tempted to take several approaches, from seeding the ESM with content to attempting to increase initial activity levels through internal marketing or trainings. We simulate these sorts of interventions through changes to either initial probabilities for agents to take certain actions or through changing the *initial information proportion* parameter. In order to simplify the models, all of the simulations include 50 agents and an information space of 100 items of information.

We focus on outcome measures related to the success of the ESM as a connective and a communal good. We measure (a) the amount of information added to the information space and (b) the proportion of agents who are active on the system over the first 1,000 'days'. To analyze

the influence of the parameters on these two outcomes, we plot the longitudinal evolution of each simulation and provide summary information about simulations with the same parameters.

Connective, Communal, and Multifunctional Goods

In order to better understand the role of ESMs as multifunctional communication goods we simulate three different classes of communication goods: purely connective goods, purely communal goods, and multifunctional goods. We simulate a pure connective good by setting the *search probability* and *contribute probability* to 0. In this situation, people's behaviors are determined solely by their desire to connect, and they are not influenced by the state of the information good. In this set of simulations, we model an organization encouraging people to log in and to reach out to others by varying the initial *activity* and *connect* probabilities. Additional information on the specific parameter values tested for all of the simulations is given in Appendix A2 in the online supplement.

We next simulate a communal (information) good acting in isolation. In this case, users do not ever try to connect with other users. They simply search for information and decide whether to contribute to the information good. This decision can be influenced by the *activity*, *contribute*, and *search* probabilities. These changes might represent an organization's efforts to internally market the existence of the communal good, to encourage contributions, or to build a good search interface. We also vary aspects of the information space by exploring how changes to the information *decay rate* and the initial *information existing proportion* influence how much people contribute to the information good.

We then simulate something closer to a modern ESM, with both connective and communal goods, and test how these goods interact with each other. In these simulations, users try to connect with others, try to search for information, and try to contribute information. As explained

above, success either connecting or searching leads to more activity, while failure leads to less. For this set of simulations, we run a sweep of plausible values for all parameters included in the earlier models: *activity, connect, contribute,* and *search* probabilities for agents, as well as *decay rate* and *information existing proportion* for the information space.

ABM Results

The results of these thousands of simulations are explained here and shown in Figure 1 and Figure 2, as well as Figures A2 through A4 in the online supplement. Each figure is composed of subfigures, which show all of the simulations at a given parameter value. For example, in Figure 1 the top left subfigure shows the simulations when starting with the *activity probability* set to 0.1. Within each subfigure, a single simulation is represented by a thin, gray line. The x-axis represents time, while the y-axis shows either the activity level or the proportion of the information space that is filled. The thicker, colored line shows the smoothed mean for that subfigure.

Connective Public Goods

When a good is only a connective good, the outcome in our simulation is straightforward, as shown in Figure A2 in the online supplement. If the activity probability starts low then the connective good fails, no matter the initial connect probability. Conversely, when the activity probability starts high the connective good succeeds. Only at the moderate activity probability of .5 is the outcome indeterminate.

The explanation is fairly simple: whenever the overall *activity probability* is at least .5 an agent seeking to connect with a random other is more likely to be successful than unsuccessful. When they are successful, they will be more likely to be active and to try to connect in the future. Conversely, if they are unsuccessful they will be less likely to be active and to connect. It is worth noting that the specifics of these dynamics are due to how we defined the relationship be-

tween activity and the connect probability. For example, we could have defined an asymmetric relationship where a successful connection increases the connect probability less (or more) than a failed connection attempt reduces it. Changing the functional form of these relationships would change the level of activity probability at which outcomes are indeterminate but it would not change the more general implication: initial activity levels and not initial connect probability are what drives the success or failure of a purely connective public good.

Communal Public Goods

When we looked at communal public goods acting in isolation, we found the behavior of the system to be much more complicated. At the individual level, people still query their environment for evidence of a critical mass, but now for a critical mass of content. As with a connective good, when the information space is less than half full people's information searches are more likely to be unsuccessful and their probability to search, contribute, or be active will all decrease. However, unlike with connective goods, starting with a sparse information good does not necessarily mean that the system will be in a worse condition the following 'day' or enter a negative spiral. This is because information is semi-persistent, so the amount of information can grow even when most searches are unsuccessful. This happens whenever information is being contributed faster than it is decaying, as shown in Figure A4 in the online supplement. There is, therefore, a race between how quickly a population becomes disenchanted with an information good and how quickly the information good improves to the point that it begins to encourage rather than discourage participation. For example, in Figure A3, even when the initial information amount is only 10% there are many simulations that result in high activity. Search has an interesting relationship with this race: instead of always being beneficial, a high initial propensity to search can be harmful if content does not already exist; people's searches will fail and they will

reduce their probability to contribute, as seen in the top row of Figure A3.

Conversely, Figure A3 shows that seeding a space with lots of content is not foolproof: even when the information space starts 90% complete, some communal goods fail. If information decays more quickly than people contribute new information, then the information good will soon drop below half full and will begin to discourage future contributions. Thus, there is a parallel race in this condition. Skeptical participants become more optimistic about a good while information is plentiful, even as the good decays. If they become convinced quickly enough and begin to contribute enough content to replace what decays, then a positive feedback loop ensues and the good succeeds The general principle is that these types of goods display more complicated dynamics: when the contribution level is sufficient to overcome decay and the information space is more than half full, then people are more likely to be active, search, and contribute. This makes the contribute probability and the rate of decay extremely important.

Multifunctional Connective and Communal Goods

In our final set of models, we simulate ESMs, where connective and communal goods are combined. In Figure 1, we visualize the main effect of our variables on the amount of information produced. For each subfigure, the gray lines represent individual simulations and the green line is the smoothed mean of information existing over time. Figure 2 shows the same parameters, but here the lines shows the proportion of users active in the system over time.

The first finding from this set of simulations is that the initial *activity probability* is the most important factor influencing both information and activity. This is not surprising for the dependent variable measuring the overall activity level: all else being equal, it makes sense that when more people start active, more will stay active. Similarly, greater activity level means a greater number of contributions, which we know is important for creating a successful communal good.

[Figure 1 Here]

However, we would think that increasing any of the connect, search, or contribute parameters would, all else being equal, also lead to more information and more activity. After all, each one represents people being more willing to use the system. Our simulations tell a different story. Only the initial contribute probability has a clear, strong influence on activity and information amount while the connect probability appears to have a negative overall relationship. We can understand this by looking more closely at exactly how our agents are making decisions. The negative relationship of connection is the simplest to explain. In this set of experiments, the activity probability starts at .4 or less (reflective of our case study findings and empirical research on the use of such systems). As we saw when testing connective goods alone, this means that initial connection attempts are likely to be unsuccessful. When initial connect probabilities are high, a larger proportion of the agents will experience early disappointment and lower their activity level. It is also important to note the difference between these results and those from the pure connective model in terms of the *activity probability*. When activity started at .4 or below with a connective-only good, the ongoing activity level quickly plummeted. However, multifunctional communication goods can survive and even thrive with surprisingly low levels of initial activity.

The other surprise is just how strong a role *decay rate* plays for both producing information goods and high activity levels. With a high decay rate, successful ESMs are rare. When existing information leaves the information space quickly it can be too difficult to replace it with new information at a pace high enough to prevent a cycle of unsuccessful search, leading to lower activity, leading to more unsuccessful connections, which in turn further pushes down activity. Alternatively, when decay rate is low, it allows information to build in the information space such that even a small amount of activity can produce a good which becomes increasingly valuable,

creating the conditions for achieving critical mass for both communal and connective goals.

[Figure 2 Here]

ABM Discussion and Limitations

As other researchers have demonstrated (Garner, 2016; Palazzolo, 2005), ABMs can be particularly useful in contexts of organizing where parameters can be adjusted to test the influence of both the material conditions of organizing (e.g., group size or resources available) as well as communicative relationships and behaviors. By comparing different conditions of ESM use, our findings extend theoretical understandings of the relationship between individuals' propensity to engage in connective or communal activities, their visibility into the communication of others, and the likelihood of an ESM reaching critical mass, or "succeeding." Our finding that the success of a purely connective good is largely dependent on initial activity level is not particularly surprising but does have implications for how organizations might manage the implementation or introduction of an ESM and reflect upon its likelihood of succeeding. Organizations could think about the opportunity to contact others as a perishable resource which will disappear quickly if not enough others are online and available. In a context where an organization is expecting primarily connective use of an information good it will be important to have early buy-in from a large number of organizational members. The results of the case study suggest initial use of the ESM may be easier to encourage, as individuals expressed a willingness to explore Gateway and only continued use was dependent on perceived critical mass. However, our findings indicate a potentially overlooked temporal dimension to the early use of an ESM by organizational members. If organizations roll out activity of an ESM to users over time then it will likely be harder for the platform to succeed based solely as a connective good regardless of users' willingness to try to connect, as the potential material connectivity (i.e., individuals available for con-

nection) will be dispersed such that fewer people are available at any given time. This indicates the importance of coordinating the timing of availability of individuals for connective goods.

These results also show the importance of the materiality of the information space. They suggest that information spaces can act as a semi-permanent store of value that can lead to higher engagement with all facets of an ESM, including using it for connection. While we showed that the decay rate is one important aspect of the materiality of a communication good, future research should directly explore the influence of other aspects that we held constant, such as group size and information space size. For example, the ratio of the size of the information space relative to the group size is likely very important, as we discuss in more detail below.

Though our work demonstrates the value of ABMs in refining and testing different potential organizational conditions and interdependent behaviors, every model must make simplifying assumptions that do not fully reflect the complexities and nuances of social life. In our case, we grounded assumptions in findings from an empirical case study, but extensions to our model could test whether our conclusions are robust to different specifications. One important future direction would be to put agents into a network structure, where they seek to communicate with those they are connected to. This would likely lead to ESMs that are adopted in some parts of the network but not others—a dynamic which is almost certainly true in the real world but which our models do not currently capture.

Overall Discussion

Our first research question was aimed at distinguishing between connective and communal uses of an information public good. The findings indicate that communal goods operate differently than connective goods for two reasons: they afford individuals multiple ways to actively participate on the platform (i.e., search or contribute), and activity at one time can remain in the

space over time and provide value to future users. The importance of search as a mechanism in influencing the success of an ESM is notable because search is similar to "lurking" and might be assumed to be of limited value. Lurking behaviors are often viewed as a form of free-riding in digital collective action contexts, and moving individuals from seemingly passive to more active behaviors (i.e., contributing) is viewed as critical to the health of online communities (Preece et al., 2004). However, even if lurking does not lead to contributions, search can still provide value, both to the user as well as to the larger system where searches can provide insight into the ongoing communicative needs of organizational communities (Bighash et al., 2018; Crawford, 2009). Our simulations demonstrate that in an information space that is heavily populated with content, high levels of search can be beneficial in the long term. As users consistently find valued information on an ESM they will likely increase their overall levels of activity, making them more available for connection and contribution.

Another important finding relates to the strong influence of the information decay rate in our simulations. Our results point to two scenarios under which an ESM is likely to succeed in the real world. The first model for success is to have a context in which participants are highly motivated to actively contribute; as a result, the rate of contributions can outpace even a fairly high rate of information decay. These conditions work well for smaller project groups where there is likely to be a high willingness for each member to contribute. Alternatively, in an environment of low information decay organizations that have many members can produce useful information artifacts and sustainable ESM communities even if the individual probability of contribution remains low. An example of this would be Wikipedia, where only a small percentage of users contribute, but the massive size of the userbase allows the information to scale steadily over time (Kittur & Kraut, 2010). ESM may be particularly well-suited to support a long-tail

phenomenon (Anderson, 2006), in which a large proportion of an information space is perceived as useful for only a small number of individuals. However, the presence of content with limited usefulness exists in tension with the experience of information overload, mentioned as a deterrent to ongoing use by Gateway users at ATA. Future research could focus on what specific forms of information availability, curation, and maintenance are optimal for ESM.

More broadly, our research indicates the value of organizations considering the logics associated with communicating *about* the implementation and use of technologies (e.g., Barbour et al., 2018) and not merely focusing on the material capabilities of the tools. The simulations demonstrate that communal uses, specifically contributions, create the potential for repeated and shared benefits in terms of perceived critical mass, while connective uses are likely to produce ephemeral effects without a coordinated roll-out. Organizations face choices in how they encourage, direct, and manage the use of organizational technologies like ESM and can emphasize or discourage certain behaviors. For example, designers and managers can populate an ESM with content that is likely to be of interest to workers before launching it. Designers can also alter the visibility of activity—though high search levels can benefit the health of a digital space, they do so in a way that is not often visible on the ESM. As a result, users may perceive a lack of critical mass even when other members are actively using the ESM as an information source. When designers and managers of systems make user activity more transparent it can benefit coordination and cooperation among users (Suh et al., 2008), and organizations should carefully consider how forms of visibility might encourage activity and contributions (Treem et al., 2020).

From an analytical standpoint, our work demonstrates the potential value of ABMs as part of a mixed methods approach to refine and test different organizational conditions and interdependent behaviors. Although early conceptions of ESM celebrated the bottom-up, organic na-

ture in which these tools were being adopted in organizations (McAffee, 2006), our simulations indicate that left on their own, many efforts to build critical mass are likely to fail. Alternatively, these results point to a number a ways that organizations can better design the conditions of adoption, encourage behaviors, and alter the features of ESM spaces to encourage success. For instance, unlike with connective goods, when rolling out a multifunctional goods organizations might consider bootstrapping adoption by focusing initial efforts on one group (Marwell and Oliver, 1993; Van Slyke et al., 2007). With a smaller group, organizations could build a core of engaged users who could help to create both communal and connective goods for others. Put differently, organizations can first engage individuals who are likely to have higher activity probabilities and lower thresholds for perceived critical mass to create conditions that will make the community more attractive to future users.

Our results point to several promising directions for future research. First, we have suggested a set of testable propositions about designing and managing ESMs, including seeding them with initial content, altering the visibility of search, and building momentum among subsets of users. Both empirical and simulation research could also extend our work to look at the role of communication networks, group size, and other aspects of information spaces, such as size, searchability, and long-tailed distributions of interest.

Conclusion

Although this work focused on ESM as a distinct form of multifunctional public good, the type of communicative context modeled in this research is likely to be increasingly reflective of contemporary work where individuals have access to numerous complex, flexible, and feature-rich information technologies. The case study and models presented here demonstrate the differing motives individuals may have in using organizational public goods, the importance of

interdependent perceptions of critical mass in creating feedback loops, and how understanding the relationship between connective and communal aspects of technologies can help organizations be successful in creating and launching useful tools. Future research offers opportunities to explore how varied technologies, with multitudes of features and functions, operate over time and among diverse organizational contexts.

Data Availability

The agent-based modeling code to produce simulations, as well as the data and code used for the ABM analyses, will all be made available upon publication in a Harvard Dataverse repository.

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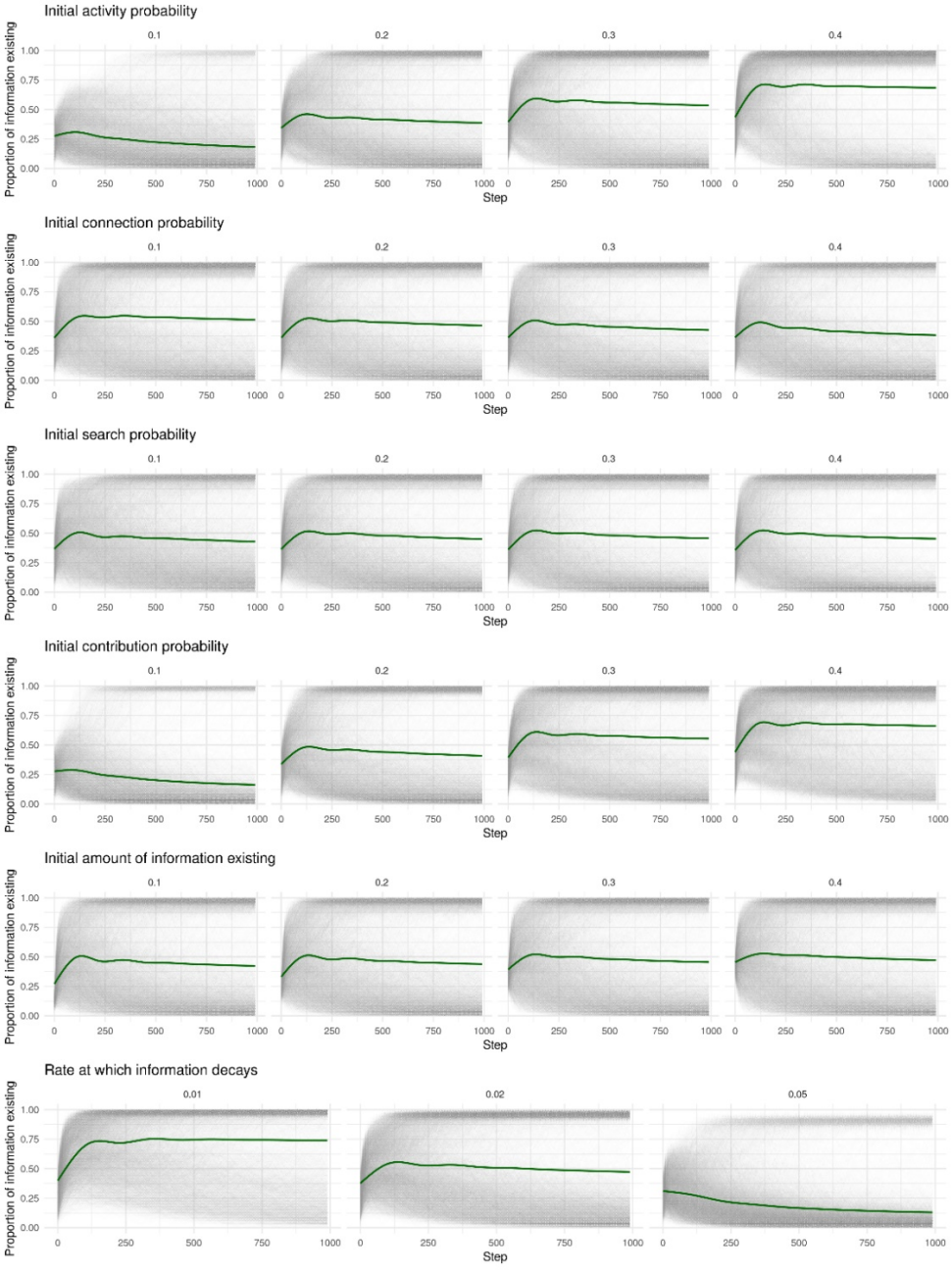
Tables and Figures

Figure 1

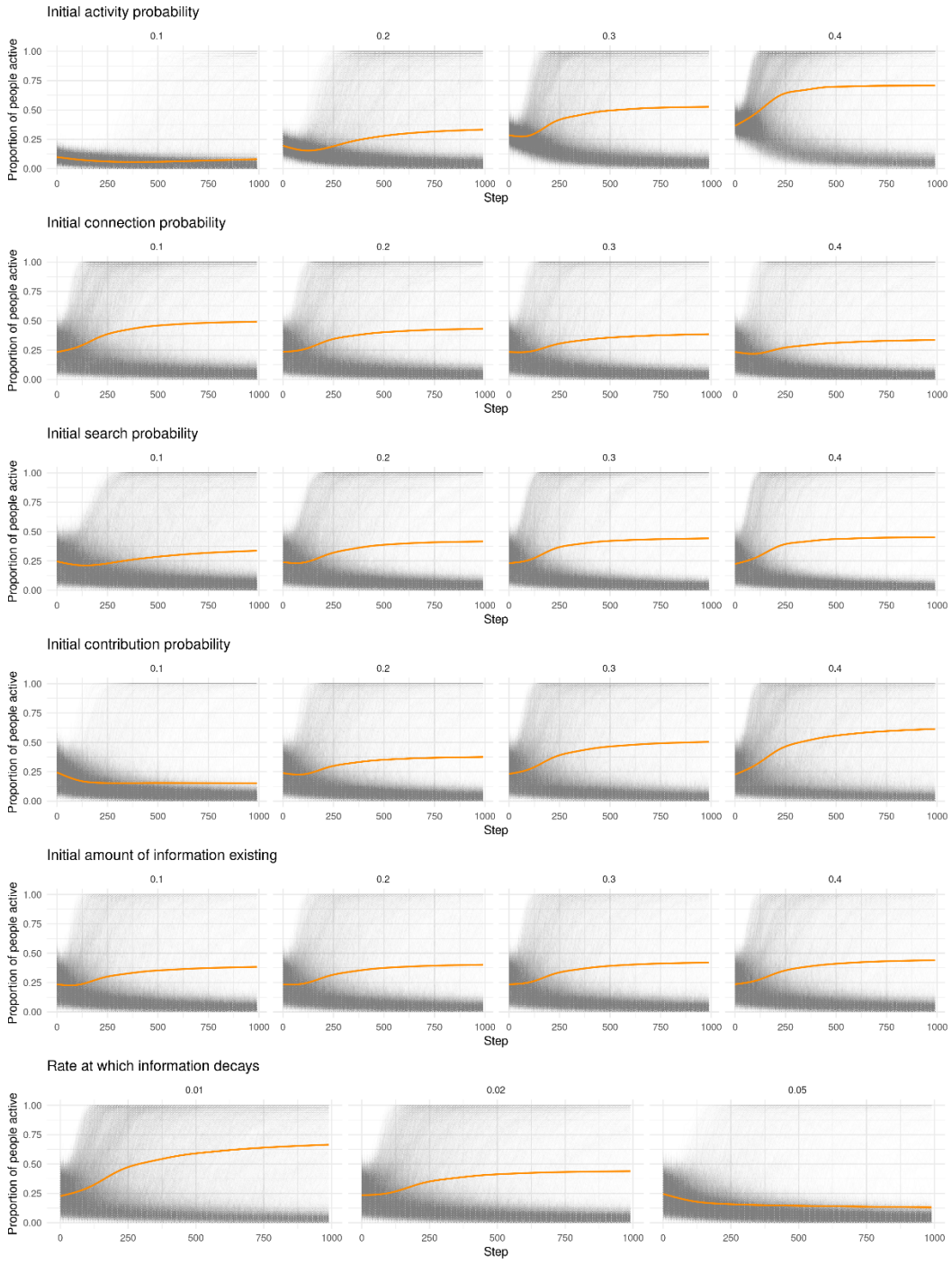
Information Levels In Multifunctional Communication Goods



Note. Each row shows the main effect of each parameter on the amount of information existing over time. Each gray line is a run of the simulation and the green line shows the smoothed mean.

Figure 2

Activity Levels in Multifunctional Communication Goods



Note. Each row shows the main effect of each parameter on activity levels over time. Each gray line is one run of the simulation and the orange line shows the smoothed mean.