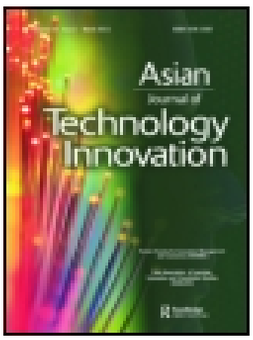

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Enhancing diffusion of consumer innovations on knowledge sharing platforms

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ABSTRACT

In the past decade, studies showed that many consumers innovate for themselves. Sometimes their innovations are useful to others and potentially enhance social welfare. Unfortunately, diffusion fails as consumers lack incentives to inform others. Online knowledge sharing platforms (OKSPs), which can be stimulated with government support, may alleviate this problem. Platform communication may trigger passive consumers into active knowledge contributors. It is however uncertain if and how platform communication affects consumers who never shared designs before. We conducted a randomised controlled experiment with 715 members of an OKSP in 3D printing. Our intervention included a series of general and personal messages, tailored to various motives to share knowledge: altruism, status, ideology, learning and community. Platform members who never uploaded designs before are positively influenced by our intervention. Specifically, messages tailored to altruism, ideology and learning made platform members upload more designs. Hence, platform communication can improve the availability of innovative designs to potential adopters, and is a useful step to alleviate diffusion failure of consumer innovations.

KEYWORDS

Consumer innovation; diffusion failure; online knowledge sharing platform; knowledge seekers; knowledge contributors

1. Introduction

Consumer innovation refers to individuals who in their leisure time develop novel products, services, processes or applications, at private cost (von Hippel, 2017). Recent studies have shown that consumers are an important source of innovation. In many countries, the frequency of consumer innovation ranges from 4% to 6% (de Jong, 2016). The lowest observed percentage of consumer innovators was 1.5% and found in Korea (Kim, 2015). This still represents over half a million innovators in the country. Many consumer innovations are also generally useful, and from a social welfare perspective, should become broadly available. Examples are devices and treatments that patients develop to improve their health (Oliveira et al., 2015), sustainable goods to reduce carbon

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footprint and energy consumption (Nielsen et al., 2016) and a range of new products related to software, household fixtures, personal transport and sports (von Hippel, 2017).

Unfortunately, consumers lack incentives to communicate their innovations to others. Diffusion is the process by which an innovation is communicated over time among the participants in a social system (Rogers, 2003). A condition for diffusion is that potential adopters should first be informed, which requires effort from the innovator (de Jong et al., 2015). But as consumers generally innovate for personal need or process benefits (Kim, 2015; von Hippel, 2017), there is no market mechanism connecting adopter benefits with additional benefits for the innovator. This market failure has been repeatedly demonstrated: in Finland (de Jong et al., 2015), Korea (Kim, 2015) and China (Chen et al., 2020). The market failure vanishes only in the rare situation where a consumer innovator has commercial interests (de Jong et al., 2015; de Jong et al., 2018). If innovations with high general value do not become available to others, social welfare is hampered (von Hippel, 2017).

Researchers have suggested to stimulate diffusion by supporting online knowledge-sharing platforms, where consumers can easily document and reveal their innovations. Online knowledge sharing platforms (OKSPs) are open web environments facilitating an accumulated knowledge base, where people can share and distribute their work and potentially work together (Baruch et al., 2016; Mancilla-Amaya et al., 2010). Examples are platforms like instructables.com, thriftyfun.com, 1000lifehacks.com and thingiverse.-com. OKSPs are usually meant to facilitate knowledge sharing in a broad sense, in the spirit of the gift or sharing economy, but in practice, they can also be helpful to reveal consumer innovations. Consumers can use OKSPs to share innovative designs, and also to find each other to collaborate and exchange knowledge, regardless of geographical distance (Kim, 2015; Ogawa & Pongtanalert, 2013; von Hippel, 2017). Hence, OKSPs can help to solve the diffusion problem by providing a platform where consumers can communicate their innovations to others.

Past OKSP studies found that platform communication can trigger members to share knowledge (e.g. Ardichvili et al., 2003; Baruch et al., 2016; Bateman et al., 2011). Platform communication is the frequency and fit of messages to inform members about new contributions to the platform, and to encourage members to post new contributions themselves. The research gap we address in this paper is that we do not know if, and how, platform communication influences consumers who *never* shared innovations before. In general, people can interact with an OKSP by seeking knowledge or by contributing to it (Kankanhalli et al., 2005; Phang et al., 2009). Knowledge seekers benefit by seising contributions made by others, while knowledge contributors expand the knowledge repository by uploading new designs (Yan & Jian, 2017). While knowledge contributors are crucial for OKSP viability, most consumer innovators resemble with knowledge seekers, that is, they do not proactively upload innovations to the OKSP.

The empirical context of our study is 3D printing, a technological field where consumer innovations are widely present (de Jong & de Bruijn, 2013; Stanko, 2016). We collaborated with YouMagine, an online platform where consumer innovators ('makers') share 3D printing designs. Makers rarely have commercial motives and are not necessarily inclined to communicate designs to others (de Jong & de Bruijn, 2013). As such, YouMagine was a suitable platform for our research.

Our contribution is twofold. First, we investigate if platform communication helps to turn knowledge seekers into knowledge contributors – as knowledge contribution is a necessary first step to communicate consumer innovations to potential adopters and alleviate the diffusion problem. Second, we explore how platform communication can be optimised by investigating if various contribution motives have a different impact. Platform members can contribute for various reasons. We investigated the influence of altruism, status, ideology, learning and community motives. These are the most frequently mentioned in the literature (for details, see our theory section) and particularly important in the open environment of makers and 3D printing (Claussen & Halbinger, in press; Moilanen et al., 2014).

We are among the first to organise a randomised controlled experiment of platform communication tailored to contribution motives. Previous studies of contribution motives relied on self-reports in survey and interviews, and did not focus on knowledge seekers explicitly (e.g. Ardichvili et al., 2003; Baruch et al., 2016; Bateman et al., 2011; Ma & Chan, 2014). Our experiment shows that platform communication turns knowledge seekers into knowledge contributors. However, this effect is present only when communication is tailored to altruism, ideology and learning motives. Our findings suggest that communication-based interventions, which can also be supported by governments to alleviate diffusion failure, are useful to convert passive consumer innovators into active online knowledge contributors.

2. Theory, proposition and research question

Online knowledge sharing platforms (OKSPs) originated from enterprises using internal platforms to document, develop and distribute knowledge (Mancilla-Amaya et al., 2010). With the Internet, OKSPs have become available also to individual end consumers. Today's OKSPs can be online environments revolving around the sharing of designs (e.g. thingiverse.com), but they can also be related to communities of practice or open-source projects. All OKSPs have a centralised and publicly available knowledge base, to which individuals contribute.

Various factors influence individual contributions to OKSPs. These include the platform's objectives (e.g. is the platform meant to commercialise designs or to share these for free (Moilanen et al., 2014; West & Kuk, 2016)), content (e.g. the quality of former contributions and perceived impact-of-use (Baruch et al., 2016; Daniel et al., 2018)), participants (e.g. social capital variables like mutual trust and shared language (Chiu et al., 2006)), design and functionalities (e.g. ease of use, executional costs, task specificity (Daniel et al., 2018; Yan et al., 2016)) and communication (e.g. frequency and volume of messages and fit with member characteristics (Baruch et al., 2016; Bateman et al., 2011)).

Our study contributes to our understanding of effective platform communication. We investigate if platform messages as such, but also if messages are tailored to contribution motives, have an impact especially when platform members are knowledge seekers. If knowledge seekers can be turned into contributors, platform communication helps to stimulate diffusion of consumer innovations.

Past studies showed that platform communication can enhance knowledge sharing. Classical communication theory counsels that individuals pass four cognitive phases before uploading a design: attention, interest, desire and action (Michaelson & Stacks,

2011). When individuals receive more messages about the platform's presence, purpose and content, they can be expected to contribute more. In line with this reasoning uploading content to OKSPs was found to be related to platform communication intensity. Ardichvili et al. (2003) conducted a qualitative study of individual motives and barriers to contribute to virtual knowledge-sharing communities. They concluded that knowledge is often shared when asked for it, but kept silent when individuals are unaware of the possibility and potential benefits to others. Baruch et al. (2016) explored why participants contribute to online crowdsourcing platforms and found that contact intensity with platform managers and other participants was paramount. McLure Wasko and Faraj (2000) found that participants in online communities of practice ' … value the processes of exchange, interaction, and the availability of feedback more so than simple access to information' (p. 167). Finally, Bateman et al. (2011) identified that contributions to an online discussion community increased when participants were given more attention, especially when participants had no formal role or ability to exercise control to the platform.

2.1. Role of prior uploading behaviour

The key problem with regard to diffusion of consumer innovations is that individuals, as soon as they completed their innovation, lack incentives to inform others (de Jong et al., 2015). We anticipate that the effectiveness of platform communication varies with members' prior uploading behaviour. Specifically, we expect that interventions are more effective for knowledge seekers, that is, will help to turn them into knowledge contributors. Our reasoning is that (at least part of) the knowledge seekers on a platform are only latently aware of the possibility to upload designs. Platform communication will more likely influence their attitude towards sharing, and push them to take action. In contrast, knowledge contributors already passed through these cognitive phases making them less responsive to increased platform communication.

In line with our reasoning, Ardichvili et al. (2003) identified that people who do not contribute to online knowledge-sharing communities may feel intimated by the idea of making a contribution. Users are 'concerned to receive responses belittling the importance of their contributions' and 'that [inputs] they might post deal with matters to which they should already know' (p. 12). These considerations especially applied to new members of OKSPs with no prior contributions. Next, McLure Wasko and Faraj (2000) found that people are deferring from knowledge contribution when they are not comfortable with their level of expertise, a situation which especially applies to passive platform users. Also, Ma and Yuen (2011) found that individuals' decision to start contributing to OKSPs increased with the degree of participation and engagement by other individuals, and the extent of social interaction, suggesting that a communication-based intervention will especially help for those who did not contribute yet. Taking this together our proposition is:

> P1: For platform members who never contributed to an OKSP, the relationship between platform communication and uploading designs will be stronger compared to those who contributed before

2.2. Differential effect of contribution motives

Members of OKSPs can have various motives to contribute, and intervening on these motives can have a different impact on their uploading behaviour (e.g. Burtch et al., 2018; Gallus, 2017). Such differences have implications for *how* diffusion failure can be remedied.

The social psychology and information systems literatures mention various contribution motives, of which we tested five: altruism, status, ideology, learning and community. Our study context is 3D printing, in which consumer innovators maintain a strong culture of being non-commercial and open. In this environment altruism, community, ideology, learning and status are mentioned as important (Claussen & Halbinger, in press; Moilanen et al., 2014). Also, the five motives are most frequently mentioned in previous qualitative and survey studies, indicating their importance. We now explain why these motives may influence contribution behaviour.

Altruism relates to individuals who are willing to share designs without expecting a return. They recognise that their designs are potentially useful to others (e.g. Batson et al., 2002; Ma & Chan, 2014; McLure Wasko & Faraj, 2000; Tseng & Kuo, 2014). For example, knowledge contribution to an online platform of teachers was significantly predicted by altruistic commitment of platform members (Tseng & Kuo, 2014). If altruism-driven platform members do not see the results of their efforts, their intrinsic motivation to share diminishes. Platform communication tailored to altruism, we expect, will prevent this from happening. When individuals can observe how a task makes an impact on others, task meaningfulness is enhanced. This will motivate individuals to continue with their tasks (Grant, 2007). Applying this reasoning to OKSPs, we can expect that platform communication related to altruism increase uploading innovative designs.

The status motive is about individuals wants to stand out from others by publicly exhibiting their knowledge (Lakhani & Wolf, 2005). In general, individual pursuit of self-enhancement explains why people want to compare themselves with others (Sedikides & Strube, 1997). In studies of OKSPs egoism was identified as a contribution motive in order to 'reaching the ultimate goal of self-benefit' (Batson et al., 2002, p. 434). Hars and Ou (2002) argued that people contribute to enhance their status by 'demonstrating their capabilities and skills' (p. 29) and 'desire for fame and esteem' (p. 30). Many platform members report to be interested in 'something like a certificate of participation or some kind of award' (Baruch et al., 2016, p. 926) which signals they are sensitive to status. In sum, we expect that platform communication related to the positive status of knowledge contribution ('best designs are shared here', 'your design clearly stands out', etc.) triggers uploading behaviour.

Ideology refers to the conviction that knowledge should be open and shared (Batson et al., 2002). Ideology is common in open-source projects (Lakhani & Wolf, 2005), but also observed in OKSPs for 3D printing (de Jong & de Bruijn, 2013). Self-verification theory (Swann, 1983) is helpful to explain why ideology can enhance knowledge sharing. By contributing knowledge individuals can verify their self-concepts and increase their sense of coherence with their convictions. In the context of OKSPs, platform communication tailored to norms of openness and sharing principles may trigger members to upload designs.

The learning motive implies that designs are shared to improve personal skills or competences. Eagerness to learn has been related with platform involvement in a range of studies (e.g. Hars & Ou, 2002; McLure Wasko & Faraj, 2000). Budhathoki and Haythornthwaite (2013) found contributions to OKSPs are partly driven by perceived opportunities to learn, from personal and others' experiences. Novak (2019) identified that contributions to online platforms help individuals to accomplish self-directed learning, and that learning is a salient motive for individuals to share knowledge online. Self-improvement theory (e.g. Sedikides & Strube, 1997) suggests that when others give feedback or comment on a design people are motivated to engage with an OKSP. Accordingly, if platform communication points out that knowledge contribution gives an opportunity to learn, this may trigger uploading new designs.

Community motivation means that individuals contribute in order to connect with likeminded others. Knowledge contributors are known to have an 'interest in maintaining the community as a whole' (McLure Wasko & Faraj, 2000, p. 168). Studies have shown the importance of perceived online attachment and relationship commitment (Ma & Chan, 2014) and community-related motivation (Bucher et al., 2016). In this vein, Ergün and Avci (2018) showed that in a sample of Turkish bachelor students, community motivation influenced knowledge sharing to an online platform. Likewise, Bouncken and Barwinski (2020) did qualitative research in which they identified that shared digital identity enhanced a sense of community, which triggers global collaboration in 3D printing designs by sharing knowledge online. Identity theory suggests that individuals will devote more effort when they can identify themselves as a community member (Tajfel et al., 1979). Social identity is a person's sense of who s/he is based on group membership. Personal identification with a group will motivate an individual to contribute to the group (Tajfel, 1978). In the case of OKSPs, platform members are more likely to contribute if their perceived group membership is strengthened.

We explore if these five motives have a different impact on uploading behaviour, especially for those who are knowledge seekers. Since we have no a priori expectations about which motives matter more than others, we formulate the research question

> RQ1: Does platform communication tailored to specific contribution motives have a different impact on uploading designs, in particular for platform members who never contributed before?

Our list of contribution motives is not exhaustive. The literature also mentions career motives (sharing knowledge to improve a job market profile, see Brabham, 2012; Lakhani & Wolf, 2005), financial motives (to make money, see Kuang et al., 2019), personal enhancement (to improve sense of self-worth and to be felt needed, see Yan et al., 2016) and fun (because the innovator simply enjoys the process of sharing knowledge, see Brabham, 2012; Coleman & Lieberman, 2015). The financial motive was not relevant in our study context, as YouMagine is a non-commercial platform. Other motives were mentioned less often. We will re-visit non-studied motives in our discussion section.

3. Data

We did a randomised controlled experiment with 715 users of YouMagine, an OKSP for 3D printing designs.

3.1. Subjects

YouMagine was founded in 2012 as a non-profit entity, by a leading manufacturer of desktop 3D printers. Platform users upload innovative designs in the form of STL files which can be downloaded or printed with a desktop 3D printer. The platform allows users to upload new or modify existing designs. They can also follow other users, and create personal collections with favourite designs.

We focused our experiment on members who had visited the platform since 1 January 2016, in order to approach active members. Also, since our intervention revolved around platform communication we only included members who had agreed to receive e-mail messages. Seven hundred fifteen users, hereafter called subjects, satisfied these criteria.

We first checked how many designs each user had uploaded. This number ranged from 0 to 135 with an average of 2.07. Forty-nine percent of the platform members had not uploaded any designs, and can be considered knowledge seekers. Twenty-six percent had previously uploaded one design, and can be considered occasional knowledge contributors. The remaining 25% had uploaded two or more designs, being repeated knowledge contributors.

3.2. Intervention

The intervention included a range of general and personal messages. We tailored the messages to the five contribution motives and to randomly assigned groups of respondents. The intervention was implemented in five weeks. Subjects received a message every four days.

Our experiment involved seven groups. Groups 1–5 received messages tailored to the altruism (group 1), status (2), ideology (3), learning (4) and community (5) motive. Subjects in group 6 received a neutral version of the intervention, not tailored to any motive. This enabled us to analyse if motives make a difference beyond the situation in which platform users are just reminded/urged to upload designs. Group 7 was a control group receiving no messages at all. By adding this group we could analyse if platform communication as such influences uploading behaviour (see Figure 1).

Since the intervention lasted only five weeks, observed effects represent a conservative estimate of the results to be obtained when platform communication is enhanced for a longer time. The intervention itself included nine messages. Details can be found in

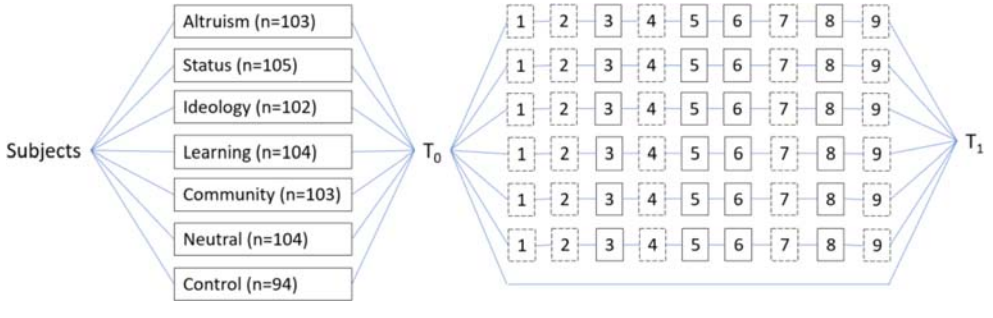

Figure 1. Experimental design.

the Appendix of this paper. The first message stated the purpose of YouMagine and invited a member to upload new designs. The content of the message was tailored to the motive at hand. For example subjects in the altruism group received an e-mail about 'YouMagine: to help others' with the sentences 'Hey, YouMagine is where makers help other people with 3D designs' and 'We appreciate your contributions to YouMagine. Do you have new designs helpful to others?', and a call-to-action button labelled 'Go to YouMagine and help'. In contrast, subjects in the status group received the message 'YouMagine: to show best designs' with the sentences 'Hey, YouMagine is where makers can reveal their best 3D designs' and 'We appreciate your contributions to YouMagine. Do you have new designs to showcase to others?', and a call-to-action button labelled 'Go to YouMagine and show others'.

The second message was similar. It had slightly different content, but was again tailored to the motive at hand. The third message was a personalised email in which we replied to the subject's most recently uploaded design. Using a standardised script, we explained that we had printed the design, provided additional comments referring to the motive at hand, then thanked the subject. We did not ask for new designs, rather, our intention was to leave the impression of a platform which revolves around the particular motive at hand. The message was sent by one of the authors of this paper, who had become a member himself. For example, subjects in the altruism group were contacted as follows: 'Hey, I am a 3D printing enthusiast from the Netherlands. I just wanted to let you know that I printed your design, which you uploaded in to YouMagine. It is very useful to me.:-) And I am sure it will be as helpful to others. Thanks!'. In case a subject had multiple uploads we picked his most recent design. If a subject had no prior uploads, we did not send the third message. (As such our experiment provides a conservative estimate for knowledge seekers.)

The fourth message was similar to the first message: a general invitation to upload a design. The fifth message was similar to the third message, but instead of an email, we posted a personal comment to the subject's most recent design on YouMagine. Again, we did not directly ask for new designs, but only complimented the subject in line with the motive at hand. To avoid that subjects would observe that the same comment was given repeatedly, we developed three alternative messages for each motive, and posted one of them (selected randomly). For example, subjects in the status group could receive one of three: 'Great design, one of the best I have seen here!' or 'Impressed by your design! Others will like it too' or 'Thank you! I find it one of the best contributions here'.

The sixth message was a general email sent by one of the founders of the YouMagine platform. For example, subjects in the altruism group received the message 'Hey, YouMagine is where makers help other people with 3D designs. With this email, we would like to show our appreciation for the designs you have offered so far. Others will benefit a lot from your work. So please keep publishing any new designs, or update existing designs. Many thanks!' Then the subject was invited to post a new design.

The seventh message was again a general email; same as message 2. The eighth message was a personal email with an explicit request to upload a new design, sent by a member of our research team. Finally, the ninth message was similar to the messages 1 and 4.

We tailored YouMagine's homepage to the different groups, to ensure that the platform's general communications resembled with the motive at hand. For example, when subjects in the altruism group clicked on the call-to-action button in an email, they were directed to YouMagine's homepage where we showed the slogan 'Where makers help other people with 3D designs' instead of the default 'Where makers publish 3D designs'.

Before conducting the intervention we tested all messages with the help of research master students who were familiar with experimental research, but not involved in our study. We provided three students with draft versions of the messages, then asked to assign them to the six groups. In the initial round of testing, no full consensus was reached. After finetuning full consensus was reached in a second-round involving another three students.

3.3. Variables

The day prior to the first message, at T_0, we recorded information on relevant variables (Table 1). 'Prior uploads' is the number of designs uploaded to the platform prior to our experiment. Again, prior uploads ranged from 0 to 135. We also recorded 'followings', which is the number of other users the subject was tracking. Previous studies showed that knowledge contribution is also related with the extent to which platform users are seeking knowledge on the platform themselves (e.g. Bateman et al., 2011; Ma & Chan, 2014).

At T_1, five weeks after the intervention started, and one week after the last message had been sent, we again recorded the number of uploaded designs per platform member. We computed a variable 'new uploads' by subtracting the number of prior uploads. This variable provides the number of new designs uploaded to the platform during our intervention, and will be the dependent variable in our analysis. We also added dummy variables to our database representing group membership, and a general dummy indicating if a subject had received *any* intervention (1 for all test groups, 0 for subjects in the control group). Finally, recall that subjects were randomly assigned to each of the groups, so the date at which they registered to YouMagine (which may influence the number of prior uploads) is already controlled for in our experimental design.

Table 1. Variables.

Variable	Description
New uploads	Number of designs uploaded by the subject during the intervention
Prior uploads	Number of designs uploaded by the subject prior to the intervention
Followings	Number of YouMagine users the subject was tracking prior to the intervention
	Dummy whether the subject received …
Intervention	… any intervention (denoted 1) or not (0).
Altruism	… the altruism-related intervention (1), or not (0)
Status	… the status-related intervention (1), or not (0)
Ideology	… the ideology-related intervention (1), or not (0)
Learning	… the learning-related intervention (1), or not (0)
Community	… the community-related intervention (1), or not (0)
Neutral	… the neutral intervention (1), or not (0)

4. Findings

Table 2 shows descriptive statistics and correlations coefficients. As an artefact of our experimental design, the 'any intervention' variable was positively related with the dummy variables for the experimental groups ($r = 0.16$, $p < .01$), while negative correlations are found between the experimental groups ($r = -0.17$, $p < .01$).

We analysed the data using ordinary least squares regression models. We cross-checked our findings with analysis of variance which provided the same results. Also, as our dependent variable has many zeros (subjects who did not upload any new designs), we did another robustness check with zero-inflated poisson regressions. Again, our findings were identical. Results of these robustness checks are available on request.

In model 1 we entered prior uploads and followings as control variables, and the intervention dummy to explore if sending *any* kind of messages has an impact on the number of new uploads. In model 2 we added the interaction term between 'any intervention' and prior uploads to test our proposition (P1) that platform communication affects knowledge seekers more than knowledge contributors. In model 3 we included dummies for each contribution motive, to explore if the five motives have any different effect on new uploads. In model 4 we added interaction effects between each contribution motive and prior uploads to explore our research question (RQ1) if messages tailored to motives are effective especially for knowledge seekers. We mean-centred the number of prior uploads to avoid multicollinearity with the interaction terms (Aiken & West, 1991). Results are shown in Table 3.

Model 1 has an acceptable fit ($R^2 = 0.320$). Both prior uploads and followings were positively related to new uploads. This resonates with earlier studies showing that the volume of knowledge contribution (prior uploads) and knowledge-seeking (followings) is positively related to new knowledge contributions. However, the effect parameter of a subject receiving any intervention was not significant ($b = 0.011$, n.s.). We suspect that our intervention lasted not long enough to observe an overall difference in new uploads. We elaborate on this in the discussion section.

Model 2 had a significantly better fit compared to model 1 ($\Delta R^2 = 0.066$, $\Delta F = 18.02$, $p < .01$). The interaction between any intervention and prior uploads was negative and significant ($b = -0.029$, $p < .01$). To interpret this effect we conducted a simple slope

Table 2. Descriptive statistics ($n = 715$).

					Correlation coefficient								
Variable	*M*	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) New uploads	0.07	0.45	0	6									
(2) Prior uploads	2.07	8.08	0	135	.45								
(3) Followings	0.23	1.21	0	22	.46	.28							
(4) Any intervention	0.87	0.34	0	1	−.02	−.03	−.05						
(5) Altruism	0.14	0.35	0	1	.02	−.03	−.06	.16					
(6) Status	0.15	0.35	0	1	−.02	−.01	−.03	.16	−.17				
(7) Ideology	0.14	0.35	0	1	−.03	.01	.04	.16	−.17	−.17			
(8) Learning	0.15	0.35	0	1	−.04	.05	−.02	.16	−.17	−.17	−.17		
(9) Community	0.14	0.35	0	1	.00	−.04	−.01	.16	−.17	−.17	−.17	−.17	
(10) Neutral	0.15	0.35	0	1	.05	−.01	.02	.16	−.17	−.17	−.17	−.17	−.17

Notes: M: mean; SD: standard deviation; Min: minimum; Max: maximum value. Correlations with absolute values >.15 are significant at $p < .01$ (two-tailed).

Table 3. Regression models of new uploads ($n = 715$).

	Model 1		Model 2		Model 3		Model 4	
Effect parameters	*b*/β	SE	*b*/β	SE	*b*/β	SE	*b*/β	SE
Intercept	.030/–	.039	.019/–	.036	.029/–	.039	.037/–	.027
Prior uploads (PU)	.019/.345^	.010	.037/.668**	.003	.019/.349^	.010	.040/.712	.002
Followings	.136/.363*	.056	.132/.354*	.064	.137/.365*	.054	.081/.218*	.035
Any intervention	.011/.008	.041	.021/.016	.035				
Any intervention × PU			−.029/−.410**	.007				
Altruism					.069/.053	.061	.056/.044	.057
Status					.000/.000	.045	.005/.004	.040
Ideology					−.042/−.033	.048	−.026/−.020	.036
Learning					−.044/−.035	.050	−.024/−.019	.034
Community					.025/.020	.048	.049/.038	.045
Neutral					.058/.047	.059	.075/.058	.075
Altruism × PU							−.038/−.132**	.005
Status × PU							−.013/−.037	.024
Ideology × PU							−.040/−.219**	.005
Learning × PU							−.039/−.422**	.002
Community × PU							.006/.017	.018
Neutral × PU							.034/.138	.027
Model fit								
R^2	.320		.386		.329		.469	

Notes: Unstandardised (b) and standardised (β) coefficients are shown. SE = robust standard errors. Two-tailed significance ** $p < .01$, * $p < .05$, ^ $p < .10$.

analysis (Aiken & West, 1991). We distinguished between knowledge seekers (PU = 0), occasional knowledge contributors (PU = 1) and repeated knowledge contributors (who evaluated at PU = average score and PU = 4 designs). In Figure 2, the top-left graph presents the regression coefficient of new uploads on any intervention. For knowledge seekers delivering any intervention has a positive and significant effect (at PU = 0 we find: $b = 0.083$, $p < .01$), while for occasional and repeated knowledge contributors the effect is insignificant. Accordingly, platform communication was effective for those with no prior uploads, which is in line with our proposition.

Model 3 considers the various motives separately. Model fit was good ($R^2 = 0.329$) but none of the experimental treatments was significant. In model 4, however, we added interaction terms between prior uploads and the experimental treatments. Model fit increased significantly ($\Delta R^2 = 0.14$, $\Delta F = 48.24$, $p < .01$) compared to model 3. Specifically for altruism, ideology and learning we found that the interaction effect was negative and significant. Again we conducted simple slope analyses for further interpretation. In Figure 2, the top-right graph shows that altruism is effective for knowledge seekers (at PU = 0 we find: $b = 0.134$, $p < .05$) and for occasional knowledge contributors (at PU = 1 we find: $b = 0.096$, $p < .05$), but not for repeated knowledge contributors. The bottom-left graph shows that the ideology intervention is marginally significant for knowledge seekers (at PU = 0 we find: $b = 0.057$, $p < .10$). The bottom-right graph shows that the learning intervention is marginally significant for knowledge seekers as well (at PU = 0 we find: $b = 0.056$, $p < .10$). All these findings suggest that platform communication can be effective to those who never, or sometimes occasionally, contributed to the platform before – but only if messages are tailored to altruism, ideology or learning motives.

Interestingly, the bottom graphs in Figure 2 also show that repeated knowledge contributors may be deprived from uploading new designs when specific motives are called

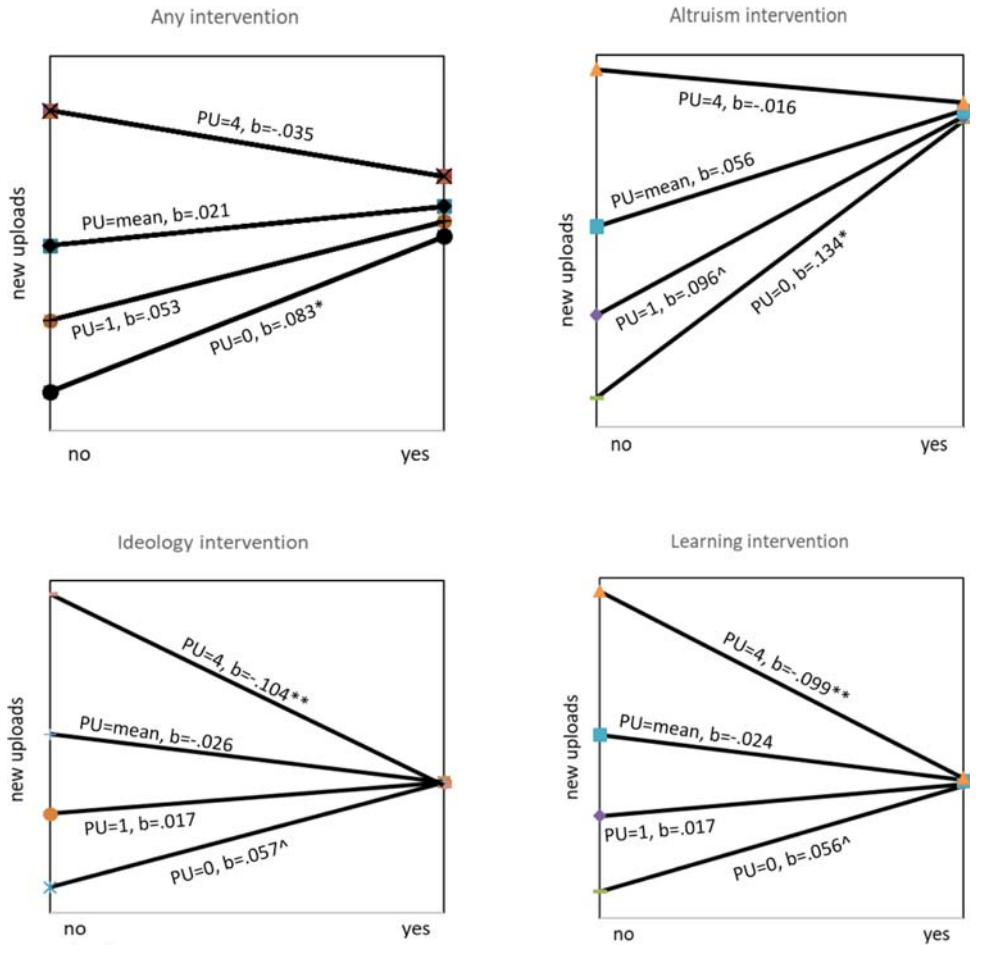

Figure 2. Simple slope regression lines between new uploads and various interventions, at specific values of prior uploads.
Notes: Simple regression coefficients are shown between new uploads and any intervention (top-left), and between new uploads and the altruism (top-right), ideology (bottom-left) and learning interventions (bottom-right), when prior uploads were none (PU = 0), one (PU = 1), average (PU = mean) or four designs (PU = 4). 'Yes' and 'no' indicates that the corresponding intervention (related to the motive at hand) was present or absent. Two-tailed significance $^{**}p < .01$, $^{*}p < .05$ and $^{\wedge}p < .10$.

upon (ideology: $b = -0.104$, $p < .01$; learning: $b = -0.099$, $p < .01$). In our discussion section, we elaborate on our findings.

5. Discussion

We conducted an experiment to investigate if platform communication can trigger knowledge seekers on OKSPs to start uploading designs. The answer is yes. Knowledge seekers were more responsive to communications about the platform's purpose and invitations to contribute. Knowledge seekers are usually the large majority on an OKSP's member base, and in the case of 3D printing they are likely to be consumer innovators

themselves – 3D printing enthusiasts usually create or modify innovative designs for a range of motives, including personal need and enjoyment of the innovation process (de Jong & de Bruijn, 2013). The behaviour we observed for knowledge seekers effectively help to alleviate a situation in which consumers do not diffuse their innovations due to lacking incentives.

However, the effect was present only when our messages were tailored to altruism, ideology and learning motives. Our findings suggest that the content of platform communication matters. For our 'neutral' group (receiving messages not tailored to a specific motive) we found no significant result. This demonstrates that our findings are not a Hawthorne effect of subjects simply being reminded of the presence of the OKSP. Instead, platform communication only helps when messages are tailored to specific contribution motives.

For the innovation management literature, and the literature on how to effectively run OKSPs in particular, our finding of a differential impact of contribution motives is important, as we demonstrated that not just any message or invitation will boost knowledge contributions. Instead content matters, and must be tweaked to the kind of motives platform members are sensitive too. Where previous studies identified a full range of contribution motives based on self-reports (e.g. Ardichvili et al., 2003; Baruch et al., 2016; Daniel et al., 2018; Hars & Ou, 2002) none of these studies provided evidence that (some of) these motives can be subject to deliberate communication in order to boost contributions to OKSPs. Also, the differential impact of contribution that we found for knowledge seekers has not been concluded before.

With regard to theoretical implications, four important comments have to be made. First, our intervention provides a conservative estimate of the effects to be expected with an intensified and longer-lasting intervention. Remind that our intervention was relatively simple and lasted for only a month. This may well be the reason that we did not find an overall effect of the intervention in model 1. We can expect bigger effect sizes if the intervention is more intensive, also because of indirect effects. Prior studies showed that interactivity between members, reflected in enhanced platform communication, is helpful for continued knowledge contribution (Ma & Yuen, 2011). When platform members upload more, and increasingly interact with each other, additional knowledge contributions can be expected.

Second, we must be careful with generalising our findings to other contexts. We are confident that altruism, ideology and learning generalise to 3D printing platforms where openness is the norm, and commercialisation is not (Claussen & Halbinger, in press; de Jong & de Bruijn, 2013) – platforms like youmagine.com, thingiverse.com and instructables.com. Other types of OKSPs, however, are concerned with communities of practice or open-source projects. In such environments, members may be sensitive to other motives. For example, communities of practice usually revolve around a particular profession (e.g. primary school teachers, SAP software coders). Members have stronger personal ties and tend to respond to online requests rather than proactively sharing knowledge (Boh, 2014). Likewise, in open-source projects, the knowledge domain is restricted to a single project, and members do a collaborative effort (Lakhani & Wolf, 2005). Community and reputation motives may be more important here. We recommend continued research to explore differences with communities of practice and open-source projects, where knowledge is shared online.

Third, we could not test all contribution motives mentioned in the literature. Being confined in resources we focused the most frequently mentioned motives and with the highest relevance to 3D printing. Yet other motives can be important. A prominent motive is financial incentives (Kuang et al., 2019). Although consumers rarely innovate for money (von Hippel, 2017), and if they do, diffusion failure is not present (de Jong et al., 2015; de Jong et al., 2018) financial incentives cannot be ruled out. Nevertheless, the existence of platforms to sell 3D designs (e.g. Shapeways.com; 3Dhubs.com, see West & Kuk, 2016) proves that money motivates some consumers to reveal their designs. Likewise, our literature search revealed other motives, including career development (e.g. Lakhani & Wolf, 2005), personal enhancement (Yan et al., 2016) and fun (Coleman & Lieberman, 2015) that are worth testing in future research.

Finally, we also observed a potential downside of enhanced platform communication. In the altruism and learning groups, some of the repeated knowledge contributors uploaded less new designs. Repeated knowledge contributors seem triggered by other motives. For the learning argument, this makes sense as repeated contributors are generally experienced designers. Apparently, ideological reasons are not compelling to this group either. Important for interventions is that there may be no easy fix to trigger contributions from *all* platform members. We cannot exclude the possibility that interventions may evoke responses from a large group of users (knowledge seekers and occasional knowledge contributors) but diminish the motivation of others (repeated knowledge contributors). We do not expect that this will be a severe problem in real life, as we found that the experiment effectively increased the number of uploads and that the negative effect for repeated knowledge contributors in two groups (altruism, learning) did not offset the positive effect for knowledge seekers and occasional contributors. Still, in future research, it is worth investigating if platform design should be further modified according to prior contribution behaviour.

5.1. Implications to practitioners

Our study findings have implications for innovation managers, especially those who are concerned with running any type of online knowledge-sharing platform, and for innovation policy makers concerned with the social welfare implications of consumer innovation diffusion.

As for innovation/platform managers, if their interest is to have more members contributing content, that is, to turn knowledge seekers into knowledge contributors, they should tailor platform communication to those motives to which knowledge seekers will be more sensitive. If a platform resembles with 3D printing and its 'maker' culture (with norms of being non-commercial and open) we are confident that appealing to altruism, community and learning motives will be effective. In a broader sense, we recommend innovation/platform managers to run small-scale experiments themselves, in order to optimise their platform messages. The methodology outlined in this paper can be used for this purpose. As platforms have their own accumulated knowledge base and access to all its members, they are well equipped to experiment in order to learn which motives make a difference.

For innovation policy makers, recall that consumers have no incentives to diffuse their innovative designs, which is at the expense of social welfare (de Jong et al.,

2015). Researchers have suggested policy support for OKSPs (e.g. Kim, 2015; von Hippel, 2017), and our study findings suggest that such policy support can help to make a difference. We observed more uploaded designs already after one month, and this helps to alleviate diffusion failure as consumer designs become visible and available to potential adopters. Possible policy measures are subsidies to innovation/platform managers and their moderators and tax reductions for individuals who invest time in facilitating OKSPs. In some circumstances, more intensive support could be given to platforms in which social welfare gains are more substantial. An example would be an OKSP where patients of rare diseases share treatment-related innovations (Oliveira et al., 2015). Sponsoring platforms where consumer innovations are commercialised would be less suitable as a policy intervention. As mentioned consumer innovators are already inclined to diffuse in the presence of commercial motives. In this context, government support is less effective.

In most countries, government support for OKSPs will be a leap. Innovation policies are usually legitimised by market failures, which implies that profit-seeking businesses tend to under-invest in innovation due to problems with appropriation, market uncertainty and indivisible investments (Arrow, 1962). Innovation policies like patents and subsidies stimulate innovation behaviour to ensure that businesses engage in innovation development (Tsipouri et al., 2008). Stimulating diffusion behaviour is a new kind of policy, revolving around diffusion incentives instead of innovation behaviour. We suggest that such policies make sense – recall that consumers generally do not innovate for commercial reasons, but for personal needs and hedonistic reasons (von Hippel, 2017).

6. Limitations and suggestions for future research

Our study had limitations, some of which directly translate into our suggestions for future research. First, we already mentioned that our experiment should be replicated and extended. Our experiment lasted for only a month. Our intervention included the general messages that a platform manager would send and the personal messages which other users would send in the situation of a platform which entirely revolves around one specific motive. If we would continuously intervene on an OKSP, and expand the time horizon, probably bigger effects will be observed. The recommended pathway is to organise a longer and more extensive experiment, in which direct effects of platform communication, and indirect effects of increased interactivity between platform members, are analysed. The potential downsides of platform support (e.g. interventions to turn knowledge seekers into contributors might discourage repeated knowledge contributors) should be investigated as well.

Next, we recommend to study differences with other types of platforms, in particular communities of practice and open-source projects. Finally, we recommend continued research which also includes motives we could not test here; related to finance, career development, personal enhancement, and fun/enjoyment of the knowledge sharing process. Such research will reveal whether members' key contribution motives differ, and to what extent our findings generalise to other contexts.

7. Conclusion

We organised a randomised controlled experiment to test if enhanced platform communication influences contributions made to OKSPs, especially for members who never contributed knowledge before. Our experiment with an OKSP for 3D printing designs shows that enhanced communication turns knowledge-seeking members into knowledge contributors. The effect was present when communication was tailored to altruism, ideology and learning motives. Our study is first to report evidence that contribution motives can be leveraged by innovation/platform managers to enhance knowledge contributions. Our study has implications for policymaking too, as we found that more innovative designs became available to potential adopters, which helps to alleviate diffusion failure of consumer innovations, and contributes to social welfare – an insight that has not been demonstrated in the consumer innovation literature so far. As such our findings offer a basis for exploring a new type of governmental intervention related to platform communication, useful to convert passive consumer innovators into active online knowledge contributors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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