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Diffusion to peers in firm-hosted user innovation communities: Contributions by professional versus amateur users

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ABSTRACT

Users can develop innovations that improve or complement a firm's product. To benefit from these, firms may host online user innovation communities (UICs) with two purposes: 1. Incorporate user innovations into the firm's products, and 2. Facilitate the direct diffusion of user innovations to peer users to increase the product's general value. The second of these objectives (antecedents of peer diffusion) is under-investigated. Peer diffusion comes with additional challenges: when the hosting firm's innovation experts (e.g., R&D workers) do not pick up the role of continued development, adoption by peers is frustrated—as many user innovators lack the expertise to improve their initial prototypes so that peers can easily adopt. We address this gap by exploring if contributions by professional external users of the hosting firm's product have better peer diffusion rates compared to those of amateur users. We argue that professionals' expertise in design and marketing enables them to improve their initial prototypes, which peers can adopt more easily. Next, taking an interactionist perspective, we hypothesize that the relationship between professional user status and peer diffusion is amplified by users' commercial motivation and their central position in the UIC's network. We analyze multiple-source data of 614 innovations contributed by 122 users of a firm-hosted UIC in 3D printing. We find that contributions by professionals indeed diffuse better, but only at high commercial motivation or favorable network positions (high closeness centrality). To firm-hosted UICs, professional users are an important asset advancing the free peer diffusion of user innovations without firm interventions and merit attention when designing UICs.

1. Introduction

It is well known that users of products—external to the producing firms—innovate to make the products better match their personal needs (von Hippel, 1978, 2005). Users can add complementary modules like plug-ins, or improve the product by replacing some of its parts or functions, to improve its use value (Gambardella et al., 2017). Many of these innovations are valuable to other users as well, and firms are advised to take advantage of user innovations related to their products (Bogers et al., 2017; von Hippel, 2017).

To benefit from user innovation, firms may host online user innovation communities (UICs) where users share their improvements and complements (Ma et al., 2019). In a typical firm-hosted UIC, users freely reveal innovations to an online platform (Yan et al., 2018). Firm-hosted UICs have two purposes: (a) detect user innovations that the hosting firm can incorporate into future versions of its products, and (b) facilitate direct diffusion of user innovations among peers so that other users can directly increase the value extracted from working with the product (Jeppesen and Frederiksen, 2006; Ma et al., 2019). Examples of firm-hosted UICs have been reported for producers of software (Dahlander and Magnusson, 2005), computer-controlled musical instruments (Dahlander and Frederiksen, 2012), and 3D printers (Amza et al., 2017; West and Kuk, 2016), to name only a few.

Previous studies of firm-hosted UICs dealt with three topics. A first line of research investigated why users contribute to firm-hosted UICs—they may do it for, e.g., recognition (Jeppesen and Frederiksen, 2006), community responses and feedback (Zhang et al., 2013), or expected benefits like extrinsic rewards (Kankanhalli et al., 2015). A second line explored how firms can best manage UICs, e.g., by offering toolkits (Jeppesen, 2005), embedded employees (Dahlander and Wallin, 2006), rating systems (Nambisan and Nambisan, 2008), and involving charismatic moderators (Becker et al., 2022). A third stream looked into if and when user contributions are valuable to the hosting firm—by looking at the novelty and perceived usefulness of contributions for new

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product development (e.g., Dahlander and Frederiksen, 2012) and, more recently, at antecedents of adoption by the hosting firm (e.g., Jensen et al., 2014; Ma et al., 2019).

In all, research so far focused on when user innovations are adopted by the hosting firm, while antecedents of direct diffusion between peers (i.e., the second purpose of firm-hosted UICs) have received little attention. This is an important omission, as peer diffusion comes with an additional challenge: lack of continued development frustrates easy adoption by peers, inhibiting user innovations from adding value to the community's welfare.

Scholars have recognized that peer diffusion of user innovations is often frustrated by users' inability to improve their innovations up to a level that makes adoption easy. For most user innovators, 'quick and dirty' prototypes are sufficient to fix their personal problems (von Hippel, 2017; de Jong et al., 2023). From the viewpoint of potential adopters, however, user innovations are often still initial prototypes imperfectly designed and not yet reliable solutions to a problem at hand. Adoption requires continued development—ideally into a full-fledged product that others can plug and play. Early studies found user innovations to lack 'dimension of merit' improvements related to product reliability, safety, and consistency (Riggs and von Hippel, 1994; von Hippel, 2005). User innovations are also less sophisticated from a technological point of view (Kristensson et al., 2004; Magnusson, 2009). In general, users lack incentives to continue with the development of their innovations—this mostly benefits the (adoption by) others and, thereby, forms an externality to the innovating users (von Hippel, 2017). All of this creates a gap towards broad diffusion: other users must have advanced skills to replicate and improve initial solution prototypes themselves (de Jong et al., 2023). This is visualized in Fig. 1.

When applied to firm-hosted UICs, Fig. 1 shows that the gap is resolved when hosting firms incorporate user innovations into their future products. The firm's innovation experts (e.g., R&D workers) are responsible for improving initial designs and ensuring that product specifications are in line with broad user demand (von Hippel, 2005, 2017). For direct diffusion to peers, however, the gap remains an obstacle. Innovations contributed to firm-hosted UICs often contain bugs, do not yet run smoothly, and require advanced skills to be replicated (e.g., Alcock et al., 2016)—adoption skills (other) users are often lacking. In our study, we take a first step in exploring what user attributes explain variation in peer diffusion—to shed light on the users contributing design that *can* be easily adopted by others, as they may have a pivotal role in driving the broad value creation in UICs.

We suggest that some users will possess the required expertise for continued development themselves, enabling them to improve their initial solution prototypes. Specifically, we propose that it makes a difference whether innovators are 'professional' or 'amateur' users. What sets professional users apart is that they generate income with the hosting firm's product (Jeppesen and Frederiksen, 2006). In practice, professional users can be employees of other companies using the product in a business environment, business owners, self-employed, and informal entrepreneurs who generate extra income with a hosting firm's product (e.g., Shah, 2006). Interestingly, although professionals work with the hosting firm's product in their job or business, their user innovations can be both work- and leisure-related (as professionals may also be enthusiasts who continue to use the hosting firm's product at home) and freely shared on online platforms like firm-hosted UICs. In contrast, amateur users exclusively employ the hosting firm's product in their spare time, and their innovations are only leisure-related.

Our central hypothesis is that peer diffusion of contributions by professional users will be better compared to contributions by amateurs. As we explain in Section 2.2, professionals are more likely to have the expertise required for the continued development of user innovations. While generating income with the hosting firm's product as part of their job or business, professional users accumulate more expertise in design and marketing, both of which help address the gap in Fig. 1 (i.e., diffusion-related expertise). Thus, we propose that professional users basically fulfill a similar role as the hosting firm's innovation experts when these would incorporate user innovations into their products, parts, or add-ons. Their expertise allows professional users to develop designs up to a more advanced stage at which others may find them easy to adopt.

Next, while professional users are expected to develop 'more advanced' user innovations, we recognize specific circumstances that may influence the extent to which they will or can deploy their diffusion-related expertise. Some decades ago, Woodman and Schoenfeldt (1990) introduced their 'interactionist perspective' on creative and innovation behaviors, which implies that contingency factors can influence to what extent individuals' competencies result in creative/innovative outputs. In user innovation research, de Jong et al. (2018) recently applied this perspective by theorizing that the diffusion of valuable user innovations may differ depending on moderators at the level of the innovator (I-factors), the object of the innovation (O-factors), and characteristics of the innovation process (P-factors). In our study, we apply this line of thinking to peer diffusion in UICs. We take a first step by exploring how individual characteristics (I-factors) moderate the relationship between professional user status and diffusion to peers. From the user innovation literature, we identified two most salient potential moderators: users' commercial motivation and their position in the UIC's network.

First, what motivates user innovators is a well-known individual factor associated with diffusion outcomes (de Jong et al., 2015; von Hippel, 2017). By default, user innovators seek to address their personal needs, but on top of that, some of them are also commercially motivated (Raasch and von Hippel, 2013). When users see opportunities to generate income with their innovations, this triggers extra diffusion effort, including continued development required to sell innovations (Shah and Tripsas, 2007). Although commercial motivation may seem irrelevant for firm-hosted UICs (where user innovations are freely revealed!), recent work identified that users may seek indirect commercial benefits (de Jong et al., 2023). Adoption by peers can strengthen their reputation as an expert, generate demand for their related business, or bring personal benefits like job offers or future return favors (Harhoff et al., 2003; de Jong and Flowers, 2018). Thus, in UICs we anticipate a different role of commercial motivation: it may amplify the relationship between professional user status and free diffusion to peers. Our hypothesis (Section 2) is that while diffusion-related expertise enables professional users to improve their innovations, commercial motivation provides a reason to deploy their expertise—as improved innovation designs help to reap indirect benefits from adopters.

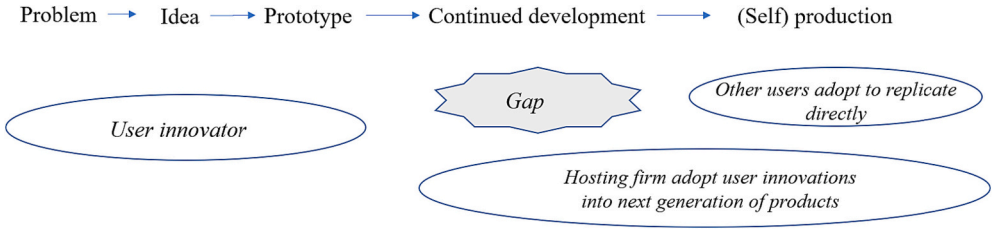

Fig. 1. Gap between solution-prototyping and broad diffusion of user innovations.
Source: de Jong et al. (2023): p. 3.

Second, how users are embedded in the UIC network is another common I-factor associated with user innovation emergence (e.g., Franke et al., 2006; Claussen and Halbinger, 2021). Previous studies found that users in core positions are more likely to become innovators (Dahlander and Frederiksen, 2012) and in a superior position to obtain detailed information about others' needs and solutions—which helps developing innovations that are more novel and better received by peers (Resch and Kock, 2021; Kuk, 2023). Here, we investigate if a central network position in terms of closeness (implying exposure to information from other users through the shortest possible path length) strengthens the relationship between professional user status and diffusion to peers. We reason that where diffusion-related expertise enables professional users to improve innovations so that peer adoption is smoothed, a central network position provides them with information advantages (in particular about user demand and the solution space) helpful to effectively deploy their expertise—so that adoption by peers is facilitated even more.

In overview, our study takes a first step in investigating user attributes associated with peer diffusion in firm-hosted UICs. We hypothesize that professional users are more likely to develop innovations up to a level at which they are easier to adopt by their peers, addressing the gap emerging when the hosting firm has not (yet) put in the effort to incorporate innovations into their products—leaving most user innovations in a rough state, frustrating adoption by other users. Also, we investigate if commercial motivation and a central network position moderate the relationship between professional user status and diffusion to peers. In doing so, we respond to calls to investigate antecedents of user innovation diffusion in more detail (de Jong et al., 2021; von Hippel, 2017).

We tested our hypotheses with multiple-source data of innovations contributed to YouMagine—a UIC hosted by Ultimaker, a leading manufacturer of 3D printers. We find that peer diffusion of contributions by professional users is better compared to amateurs, but only if users are highly commercially motivated or hold a central network position in terms of closeness. For peer diffusion in firm-hosted UICs, professional users are advantageous to be involved and more relevant than has been recognized in previous studies.

2. Theory and hypotheses

In this section, we first explain the key concepts in our study. Then, we develop our hypotheses.

2.1. Key definitions

2.1.1. Professional and amateur users

We compare two types of contributors to firm-hosted UICs: professional and amateur users. To clarify our focus, Fig. 2 shows which actors are present in firm-hosted UICs.

Professional users are those who generate income using the hosting firm's product. All other users are considered amateurs. The same distinction was made in Jeppesen and Frederiksen's (2006) study of contributors to a UIC dedicated to computer-controlled musical instruments.

Professional users can be employees of other companies using the product in a business environment, formal business owners, self-employed, and sometimes even informal entrepreneurs who generate extra income with a hosting firm's product from their homes (e.g., Shah, 2006) on an informal basis (Williams, 2014). Interestingly, innovations developed by professional users are not necessarily work-related. Many professionals are also product enthusiasts who may keep working with (and innovating) the hosting firm's product in their leisure time (Lukoschek and Stock-Homburg, 2021). The same phenomenon is encountered in the related field of open-source software (OSS), where individuals contribute to a general-purpose project instead of a firm-hosted platform. OSS contributors can be professionals (e.g., software developers) and amateurs (e.g., students or volunteers). Perhaps surprisingly, professional coders often partake voluntarily in their leisure time (Lakhani and Wolf, 2005; Bitzer and Geishecker, 2010). In the context of UICs, where innovations are freely revealed, it is usually a mix of work-related and leisure-related problems that professional user innovators seek to solve. In contrast, amateur users exclusively use the hosting firm's product in their leisure time. The complements and improvements developed by amateurs are triggered by personal interests and problems at home.

Previous studies mainly compared external user innovations with the innovations that a hosting firm's innovation experts developed (see Fig. 1, left-hand side) (e.g., Magnusson et al., 2003; Poetz and Schreier, 2012; Pollok et al., 2021). The purpose of these studies was usually to explore if innovations (or ideas) offered by external users were more novel or useful (e.g., Pollok et al., 2021). External users were lumped together under the umbrella of 'hobbyists', regardless of whether they were professional or not. Since our objective is to compare the two types of *external* users, for conceptual clarity, we avoid the term 'hobbyist' to denote amateurs in our study.

In summary, we compare the diffusion rates of user innovations

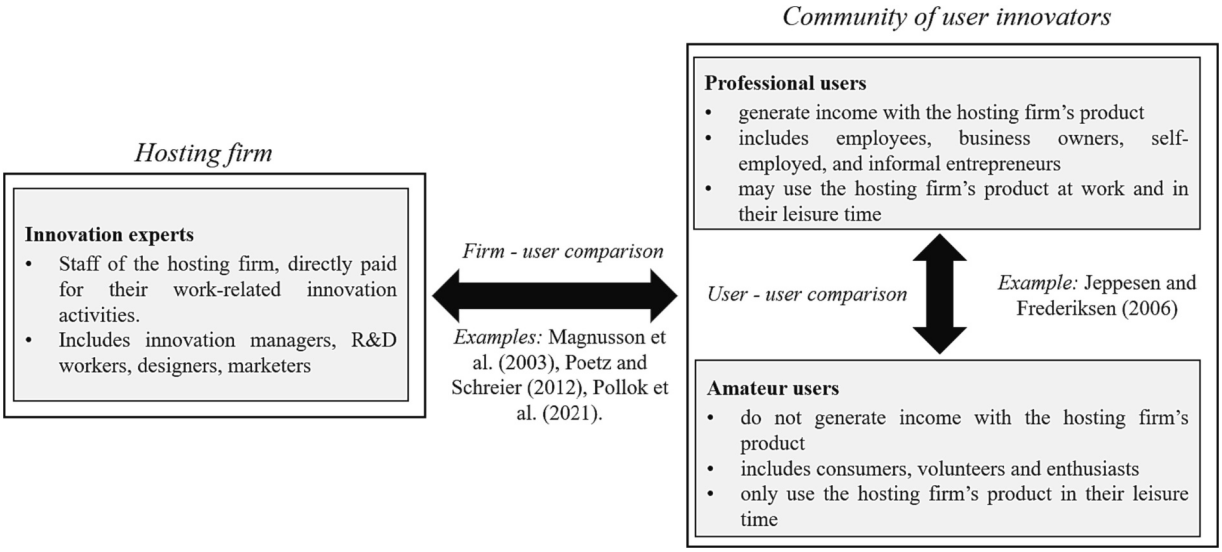

Fig. 2. Actors involved in firm-hosted user innovation communities.

developed by professionals and amateurs (right-hand side of Fig. 2). The hosting firm's staff members are not part of our study since—for diffusion among peer users—they have no formal role in improving initial solution prototypes.

2.1.2. Motives to innovate

By definition, user innovation describes the development of innovations to satisfy a personal need—users develop innovations to use themselves (von Hippel, 1978, 2005). More recently, studies found that, in parallel, users' motivation can also be commercial or process-related (Chen et al., 2020; Raasch and von Hippel, 2013; Stanko and Allen, 2022). Fig. 3 visualizes possible mixes of motives that may apply to innovating individuals. In the classical case of user innovation (point A), individual innovators are solely motivated by their personal needs (von Hippel, 1978).

On top of need motivation, user innovators may also be commercially motivated (point B) (Chen et al., 2020; Raasch and von Hippel, 2013). They may see opportunities to sell their innovation (e.g., de Jong et al., 2015; Shah and Tripsas, 2007) or to pursue indirect commercial benefits, like developing an expert reputation, promoting and generating interest in a related business that they run, or receiving job offers (de Jong and Flowers, 2018; Harhoff et al., 2003; Kankanhalli et al., 2015). Such indirect benefits apply to firm-hosted UICs where innovations are shared for free but where commercial follow-ups do occur (Holzmann et al., 2017).

Users' motivation can also be a mix of need and process-related benefits (point C). Users may derive benefits from the innovation process itself: enjoyment, personal development, or learning new skills (Raasch and von Hippel, 2013). Process benefits are quite common among UIC contributors (e.g., Jeppesen and Frederiksen, 2006; Ma et al., 2019). Finally, some users will be motivated by a mix of all three types (point D).

We should notice that individuals who are solely commercially motivated (point E) are not within the scope of our study. Such individuals would resemble producer innovators—who, by definition, only benefit from innovation when others adopt or buy their innovation, usually in the form of a full-fledged product (von Hippel, 2005, 2017). Likewise, individuals driven only by process benefits (point F) represent a specific group that regards innovation as part of their lifestyle. To these individuals, the actual application of their innovation is not a primary purpose. For a detailed discussion about the differences between user, producer, and process-driven innovators, we refer to de Jong and von Hippel (2023).

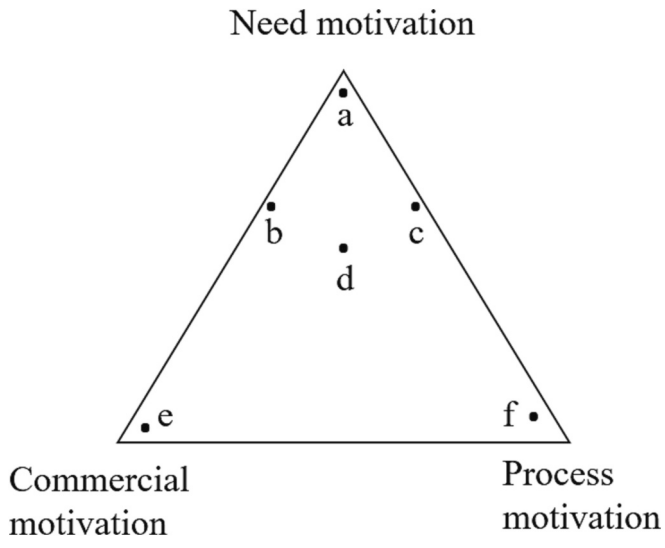

Fig. 3. Three types of motivation to innovate.
Source: Raasch and von Hippel (2013): p. 36.

It may be tempting to think that the contributions of professional users are only commercially motivated while those of amateurs are not. In the context of UICs, this is not the case. Professionals use the hosting firm's product as part of how they generate their income (i.e., it is part of their job or business). However, their user innovations are not necessarily work-related, and if they are, not a direct source of additional income. Being user innovators, professionals' main motivation is a personal need experienced at work or in their leisure time, and they may not mind sharing their innovations (recall that contributions to UICs are usually freely revealed). Again, similar motivations are present in the parallel field of OSS, where most professional coders contribute voluntarily for various reasons, including personal needs, process benefits (fun, personal development, learning), and sometimes indirect, commercially-related benefits (e.g., seeking career advancement) which may even deviate from their employer's interest (Lakhani and Wolf, 2005; Bitzer and Geishecker, 2010). Likewise, amateurs sometimes contribute to UICs for indirect commercial reasons, e.g., to build an expert reputation, develop professional relationships, and possibly pursue a future career at the hosting firm or its related domain (Kankanhalli et al., 2015).

In summary, both professional and amateur users can have various innovation motives. On top of personal needs, they may be commercially motivated, which we hypothesize to be a moderating factor in our research (see Section 2.2).

2.1.3. Network position

Ever since Granovetter (1973) pointed to weak and indirect relations as having a key role in transferring nonredundant, complementary information, scholars have recognized that—for the study of information transfers and resulting innovation outcomes—it is imperative to consider the structures of social networks and individuals' positions in these. Innovations seem to arise from the acquisition of complementary knowledge, and the acquisition of such is facilitated when individuals manage to bridge different tight-knit clusters (Burt, 2004; Granovetter, 1973; Zaheer and Bell, 2005). Within such clusters, information is more specialized (Tortoriello et al., 2012) but likely also more homogenous, which hampers novelty and innovation (Burt, 2004). Innovation is, therefore, facilitated by network positions that provide rich access to information.

To describe how users are embedded in the UIC's social network, structural and relational perspectives are possible—representing the position of a user in the network's total configuration (i.e., structural) or the characteristics of connections between individual users (i.e., relational) (e.g., Moran, 2005).

To our research on the moderating role of users' access to information provided through the community (as a whole), structural embeddedness is the most relevant perspective. Then, out of the available structural embeddedness measures, closeness centrality best matches the specific mechanism we are testing for. Closeness centrality indicates the network distance of a user to all other users active in the firm-hosted UIC. For example, if we consider Fig. 4, user *X* is most central in terms of closeness. To all other users, *X*'s path length is only one. *Z* and *Y* hold the second most central position, while *W* has the least central position.

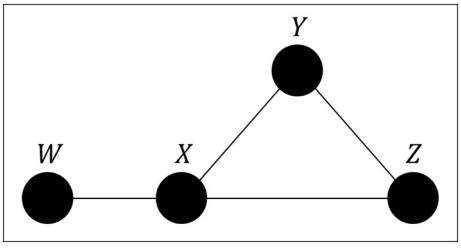

Fig. 4. Example of a community network with four members.

Since most information in user communities spreads through indirect connections (Resch and Kock, 2021), the further two users are separated, the less likely relevant information is transferred (accurately). Therefore, user innovators are best exposed to information when connected to others through the shortest possible path length—which is captured by having the most central network position in terms of closeness (Vriens and Corten, 2018).

2.2. Hypotheses

2.2.1. Professional user status and diffusion to peers

Our main hypothesis is that in firm-hosted UICs, diffusion to peers of contributions by professional users will be better compared to those of amateurs.

In general, studies found positive effects of individuals' domain-specific professional expertise on their ability to solve problems to the benefit of broader populations. For example, Sweller (1988) found that domain-specific expertise is a major factor distinguishing the problem-solving abilities of professional experts versus novice amateurs. Professionals develop more expertise about types of problems in the domain of interest and also about potential remedies. Likewise, Batra and Davis (1992) found that professionals are better able to design solutions in line with broad user requirements. In contrast, solutions developed by amateurs contain more errors—which Batra and Davis attributed to amateurs' inability to quickly process information and to match problem types with domain-specific design principles. Another example is Robey et al. (2019), who found that the expertise of professionals (i.e., paid innovation workers) helped develop products effectively addressing the demands of others. Compared to amateurs and volunteers, professionals were better at recognizing patterns in problem situations, while amateurs lacked these heuristics.

When we specifically consider the continued development effort required for peer diffusion in firm-hosted UICs (Fig. 1), professional users will have more expertise in design and marketing—two important competencies enabling them to develop innovations that are easier to adopt by peers.

First, professional users will have better design skills in the context of the hosting firm's product. Professional designers are individuals "who apply their knowledge to their vocation with rigor and probity, usually within a professionally oriented community" (Swindells et al., 2001: p. 130). Professionalism requires the accumulation of specialized design competencies, obtained from education, training, work experience, and frequent practical application (Füller et al., 2017). A key characteristic distinguishing professional designs from other contributions is that it is judged upon a social standard; whether the professional shows the ability to produce designs that do justice to the rigorous application of knowledge (Parkan, 2008). Professionalism also requires continuous inquiry into the latest developments and advancements in a field (Parkan, 2008). In contrast, amateurs' design competencies are mainly accumulated by the trial and error of individual practice (Moore, 1970). As a consequence, professional contributions will be more standardized, reliable, and better designed for replication.

Second, professional users will have acquired more marketing expertise in the area of the hosting firm's product. Marketing expertise enables individuals to develop innovations that cater to the needs of other users, and to shape their initial solutions to facilitate flawless adoption (Zhu et al., 2017). Marketing expertise is obviously crucial to self-employed and business-owning professionals, but actually, most professionals develop some marketing expertise in the domain of the business they are working for. Research has shown that marketing expertise tends to filter down to any employee to some extent by working in a commercial environment, even when marketing is no job requirement (Grizzle et al., 2009). Moreover, marketing expertise tends to be domain-specific (Dreyfus and Dreyfus, 2005; Füller et al., 2017). Consequently, user innovators generating income with the hosting firm's products will be better able to empathize with other users and deploy their marketing expertise to develop innovations in line with broader demand.

We anticipate design and marketing expertise to enable professional users to improve their innovations, regardless of whether their initial user solution addresses a problem at work or home. Professionals cannot be expected to do an 'amateurish' job but rather to maintain their advanced standards, no matter where they innovate, also because it is part of their professional identity (Lukoschek and Stock-Homburg, 2021). In this vein, Lukoschek and Stock-Homburg (2021) demonstrated that the innovation expertise and resources people obtain at work spill over to the development of innovations at home. Our argument is also consistent with Bitzer and Geishecker (2010), who found that professional OSS coders exert more effort to optimize and improve their contributions, also when contributing to open-source projects in their leisure time. Compared to amateur coders, their efforts result in OSS contributions of higher quality and better-anticipated diffusion outcomes.

In all, professional users have expertise that facilitates peer diffusion (i.e., diffusion-related expertise), particularly in design and marketing—which enables them to innovate beyond an initial prototype that quickly fixes a personal problem. We hypothesize:

H1. In firm-hosted UICs, the diffusion to peers of innovations contributed by professional users is better compared to innovations contributed by amateur users.

2.2.2. Moderating role of commercial motivation

In the context of contributions to firm-hosted UICs, we consider a different role of commercial motivation than has been investigated so far. We expect commercial motivation to strengthen the relationship between professional user status and diffusion to peers. Contributions to firm-hosted UICs are freely revealed. Hence, directly selling user innovations cannot drive users' motivation. However, as mentioned before, users may be motivated by indirect commercial benefits of free adoption by others, like developing an expert reputation, promoting a related business, expanding their networks, or receiving job offers (Harhoff et al., 2003; de Jong and Flowers, 2018; de Jong et al., 2023).

When user innovators seek indirect benefits, adoption by others becomes more important to them. This clearly differs from the situation where a user innovation is only developed for personal needs or process benefits, in which case user innovators generally have low incentives to invest in continued development to facilitate peer diffusion. An initial prototype often fixes their problem or caters to their process-related needs, and adopter benefits are an externality to them (de Jong et al., 2015, 2018; von Hippel, 2017). In contrast, we can expect that seeking indirect commercial benefits from adoption triggers an additional effort required to improve innovations—but only if users have the required diffusion-related expertise in the first place.

Hence, we anticipate that peer diffusion of professional contributions will get better, the more their developers are also commercially motivated. We already theorized that professional users possess the design and marketing expertise required to improve their innovations up to a stage where they become easy to adopt (H1). Commercial motivation adds a reason for professionals to maximally deploy their expertise. This argument is consistent with findings presented by de Jong et al. (2018) based on a sample of innovations developed by German consumers. They analyzed moderating factors associated with the diffusion of innovations in a different context, i.e., innovations not restricted to firm-hosted UICs and adopted by either peers or commercial businesses. de Jong et al. (2018) reported that users' willingness to commercialize (i.e., their commercial motivation) strengthened the relationship between the perceived general use value of their innovations and any first adoption by others. General use value is defined as the extent to which other users can benefit from obtaining a copy of the innovation. Arguably, general use value increases with a continued development effort (which improves the innovation's reliability, simplifies its design, etc.), which

especially professional users are capable of doing. In contrast, amateur users generally lack diffusion-related skills in the domain of the hosting firm's product, so being motivated by obtaining indirect commercial benefits is less likely to materialize in advanced designs.

In all, while diffusion-related expertise enables professionals to develop 'more advanced' user innovations (H1), commercial motivation triggers them to deploy their expertise more intensively. Our second hypothesis is:

H2. In firm-hosted UICs, the relationship between professional user status and the diffusion of contributions to peers will be stronger, the more a user is commercially motivated.

2.2.3. *Moderating role of network position*

As another individual-level moderator, we investigate if a central position in the UIC's network strengthens the relationship between professional user status and diffusion to peers.

The more users have a central network position in terms of closeness, the more information benefits will accrue to them (Vriens and Corten, 2018). Some of these information benefits provide users with directions on how to improve their initial innovations so that peer diffusion is eased. Specifically, in the context of user innovation, central network positions provide two information advantages.

First, users with central network positions can learn more about other users' needs and what a community demands (Claussen and Halbinger, 2021; Oehlberg et al., 2015). One of the prime channels through which users of the hosting firm's product acquire information relevant to their innovation process is the information that other contributors share within the community (Jeppesen, 2005). A central network position in terms of closeness enables users to observe the kind of problems that other users face when using the hosting firm's product and their (in) ability to replicate innovations that have been shared on the platform—by keeping track of other user innovations, and the comments and questions posted for these.

Second, users with central network positions obtain more knowledge about the solution space by observing the peculiarities of other user innovations (Oehlberg et al., 2015). They are also better positioned to copy modules and best practices from other users to improve their designs (Claussen and Halbinger, 2021).

Recent work by Resch and Kock (2021) suggests that network-related information advantages (user needs, solution space) are not uniformly distributed among professionals and amateurs. Their study of how network positions influence the novelty and perceived usefulness of innovations suggests that professionals are more likely to benefit from central network positions than amateurs. Users need deep knowledge about the product domain in which they are innovating before they can absorb the information acquired through their network (Resch and Kock, 2021). As we reasoned in Section 2.2.1, such knowledge is more likely accumulated by professional users. Hence, network-related information advantages may provide users with directions on how to improve their initial innovations, but only if they have diffusion-related expertise (i.e., if they are professional users), enabling them to process this information effectively and improve their initial prototypes.

In overview, we expect that the information benefits accrued through a central network position in terms of closeness positively moderate the relationship between professional user status and peer diffusion. A central network position provides user innovators with information advantages (other users' needs and the solution space) helpful to applying their diffusion-related expertise more effectively. Even when professionals and amateurs have the same network position, professionals have the design and marketing expertise required to absorb network information and improve their innovations. Our third hypothesis is:

H3. In firm-hosted UICs, the relationship between professional user status and the diffusion of contributions to peers will be stronger, the more central a user's network position is in terms of closeness.

Our hypotheses are summarized in Fig. 5.

3. Methods

Our empirical context is YouMagine, an online knowledge-sharing platform where users of the Ultimaker—one of today's leading commercial 3D printers—can share 3D printing designs. Part of YouMagine's environment is dedicated to incremental improvements and complements to Ultimaker's printers. Designs posted in this category fit the accepted definition of user innovations contributed to a firm-hosted UIC (Jeppesen and Frederiksen, 2006; Ma et al., 2019).

An example of an incremental improvement contributed to YouMagine is a nozzle tool developed by Anders Olsson (www.youmagine.com/designs/nozzle-torque-wrench). The nozzle of a 3D printer has to be replaced regularly, especially when crafting with hard materials. When replacing the nozzle, reaching the right torque is essential to avoid damage to printed objects due to over-tightening or leaking. Olsson's user innovations included a new nozzle block for the Ultimaker printer and a torque wrench, to ensure proper force every time the nozzle is changed. After reaching optimal torque, the tightening tool started slipping and produced clicking sounds.

An example of a complementary application that expanded the general value of the Ultimaker printer is a camera mount created by Erik Cederberg (www.youmagine.com/designs/ultimaker-2-camera-mount). To users of 3D printers, filming the printing process can be enjoyable and serve a purpose—to detect errors if printing fails. Cederberg's camera mount is a module that users can click on the machine.

3.1. *Data*

We collected data from three sources. First, YouMagine provided us with access to its databases, including data on the diffusion to peers of user innovations and users' social network positions. Second, we searched the Internet to code user innovators as professional or amateur. Third, we surveyed the user innovators to measure their commercial motivation and various control variables. By using these different sources, we mitigate problems with endogeneity and common method bias (Lindeboom and Kerkhofs, 2009).

First, we mined a copy of YouMagine's full database, including all posted designs and registered platform users. We selected all designs that could be regarded as incremental improvements of Ultimaker's products or complements that expand their general use value. Specifically, we looked at designs that—based on Ultimaker's offerings—improved existing functions or enabled new features (Hoonsopon and Ruenrom, 2012) and can be considered user innovations. Users uploaded these to YouMagine's category of "Ultimaker printer parts and enhancements". We manually inspected all designs in this category to exclude erroneous uploads. Our initial database included 1426 user innovations uploaded by 378 members.

Second, we searched the Internet to code users as professional (i.e., whether they generated income using or working with Ultimaker's 3D printers) or amateur. Most users had filled in their profile page at YouMagine and/or provided links to a personal website. If such information was missing, we used users' names and e-mail addresses to find their details on other platforms, web pages, and social media.

Our third source was a brief electronic survey sent to all 378 users in our database. The survey was first announced by YouMagine's platform manager. After one reminder, within two weeks we received completed 122 responses (32 % response rate). We used the survey's introduction page to explain that our questions were concerned with innovations designed to improve or enhance Ultimaker's 3D printers. To avoid confusion, for each respondent, we printed the description of the respondent's contributed designs fitting with the definition of user innovation on the first page. We then asked users about their motives for developing such innovations and a range of control variables (see

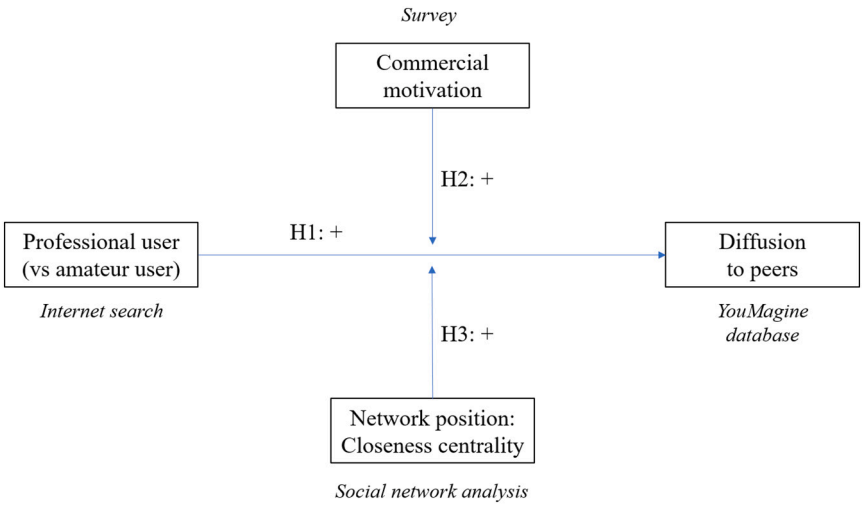

Fig. 5. Conceptual framework.
Notes: Data sources in italics.

hereafter). On average, our survey respondents worked with 5.4 different 3D printers and had 7.2 years of experience in 3D printing. Thirty-six percent had a Master's or doctoral degree. In terms of education and experience, these figures are highly similar to previous samples of Makers surveyed about 3D printing (Moilanen and Vadén, 2013).

After merging the three different sources, our final dataset included 614 innovations contributed by 122 users (a robustness check showed that selectivity of responses did not influence our findings; see Section 4.3).

3.2. Variables

Table 1 shows the variables we analyzed to test our hypotheses. Notice that some of our variables are measured at the individual level, while others are at the innovation level. Hence, we dealt with multilevel data with user innovations nested in the portfolios of individuals.

Our dependent variable is the extent to which user innovations directly diffused to peers within the YouMagine community. We composed an index of multiple indicators: (1) the number of downloads of an innovation's computer-aided-design (CAD) files, (2) the number of downloads of the instruction files submitted with an innovation, and (3) the number of times other YouMagine users had added the innovation to their collection of favorites. We first standardized the indicators, then merged them by taking the average score (Cronbach's $\alpha = 0.88$). A similar variable was used by Claussen and Halbinger (2021) in a study of the diffusion of designs developed by individual end consumers (their study was not restricted to user innovations nor to firm-hosted UICs, but they also analyzed diffusion to peers, so we applied a similar measure). As we found that the distribution of the resulting diffusion measure was positively skewed, we log-transformed the variable.

Our main independent variable is a dummy indicating whether a user innovator is professional (16 %) or amateur (84 %). We coded this variable based on Internet search (similar approaches were taken by Jeppesen and Frederiksen (2006) and Pollok et al. (2021)). Two researchers independently checked respondents' affiliations and relevant web profiles. Users were deemed professional if they somehow generated income from (working with) Ultimaker's 3D printers. We encountered a range of professional users, including employees, business owners, self-employed, and individuals running informal 'businesses' as parttime entrepreneurs. They generated income by selling 3D printing machines and/or related materials (such as filament), by providing technical consultancy services related to 3D printing, by selling products that were manufactured with 3D printers, or by working with the Ultimaker as a designer, architect, or technical engineer. Other users that we coded as professionals generated income by popularizing 3D printing or by sharing expertise in a blog, usually in combination with the provision of commercial services, advertisements, and affiliate marketing activities. If no income-generating activities could be detected, we regarded users as amateurs. Inter-rater agreement was excellent (kappa = 0.88) (Landis and Koch, 1977). A few ambiguous cases were discussed by the coders and usually conservatively coded as amateurs.

Our first moderating variable measures the extent to which the users had innovated for commercial reasons. We first asked respondents to think of all innovations they had created in the past five years to make Ultimaker's printers better, easier, or more convenient. In line with previous studies (e.g., Chen et al., 2020), we then offered the statement 'I created my 3D printer designs to generate income'. For our robustness checks (see Section 4.3), we also asked for alternative innovation motives: need motivation (i.e., 'I created these designs for personal need; I use (prints of) my designs myself') and process motivation (i.e., a two-item measure 'I created these designs for the fun/enjoyment of the design process' and '…for intellectual stimulation'; $\alpha = 0.89$). All motivation questions were answered on a five-point scale (1 = never, 2 = sometimes, 3 = regularly, 4 = often, 5 = always). As expected, need motivation was by far most important (M = 4.24) and never reported as playing no role in the respondents' motivation, confirming that the innovations in our database were primarily developed for personal use, i.e., can be considered user innovations. Process motivation was somewhat important (M = 3.54), while commercial motivation was relatively unimportant (M = 1.43) but still relevant to some respondents.

Our second moderating variable is closeness centrality, obtained from a social network analysis. YouMagine enables participants to follow other platform users. In accordance with the structure of the YouMagine platform, we constructed a directed social network—YouMagine users can follow others but reciprocity is not required. Our survey respondents followed 2.66 other users on average. The complete network structure had 1435 nodes—of which 122 were survey respondents—and 2118 directed connections between the nodes. To indicate the effect of information acquired from other users, we constructed our measure of closeness based on outdegree. Closeness centrality by outdegree takes into account the number of other users that are followed and the indirect connections resulting from following others. Higher closeness by outdegree implies that a user has a shorter path length to other network members and is in a better position to obtain (accurate) information (Vriens and Corten, 2018). By constructing the closeness measure based on outdegree, we can isolate the effect of information provided (indirectly) by others—which plays a central

Table 1
Variables and descriptive statistics.

Variable	Source	Description	M	SD
Individual level (n = 122)				
Professional	Web search	User innovator is a professional (coded 1) versus amateur (coded 0)	0.164	0.372
Commercial motivation	Survey	User created his/her innovations to generate income in the past five years (1 = never; 5 = always)	1.426	0.726
Closeness by outdegree	Database	User's closeness centrality by outdegree	0.714	0.026
Master/doctorate	Survey	User obtained a Master's or doctoral degree (0 = no; 1 = yes)	0.361	0.482
Experience 3D printing	Survey	User's experience in 3D printing (in years)	7.172	2.068
Lead userness	Survey	Construct of two items: 'When I think of the available tools, equipment, methods and processes in 3D printing…I am dissatisfied with some pieces of commercially available 3D printers' and '…I have needs which others experience only later' (1 = never; 5 = always) (α = 0.77)	2.553	0.888
Innovation level (n = 614)				
Diffusion to peers	Database	Log-transformed index variable composed of three indicators: downloads of an innovation's CAD files, downloads of an innovation's instruction files, and number of times the innovation is favorited by other users (α = 0.88)	−0.130	0.418
Words	Database	Number of characters used to describe the innovation	823.7	1217.1
Days	Database	Number of days since the innovation was posted	1901.5	450.7
License	Database	Presence of a license constraint on commercial derivates or continued development (0 = no; 1 = yes)	0.215	0.411

Notes: M = mean, SD = standard deviation.

role in our third hypothesis.

We added various control variables to our analysis. At the individual level (n = 122), we included experience in 3D printing (in years) and level of education (dummy variable indicating if the respondent had a Master's or doctorate degree)—both obtained from our survey. These controls ensured that our main independent variable (professional user status) better reflects users' design and marketing expertise; and not the differences that emerge because respondents have more experience in using 3D printers or have better cognitive skills in general. We also controlled for users' lead userness (two-item measure; items with the highest factor loadings taken from Franke et al. (2006), α = 0.77). Lead users are ahead of other users with regard to important trends (in our case, concerning the use of 3D printing equipment) and strongly expect to derive benefits from developing solutions to unsatisfied needs. As such, they are more likely to innovate (von Hippel, 2005). We controlled for lead userness to ensure that our main independent variable (professional user status) reflects the differences in users' diffusion-related knowledge and not differences in how their personal needs may have triggered them to innovate.

At the design level (n = 614), we controlled for the level of detail of user innovations' documentation (number of words in its design description) and time since the design was posted (in days)—as detailed documentation and longer online exposure positively influences diffusion (Flath et al., 2017; Stanko, 2016). We also controlled for diffusion restrictions embodied in the license attached to an innovation. By default, YouMagine's designs are shared with a CC BY-SA license, the Creative Commons license that allows other users to share and adapt (also for commercial purposes). However, users can put limitations on commercial derivates (e.g., CC BY-ND or CC BY-NC licenses). Our dummy variable indicates whether users have put restrictions on their innovation concerning derivatives and/or commercial diffusion.

3.3. Analysis

As we dealt with nested data, we conducted multilevel regression analyses to test our hypotheses. Ignoring the multilevel structure of our data would violate the critical assumption of independence among observations (Julian, 2001), as unobservable individual characteristics of users may influence peer diffusion. Our multilevel regressions estimate the effects of innovation- and individual-level variables on diffusion, accounting for "the existence of the heterogeneity caused by non-observed characteristics which cannot be considered in the model but which explain in part the variation" (Bellavance et al., 2009: p. 448). To illustrate, our first model—containing only control variables—is given by:

$$diffusion_{i,j} = \beta_0 + \beta_1 words_{i,j} + \beta_2 days_{i,j} + \beta_3 license_{i,j} + \beta_4 lead\ userness_j + \beta_5 master/doctorate_j + \beta_6 experience_j + u_{0j} + \varepsilon_{i,j}$$

In this equation, diffusion to peers of innovation *i* developed by user *j* is explained by level one variables defined both at the level of innovations *i* and individuals *j*, and level two variables only defined at the level of individuals *j*. We initially estimated random intercept models; in which the intercept u_{0j} differs across users to capture unobserved variation.

4. Results

Bivariate correlations between our variables are displayed in Table 2. For diffusion to peers, we found significant correlations with the innovation-level control variables: words, days, and license.

For the user-level variables, professional user status is correlated with general experience in 3D printing (r = 0.298, p < .01) and self-reported lead userness (r = 0.449, p < .01). Again, in our multilevel regressions (hereafter) we control for these variables, to ensure that the relationship between professional user status and diffusion to peers reflects the differences in design and marketing expertise that we theorized. Also, being a professional user is significantly and positively related to closeness by outdegree (r = 0.105, p < .01) and commercial motivation (r = 0.297, p < .01). As expected, professional users are more commercially motivated, but the correlation coefficient also shows that this relationship is far from perfect (as we explained in Section 2, both professionals and amateurs may innovate for commercial reasons). Overall, the correlations in Table 2 do not raise multicollinearity concerns.

4.1. Testing the hypotheses

Table 3 displays the results of our multilevel regression analyses, in which we first standardized users' commercial motivation and closeness centrality by outdegree to ease the interpretation of interaction effects.

Model 1 contains only the control variables. The diffusion of user innovations to peers increases when the design is described in more detail (words), has been online for a longer time (days), and when its license puts restrictions on unprecedented future use. Our interpretation of this latter result is that users choosing a restrictive license probably

Table 2
Correlation matrix.

Variables		1	2	3	4	5	6	7	8	9
1	Diffusion to peers									
2	Professional	−0.001								
3	Closeness by outdegree	−0.049	0.105**							
4	Commercial motive	−0.073	0.297**	0.039						
5	Words	0.308**	−0.038	0.061	−0.064					
6	Days	0.470**	−0.004	−0.005	−0.151**	0.026				
7	License	0.143**	−0.192**	0.178**	−0.037	0.212**	−0.095*			
8	Lead userness	−0.028	0.449**	0.088*	0.305**	0.066	−0.082*	−0.085*		
9	Master/doctorate	−0.028	−0.130**	−0.052	−0.040	0.115**	−0.095*	0.073	0.010	
10	Experience 3D printing	0.047	0.298**	−0.086*	−0.085*	−0.083*	0.256**	−0.233**	0.125**	−0.297**

Notes: n = 614. Pearson correlations are shown.
** p < .01.
* p < .05.

Table 3
Multilevel regression models of diffusion to peers.

	(1)		(2)		(3)		(4)		(5)	
	dy/dx	S.E	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.	dy/dx	S.E.
Professional (P)			0.034	0.059	0.046	0.053	0.020	0.061	0.033	0.055
Commercial motive (CM)			0.022	0.019	0.011	0.018	0.019	0.018	0.009	0.018
Closeness outdegree (CO)			−0.037ˆ	0.022	−0.040ˆ	0.023	−0.055*	0.025	−0.056*	0.025
P * CM					0.170*	0.068			0.158*	0.067
P * CO							0.093*	0.045	0.080ˆ	0.047
Words	0.000**	0.000	0.000**	0.000	0.000**	0.000	0.000**	0.000	0.000**	0.000
Days	0.001**	0.000	0.001**	0.000	0.001**	0.000	0.001**	0.000	0.001**	0.000
License (restricted)	0.169**	0.063	0.175**	0.064	0.177**	0.064	0.177**	0.065	0.178**	0.065
Lead userness	−0.036	0.023	−0.038	0.024	−0.045ˆ	0.024	−0.035	0.023	−0.042ˆ	0.024
Master/doctorate	0.003	0.054	−0.001	0.053	0.001	0.051	0.008	0.051	0.008	0.051
Experience 3D printing	−0.008	0.013	−0.006	0.013	−0.002	0.014	−0.006	0.013	−0.003	0.013
AIC score	331.91		334.65		333.00		334.64		333.48	
Wald-χ^2 (df)	215.48(6)**		241.26(9)**		253.97(10)**		245.32(10)**		247.09(11)**	

Notes: Estimates based on 614 designs by 122 individuals. Marginal fixed effects are shown (dy/dx) with robust standard errors (S.E). All independent variables pass the VIF test for multicollinearity (highest VIF = 1.51). Two-tailed significance **p < .01; *p < .05; ˆp < .10.

more carefully considered the broader value of their innovations.

Model 2 tests our first hypothesis (H1). A direct relationship between professional user status and diffusion to peers is absent in our data (dy/dx = 0.034, p = n.s.), so H1 is not supported.

Models 3 and 4 test the moderating roles of commercial motivation (H2) and closeness centrality (H3). Model 5 estimates both effects simultaneously. We find that the designs by professional users diffuse better than those offered by amateurs, the more users are commercially motivated (model 3: dy/dx = 0.170; p < .05). This supports H2. The relationship between professional user status and diffusion to peers is also stronger, the more central users have a central network position in terms of closeness by outdegree (model 4: dy/dx = 0.093; p < .05). This is in line with H3. These findings are maintained when both interaction terms are estimated simultaneously (model 5), although the interaction term of closeness by outdegree then is only marginally significant at p < .10.

4.2. *Probing interaction effects*

To interpret the interaction effects, we estimated simple slopes based on Cohen et al.'s (2013) procedures. In Fig. 6, we see that when users are highly commercially motivated, the contributions of professional users

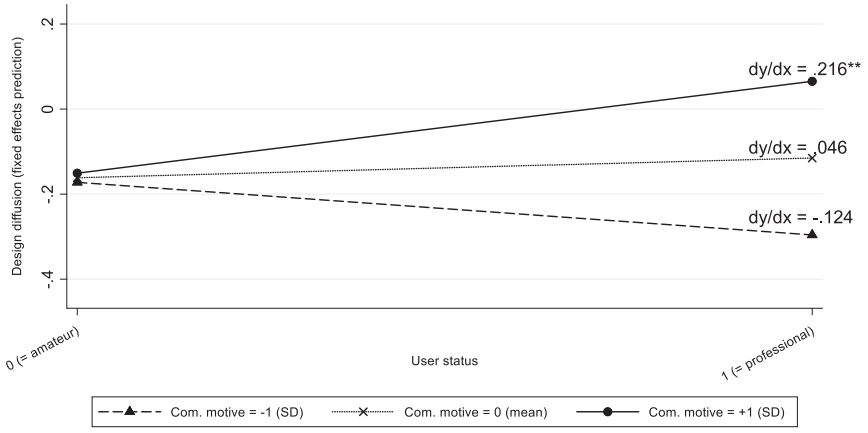

Fig. 6. Simple regressions of peer diffusion on professional user status at levels of commercial motivation.
Notes: Two-tailed significance **p < .01.

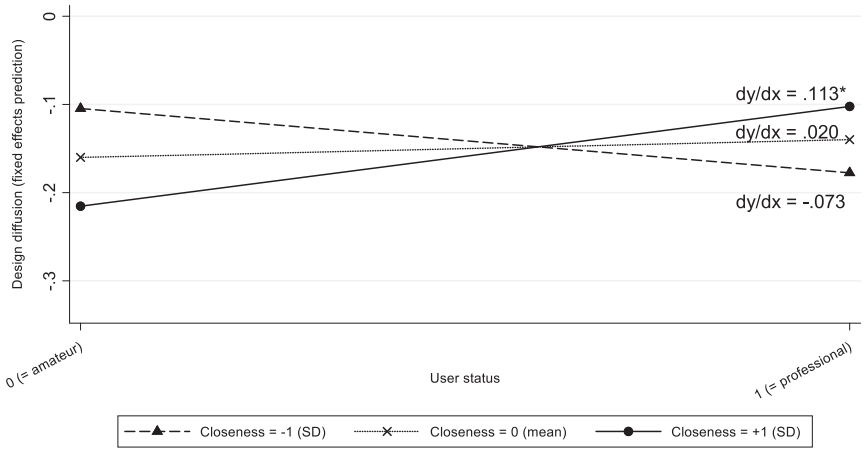

Fig. 7. Simple regressions of peer diffusion on professional user status at levels of closeness by outdegree.
Notes: Two-tailed significance *p < .05.

diffuse better compared to those of amateurs. At high commercial motivation (M + 1 SD), the relationship between professional user status and diffusion to peers is positive and significant (dy/dx = 0.216, p < .01). Specifically, at one standard deviation above the mean level of commercial motivation, design diffusion is 24 % higher for professionals as compared to amateurs. We find no significant effects when users' commercial motivation is at average or low levels.

We find similar results when probing the interaction effect of closeness by outdegree—see Fig. 7. At high levels of closeness by outdegree (M + 1 SD), the effect of professional user status on peer diffusion is positive and significant (dy/dx = 0.113, p < .05). When users' closeness by outdegree is one standard deviation above the mean, peer diffusion of professional contributions is 12 % higher compared to amateurs. At average or low levels of closeness by outdegree, no significant effects are found.

4.3. Robustness checks

We first checked if—instead of only random intercepts—modeling random slopes for each independent variable of interest would change our findings. As suggested by Bell et al. (2019), we re-estimated our regressions by allowing random slopes of professional user status, commercial motivation, and closeness by outdegree. Our findings were similar. Given that random slope models are less parsimonious (Matuschek et al., 2017) and require high cluster sizes (i.e., more innovations per user) (Snijders, 2005), we here reported random intercept models. Moreover, a likelihood ratio test indicated no improvement in model fit from random slopes.

Second, we analyzed whether our findings were sensitive to adding or removing control variables. We included the additional control variables that measured personal need motivation and process-related motivation. Their inclusion did not change our findings. We also re-estimated our models while leaving out user-level control variables (lead userness, experience, master/doctorate) one by one, with similar results.

Third, we considered an alternative network measure. As explained, closeness by outdegree best reflects a network position in which information from others can be obtained (Vriens and Corten, 2018). Yet, we could have used an alternative indicator: by simply counting how many others a user was following and, thereby, ignoring indirect knowledge flows. Our findings were maintained using this simplified network measure but the model fit was significantly lower.

Fourth, we recognized that users may follow other YouMagine users in the hope of reciprocity. When other users start following them in return, this increases their exposure and potentially the diffusion of their designs—by this mechanism, users may follow others for the very commercial reasons central to our second hypothesis. We would then expect to find a strong, positive correlation between a user's outdegree (the number of others a user is following) and indegree (a user's number of followers). However, in our data, the correlation between indegree and outdegree was weak and insignificant (r = 0.078; p = n.s.), indicating no concern for this alternative explanation.

Finally, recalling that only 32 % of the user innovators in our initial database completed our survey, we checked for potential selection bias. We estimated a Heckman regression in which survey response (1 = yes, 0 = no) was the dependent variable in the selection equation, and diffusion to peers was the dependent variable in the main regression equation. The selection equation included the independent variables we obtained from YouMagine's database and our Internet search: professional user status, closeness by outdegree, words, days, and license. In the selection equation, only the variable 'days' was negative and significant—indicating that users who had posted their designs a longer time ago had responded less to our survey. The main regression equation included all independent variables, with results similar to Table 3.

5. Discussion

We took a first step in investigating the antecedents of peer diffusion in firm-hosted UICs; which is a purpose of such platforms (Jeppesen and Frederiksen, 2006) that has not been investigated so far. Peer diffusion brings additional challenges: contributions to UICs are usually quick fixes that solve user innovators' immediate problems, but not yet applications that other users can easily adopt (de Jong et al., 2023; von Hippel, 2017). In the absence of hosting firms taking care of continued development (e.g., to improve replicability and reliability, meet safety standards, align different product parts, etc.), a 'peer diffusion gap' exists (see Fig. 1).

Our main focus was on the professional background of user innovators, with professional users generating income with the hosting firm's product, while amateurs do not (Jeppesen and Frederiksen, 2006). We reasoned that when the hosting firm facilitates innovation sharing but refrains from continued development, professional users within the community may be essential to fulfill the role of developing user innovations that are easy to adopt by peers. Our analysis confirmed that professional contributors accomplish better diffusion rates compared to amateurs, but only when they are highly commercially motivated or hold a central network position in terms of closeness.

5.1. Implications for theory

Our study has various implications for the literature on firm-hosted UICs and user innovation theory in general.

Our findings show that for peer diffusion in firm-hosted UICs, professional users are more important than suggested by previous research. Studies, so far, mainly compared innovations that originate from external users (professionals and amateurs lumped together) with those of the company's innovation workers (e.g., Magnusson et al., 2003; Poetz and Schreier, 2012; Pollok et al., 2021). A general finding is that innovations from external users are more novel and generally useful (e.g., Pollok et al., 2021) and have higher market creation potential (Nishikawa et al., 2013). Few studies delineated professional and amateur external users as we did. One exception is Jeppesen and Frederiksen's (2006) study of a UIC dedicated to computer-controlled musical instruments, where amateur contributions appeared more innovative and novel. All of this might leave the impression that external users, and in particular amateurs, are most valuable from the perspective of the hosting firm. Indeed, the highly novel and first-of-kind innovations that emerge from their inputs are certainly worth considering—a view that is present in the broader user innovation literature as well (von Hippel, 2017). What our study adds is that when the focus is on peer diffusion in firm-hosted UICs (instead of the type of innovations offered to these communities), contributions by professional external users are of particular importance. This is not in contradiction with Jeppesen and Frederiksen (2006), who looked at innovation novelty as a dependent variable (whether users had developed new-to-the-world, regular, or no innovations). For highly novel innovations, amateur users may be preferential, but for diffusion to peers, contributions by professional users are more effective. Professionals' domain-relevant expertise in design and marketing (obtained by working with the hosting firm's product) enables them to develop user innovations up to a level where others can easily adopt.

However, our findings show that professional users only pick up this role under specific circumstances. First, diffusion to peers of professional contributions is better when their developers have incentives to truly accomplish peer adoption. Our interpretation of the significant moderating role of commercial motivation is that professional users pursue indirect benefits from peer diffusion. For example, they seek to develop an expert reputation, promote and generate demand for a related business, expand their network, or pursue job offers or future favors. All of these things can eventually help them generate income and provide a reason to deploy their expertise to make their innovations easy to adopt.

For the emerging theory on diffusion of user innovations (de Jong et al., 2015, 2018; von Hippel, 2017), our finding about commercial motivation is significant. User innovation scholars already recognized users sometimes engage in commercial activities, e.g., they may start businesses (e.g., Shah and Tripsas, 2007) or transfer their innovations to existing firms for money (e.g., de Jong et al., 2015). The new insight from our study is that, even in a context where users freely reveal their innovations, commercial motivation can be influential—as it triggers users to continue with the development of their innovations, provided that they have the required diffusion-related expertise. Obviously, such users would do this to reap aforementioned indirect benefits, but another reason to freely share may be that users seek to test potential market demand—consistent with Shah and Tripsas' (2007) observation that users freely reveal innovations as an intermediary step towards business emergence.

Second, professional contributions diffuse better when their developers have a central network position in terms of closeness. Where previous studies found that users' embeddedness in the UIC network is important for innovation development (Dahlander and Frederiksen, 2012) and for the novelty and perceived usefulness of their innovations (Resch and Kock, 2021), our study adds is that network positions also matter for the direct dissemination of user innovations to peers. Here, our interpretation is that central network positions enable users to learn about other users' needs and the solution space in general, which provides them with directions on how to deploy their diffusion-related expertise.

The significant interaction effect of network position (Table 3) is consistent with Resch and Kock's (2021) theorizing about information overload. They argued that—unless users can couple network-based information with specialized knowledge—information acquired through superior network positions can be overwhelming to users. Recalling our findings that professional users benefit from network centrality while amateur users do not, we can also interpret our significant interaction effect as evidence that professional expertise equips users with the skills necessary to mitigate information overload. Professional expertise helps users to incorporate information about other users' needs and solutions to develop innovations that are easier to adopt.

In all, commercial motivation and central network positions seem necessary conditions for the benefits of professional expertise to surface. Without commercial motivation, it seems that also professional users do not feel the urge to develop their innovations up to a level where adoption becomes easy. Or, without a network position facilitating access to up-to-date information, even the contributions by professional users are insufficiently aligned with the latest community needs and solutions.

5.2. Implications for practitioners

Our findings have implications for firms that host user innovation communities. The studies that were done so far only considered the emergence of user contributions and the absorption of promising innovations into the firm's products (e.g., Jensen et al., 2014; Ma et al., 2019). However, facilitating peer-to-peer diffusion is another objective of firm-hosted UICs. Stimulating the diffusion of incremental product improvements and complements creates extra value for customers and, thereby, for the company itself.

Based on our study, we can offer three suggestions to hosting firms. First, it seems wise for firms to attract professional users and stimulate contributions of those professionals who participate already. In principle, professional user status is easy to identify, in contrast to previously identified antecedents of user innovation emergence—like lead userness (Franke et al., 2006). Yet, simply attracting new community members is not enough. When hosting firms want user contributions that can be easily adopted by peers, it is important that professional users developed their innovations with commercial motivation (at least partially) and/or occupy central network positions. Accordingly, firms can give professionals more prominent, formal roles as ambassadors, core community members, or platform moderators. When such recognition is made visible to outsiders, it will help professional users to generate income indirectly, for example, by providing consultancy services. Alternatively, hosting firms can consider compensating professional users for their efforts with a fee or particular favors when they increase their contributions (e.g., discounts on the firm's products and parts, obtaining free samples, prominent mentioning in the firm's communications, etc.). Absent commercial motivation, professional users will probably not respond to such incentives.

Second, we recommend tailoring the community environment, recognizing that users have diverse motives to innovate. To stimulate professional users, it will probably help to provide platform tools to support commercialization. Although need motivation is most important, and process-related motivation comes second, some users (also) strive for commercial benefits. Free revealing should still be central, but the hosting firm could offer appropriate tools specifically relevant for commercially-driven participants. For example, they may include buttons on their platforms where adopters can order copies of user innovations—to save the hassle of downloading design files and replicating designs for themselves (a convenient option for adopters who only want a copy to solve a personal problem). Of course, the challenge would be to

avoid disbalance: too much focus on commercialization may alienate user innovators who only seek need or process benefits. Alternatively, firms can create a second platform facilitating the commercialization of full-fledged innovations. In 3D printing, an example of such a platform is Shapeways.com, which offers a 'marketplace' to developers willing to sell their designs.

A third suggestion is to directly stimulate the continued development effort required to make user innovations easier to adopt. Hosting firms may, for example, lower the threshold for adopters to ask questions to developers or to file problems encountered during replication. Their platforms could offer facilities to nominate innovations as 'high-potential designs' that should be improved or think of other ways to visualize potential demand—recent work shows that this triggers user innovators to increase their diffusion effort (von Hippel and Cann, 2021). Alternatively, hosting firms could embed their employees in the community (Dahlander and Wallin, 2006) to initiate and stimulate dissemination processes. Finally, they may offer extra diffusion incentives to user innovators, like awards, prizes, certificates, or rankings.

In any case, we advise hosting firms to design their UICs for different kinds of users, including both professionals and amateurs. It is still true that amateur users are valuable sources of initial solution-prototypes with high functional novelty (Jeppesen and Frederiksen, 2006) that potentially address a broad demand (Franke et al., 2006). A mixed community is merited because professional users do not innovate in isolation but require a critical mass of other users—including amateurs signaling their needs and solutions by posting designs, providing feedback, and remixing and adopting existing designs. Moreover, we observed in our Internet search (when we coded user status) that many professional users once started as amateurs and became entrepreneurs later—which is a common pattern in user innovation research (Shah and Tripsas, 2007). In all, our study certainly does not imply that amateur contributions to firm-hosted UICs are unimportant.

5.3. Limitations and suggestions

Our study had some limitations, which translate into opportunities for future research. First, we assumed that all user innovations in our sample had the same chance of being observed by community members. However, professional users may invest more in informing potential adopters. By controlling for the number of words (i.e., quality of the design's documentation) and time since designs were posted, we partially controlled for how much innovations were broadcasted. However, users may have called upon other channels (e.g., their weblog or social media) to bring their innovations to general awareness. An alternative explanation for the patterns we observed is that professional user status is associated with peer diffusion also because of such increased promotion efforts. Our findings would not dramatically change (since diffusion to peers occurs anyway, adding to social welfare), but it would be worth investigating if this mechanism exists in parallel with professionals' design and marketing expertise.

Second, our measure of professional user status merged all professionals with different business models to generate income, e.g., employees, business owner, self-employed, and informal entrepreneurs with unregistered businesses, generating income from home. They were concerned with a range of activities, including trade, manufacturing, technical services, and promotion (popularizing 3D printers on a blog or website). Our dataset did not allow us to delineate types of professional users as the subsamples would become too small. It would be interesting to explore if different relationships between professional user status and diffusion to peers can be detected for various types of professionals.

Third, our dependent variable for peer diffusion was an index variable based on the numbers of downloads and times being favorited by other users. Since firm-hosted UICs are online environments where knowledge is shared (e.g., Becker et al., 2022; Dahlander and Magnusson, 2005; Jeppesen and Frederiksen, 2006; Ma et al., 2019; Yan et al., 2018), this is a valid measure. However, uncharted territory is if our study can be extended to offline user communities, where innovation is encouraged and facilitated by the manufacturer of a product and where knowledge exchange partially takes place at periodic events. For example, the British kit car industry brings together groups of consumers and professionals who build and innovate their own cars, based on a manufacturer's kit (e.g., https://midascars.co.uk/). In offline environments, alternative measures of diffusion should be sorted out.

In line with de Jong et al.'s (2021) call for continued work on diffusion, we hope that this study inspires a line new of research: concerned with peer diffusion of contributions to firm-hosted UICs. We took a first step by looking at professional users and their commercial motivation and network positions—all variables at the level of the individual innovator. Clearly, many more antecedents can be investigated. de Jong et al. (2018) theorized that diffusion of user innovations (not necessarily in firm-hosted UICs) also depends on the characteristics of the innovation (O-factors, e.g., technical novelty of innovations) and the innovation process (P-factors, e.g., whether innovations are developed individually or in collaboration). Likewise, Ma et al. (2019) studied adoption by hosting firms, looking at a range of innovation, innovator, communication, and scarcity-related factors—many of which can also be considered in light of peer diffusion.

CRediT authorship contribution statement

Max Mulhuijzen: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Jeroen P.J. de Jong:** Conceptualization, Methodology, Investigation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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