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First adoption of consumer innovations: Exploring market failure and alleviating factors

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ABSTRACT

Consumers innovate usually for non-commercial motives. They generally lack incentives to diffuse, and this is expected to hamper first adoption – even if consumer innovations are valuable to many other people. We confirm this market failure with survey data of 164 German consumer innovators. First adoption by others is unrelated with general use value, unless the innovator is highly willing to commercialize. Next, as classical diffusion theory does not explain when consumer innovations become available to others, we propose an individual-object-process (I-O-P) framework to study factors alleviating the market failure. The viability of the framework is explored by studying the moderating role of entrepreneurial experience (I), product newness (O) and community engagement during the innovation process (P). First adoption of generally valuable consumer innovations is enhanced when a community was involved. We also find tentative evidence for a moderating role of entrepreneurial experience and product newness.

1. Introduction

A consumer innovation is defined as a functionally novel product, service, process or application, developed by consumers at private cost in their unpaid discretionary time (von Hippel, 2017). Consumers occasionally innovate for commercial reasons. Much more often, however, consumers are driven by personal need or benefits derived from the innovation process itself (e.g., enjoyment, learning) (Raasch and von Hippel, 2013). Surveys done in various countries (summarized by de Jong, 2016) show that the frequency of consumer innovation in general populations is 4–6%.

Some consumer innovations are highly useful to others. General use value is the perceived utility of an innovation by others in a social system, apart from use or process benefits that the innovation offers to its creator. Compared to existing products innovations with high general use value deviate in terms of market-related factors. They address a problem or need that many others face, with the potential to address a sizeable market (Garcia and Galantone, 2002). Earlier work indicates that some consumer innovations have the potential to diffuse and advance social welfare. For example, micro-economic models show that consumer innovations can put price pressure on existing commercial products, or drive producers to improve the quality of those products. Consumer innovations may also complement existing producer offerings so that the aggregated use value increases (Gambardella et al., 2017). Empirical observations shows that consumer innovations can become new products with better revenues than products obtained from traditional new product development (e.g., Fuchs and Schreier, 2011; Lilien et al., 2002). Consumer innovation can also result in start-ups at the edge of new industries (Shah and Tripsas, 2007).

Social welfare is the general well-being obtained by individuals in a society by an allocation of resources (products, services, processes, applications) that is suboptimal, i.e. not distributed to those who gain most utility to them (Feldman, 2008). Social welfare requires diffusion, referring to a process by which an innovation is communicated over time among the participants in a social system (Rogers, 2003). First adoption by others, or the act that other people start using the consumer innovation, is a necessary first step in a diffusion process.

In the case of consumer innovation first adoption is not self-evident. Von Hippel (2017) discusses that as consumers derive benefits from personal use or direct engagement in the innovation process, value to others is an externality to them. Consumer innovation differs from the traditional producer innovation model. For commercial producers diffusion of innovations is likely, as producers will have to sell their innovations in order to benefit. In general, a market failure is a situation in which the allocation of products, services, processes or applications is inefficient; in an alternative outcome (some) individuals can be better off without making others worse off (Krugman and Wells, 2006). Typically, market failures exist when individual pursuit of self-interest

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leads to results that can be improved from a social welfare perspective. Accordingly, lack of diffusion due to missing incentives has been proposed as a new type of market failure. Initial evidence for consumer innovators was reported by de Jong et al. (2015) based on survey data of Finnish citizens. The authors recommended to further study the circumstances that would alleviate lack-of-diffusion of consumer innovations. In this paper we address this research gap. (The market failure was also demonstrated in a study of American physicians (von Hippel et al., 2017), but in the current paper we are concerned with consumer innovators.)

Our contribution is twofold. First, compared to the consumer innovation study reported by de Jong et al. (2015) we provide more robust evidence for a market failure with regard to diffusion. A drawback in the aforementioned study is that consumers self-rated the general use value of their innovations. In the current paper we analyze data from 164 German consumer innovators, including detailed descriptions and visualizations of their innovations. We had independent coders to rate general use value in order to obtain an independent measure.

Second, we propose and apply a framework to analyze the circumstances in which first adoption is more likely. By doing so we also contribute to the diffusion of innovations literature. Diffusion studies assume that innovations are available to others, that is, some first adoption has occurred already. First adopters are typically cosmopolite and connected to other populations, enabling them to introduce the innovation into their social system (Rogers, 2003). Diffusion studies usually also identify a 'change agent' with an interest in diffusion (e.g., a business, government, or charity organization). In the case of consumer innovations, however, due to lacking incentives a change agent is missing, and the innovation may never become available to others to begin with.

Drawing on entrepreneurship, user innovation, and diffusion of innovation literature, we suggest to study individual (I), object (O) and process variables (P) that can moderate the relationship between general use value and first adoption. To explore the viability of the framework we analyze as moderating variables: entrepreneurial experience (I), product newness (O) and community engagement (P). We find that general use value and first adoption are positively related if a community of like-minded individuals was involved in the innovation process. We also find tentative evidence that prior entrepreneurial experience and product newness are circumstances in which market failure with regard to first adoption is alleviated.

2. Theory and hypotheses

In this section we elaborate on the relationship between general use value and first adoption, which is expected to be absent. The relationship is anticipated to be moderated by the innovator's willingness to commercialize, but not by the innovator's willingness to reveal. Next, we introduce our theoretical framework to study factors alleviating market failure, and develop hypotheses with regard to the moderating role of entrepreneurial experience, product newness and community engagement.

2.1. General use value and first adoption

The proposed market failure is due to a lack of diffusion incentives. Consumers may innovate for a variety of reasons, but the main ones are personal need and process benefits (engagement in the innovation process, like enjoyment and learning) (Hienerth et al., 2014; Raasch and von Hippel, 2013). Beyond individual consumers these motives apply to those innovating collectively in open-source projects (e.g., Hertel et al., 2003; Lakhani and Wolf, 2005). Consumer innovations originating from commercial motives are rare. For example, von Hippel (2017) reported that only nine percent of the innovators in a sample of consumers in Finland was driven by commercial considerations.

Von Hippel (2017) argues that being motivated by personal need or process benefits, consumers see no mechanism in place to share any benefits that others would reap from adopting their innovations. Adopter benefits are seen as an externality, so that consumers fail to invest in diffusion:

> "Investment in diffusion by [consumer] innovators can increase social welfare because it is often the case that even relatively small investments can greatly reduce search and adoption costs for [others]. For example, if I (…) would invest just a little extra effort to document my open source software code more clearly, I could greatly reduce the time that perhaps thousands of adopters would require to install and use my novel code. (…) System benefit is maximized at the point where an additional dollar of investment in diffusion by the innovator (…) reduces adoption costs by a dollar across all (…) adopters. (…) The problem is that innovators have to bear the costs of investments in diffusion, while adopters get all of the benefits and do not share those costs. There is no market link that would enable a more appropriate allocation" (von Hippel, 2017: p. 65–66).

This situation is what economists generally consider a market failure: consumer innovators' pursuit of self-interest results in a suboptimal allocation of knowledge. It should be pointed out that consumer innovators can obtain non-monetary benefits from adoption, such as increased reputation or self-esteem (Lakhani and Wolf, 2005). However, in previous studies such motives applied to very few consumers, and did not seem to offset a lack of monetary rewards (de Jong et al., 2015).

From a social welfare perspective, diffusion of consumer innovations is merited to the extent that these innovations have general use value: useful to others in the social system, addressing a problem or need that many other people face, with the potential to address a sizeable market. Recent household sector surveys brought to awareness that only a minority of all consumer innovations diffuse (de Jong, 2016), but this cannot be considered evidence of market failure: *"Many or even most of the innovations […] may have been of interest only to the innovating user. In such cases, non-diffusion is not evidence of a shortfall in investment in diffusion by the user innovator: it simply is a reflection of the expected lack of adopter interest"* (de Jong et al., 2015: p. 1857–1858).

A first pattern we expect to see in the presence of market failure is that the general use value of consumer innovations is unrelated with first adoption by others. If consumers would do a significant diffusion effort the relationship would be positive and significant − as others would likely adopt innovations with high general use value. Because it is unusual to formulate a hypothesis with regard to a missing relationship, we formulate the research question:

RQ1. What is the empirical relationship between general use value of consumer innovations and first adoption by others?

The proposed market failure also implies that if consumer innovators are highly willing to commercialize, the relationship between general use value and first adoption should be positive and significant. We define willingness to commercialize as a consumer's attitude of being open and receptive to sell the innovation for economic benefits. In general, a positive attitude towards a behaviour increases the odds of developing intentions and conducting the particular behaviour (Ajzen, 1991; Fishbein and Ajzen, 1975). The more consumer innovators are willing to commercialize, the better the odds that they will engage in diffusion behaviours like showing off their innovation to producers, documenting their innovation for the sake of knowledge transfer, or starting a venture. Willingness to commercialize would restore a connection between the innovator's diffusion effort and adopter benefits. The innovator would partially appropriate those benefits via license fees or sales revenues (von Hippel, 2017). As a consequence first adoption is expected to be observed, provided that the innovation has high general use value − if not, adopters would simply not be interested. We hypothesize:

H1. The relationship between general use value and first adoption of consumer innovations is moderated by the innovator's willingness to commercialize. At higher willingness to commercialize, generally useful innovations are more likely adopted by others.

Finally, the proposed market failure would imply that the relationship between general use value and first adoption is NOT moderated by the innovator's willingness to reveal. Willingness to reveal is the consumer's attitude to be open and receptive to freely share his/her knowledge without claiming intellectual property, so that the innovation becomes a public good (Harhoff et al., 2003). Although consumer innovators generally do not protect their innovations with intellectual property rights, and report to be highly willing to reveal (von Hippel, 2017), we cannot expect that willingness to reveal will make consumers do an effort to diffuse − as the lack of connection between adopters' benefits and the innovator's diffusion effort remains. In this context de Jong et al. (2015) found that consumers did not do extra efforts to inform their peers, and that the relationship between general use value and peer adoption was lacking. Thus, a third empirical observation in line with the proposed market failure is that willingness to reveal does not influence the relationship between general use value and first adoption. We explore the research question:

RQ2. What is the relationship between general use value of consumer innovations and first adoption at various levels of the innovator's willingness to reveal?

2.2. Factors alleviating market failure

From a social welfare perspective consumer innovations with high general use value should diffuse. As a first step, diffusion requires adoption by others. Classical diffusion studies have shown that innovations are introduced into social systems by highly cosmopolite first adopters (Rogers, 2003). As we discussed, consumers may do no diffusion effort, so that their innovations are not available for first adoption. Absent a source that originates a message about the innovation, potential adopters will not be aware of it, and the diffusion process never takes off.

To explore circumstances in which first adoption is more likely, we propose a framework of potential moderating factors. See Fig. 1. The framework recognizes that moderators can be classified to the innovating individual (I), the innovation object (O) and the innovation process (P). We identified these categories from the diffusion of innovations, user innovation and entrepreneurship literatures. I-factors include variables at the level of the innovator: traits, cognitive abilities, motivations and resources. O-factors refer to the characteristics of the innovation, for example its compatibility, complexity and relative advantage compared to existing products. P-factors refer to the innovation process, like external collaboration and sources used as innovation inputs. In what follows we explain how we identified these categories from the three literatures.

The diffusion of innovations literature identifies object factors as important for diffusion, but does not pay attention to the individual innovator or initial innovation process. With regard to O-factors, Rogers (2003) summarized research showing that diffusion is more likely if an innovation is observable, compatible, triable, simple and beneficial compared to existing practices. Diffusion studies do pay attention to individual factors, but only from the adopter perspective. For example diffusion studies identified adopter characteristics (embodied in the well-known classification of early adopters, early majority, late majority and laggards), but the actor who *created* the innovation has not been considered. Likewise, diffusion studies have looked at process variables, but with focus on the adoption process and not the initial innovation process. Thus, diffusion is known to be "*a very social process that involves interpersonal communication relationships*" (Rogers, 2003: p. 19). Process-related determinants include the kind of communication channels and network ties between potential adopters, to mention more examples.

From the literatures on user innovation and entrepreneurship we can add I-factors to the proposed framework. User innovation studies show that diffusion of generally valuable innovations partly revolves around the innovator's dispositional traits. Stock et al. (2016) found that the psychological traits of consumer innovators associated with idea generation, development and diffusion differ. Accordingly, it will be rare for innovators to have a personality associated with diffusion behaviour. Likewise, a popular view in the entrepreneurship literature is that the co-existence of individual and opportunity matters for successful opportunity pursuit (Shane, 2003). Individual factors related with entrepreneurship (one of the mechanisms by which consumer innovations can diffuse) include personality traits (e.g., Rauch and Frese, 2007) and cognitive factors, motivations and access to financial and social capital (Wright et al., 2012).

Compared to classical diffusion of innovations research, user innovation and entrepreneurship studies also suggest that P-factors can moderate the relationship between general use value and first adoption. Franke and Shah (2003) identified that consumer innovators engaged in sports-related communities for assistance and advice, which helped for subsequent diffusion. Likewise, Shah and Tripsas (2007) argued that user innovators primarily solve a personal need, but may detect entrepreneurship opportunities after interacting with their peers. Feedback, and sometimes also follow-up innovations developed by peers, may result in a situation of strong demand-pull by first adopters. P-factors are also recognized in the entrepreneurship literature. The odds of successful opportunity pursuit increase with a stepwise entrepreneurial process in which risks are systematically identified and tested (Blank, 2013) or minimized upfront by starting from existing means rather imagined ends (Sarasvathy, 2012).

Within the proposed framework many variables can be identified for a first empirical test. We investigate prior entrepreneurial experience (I), product newness (O), and community engagement during the innovation process (P). We will explain that these variables represent circumstances in which the problem of a disconnect between adopter and innovator benefits diminishes, or is circumvented. The three moderators are prominent in the diffusion, user innovation and entrepreneurship literatures, and the most obvious choices for a first application of the proposed framework.

2.2.1. Entrepreneurial experience

Prior experience with entrepreneurship is one of the most important determinants of opportunity identification and exploitation (Shane, 2003). We hypothesize that this 'usual suspect' from the entrepreneurship literature also helps consumer innovators diffusing their

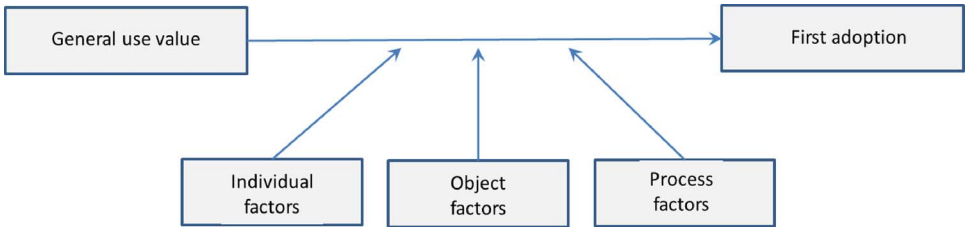

Fig. 1. Individual-object-process framework of first adoption of consumer innovations.

innovations, provided that their innovations have general use value. We offer four arguments: opportunity recognition, cognition/know-how, personality factors, and access to resources.

First, entrepreneurial experience enables consumers to recognize if their innovation has general use value. Former entrepreneurs have developed expertise to process information; they are more likely to be aware of, and able to interpret, market stimuli. In a broader sense, they can better judge if their innovations are useful to others and truly differ from existing products on the market (Baron and Ensley, 2006; Ucbarasan et al., 2008).

Second, entrepreneurial experience provides a consumer innovator with diffusion-related know-how: what other people would need to adopt, and the kind of effort that is required to realize the opportunity. In this context Shane (2001) found that patents belonging to inventors with prior firm-founding patents were more likely to be exploited through firm formation. Alsos et al. (2003) found that managerial capabilities of founders accumulate with entrepreneurial experience. In a study of founders of biotech and electronics ventures, Rueber and Fischer (1993) found that previous start-up experience was valuable in subsequent opportunity exploitation processes.

Third, entrepreneurial experience is related with a range of personality traits helpful for diffusion. Examples include need for achievement, self-efficacy and proactive personality (Rauch and Frese, 2007). In this context Robson et al. (2012) found that individuals with more entrepreneurial experience were more often doing effort to introduce innovations to the market, and more likely to succeed.

Fourth, entrepreneurial experience indicates better access to diffusion resources. Earlier work has shown that individuals with entrepreneurial experience can invest more personal funds to spread innovative ideas, and are better able to manage and organize people and resources by partnering with others (Alsos et al., 2003; Westhead et al., 2003).

In all, entrepreneurial experience is expected to increase the odds of successful opportunity identification and exploitation, provided that the consumer innovation has general use value so that it is eligible for adoption in the first place. At a given diffusion effort, entrepreneurial experience will imply that the consumer innovator does a better job compared to those without entrepreneurial experience. In this circumstance the lack of connection between adopter and innovator benefits is less problematic, and the market failure would diminish. We hypothesize

H2a. The relationship between general use value and first adoption of consumer innovations is moderated by the innovator's entrepreneurial experience. If s/he has prior entrepreneurial experience, first adoption of generally useful innovations is more likely.

2.2.2. Product newness

Product newness is the extent to which a consumer innovation embodies new technology and/or functionalities, and is deemed original. The product development literature counsels that degree of innovation newness can be evaluated from a market and a technological dimension (e.g., Cooper, 1979; More, 1982). Garcia and Galantone (2002) reviewed this literature concluding that innovation newness can be modelled as 'the degree of discontinuity in marketing and/or technological factors' (p. 112–113). In this paper product newness refers to the technological dimension, and differs from general use value which represents the market dimension. Product newness resembles with the supply side of an innovation (discontinuous offering), while general use value represents demand (potential to address the needs of many consumers).

We hypothesize that product newness is helpful to alleviate lack of first adoption. We anticipate that at high levels of product newness, the relationship between general use value and first adoption will be positive. Our reasoning is that for first adopters product newness is an attractive feature. They are usually highly cosmopolite individuals connected to different thought worlds, with a strong preference for deviant issues. First adopters are usually venturesome and risk-taking, and willing to accept innovations that not fully reliable and/or in need of improvement (Rogers, 2003). In this context the entrepreneurship literature typically holds that adoption of opportunities requires the simultaneous presence of demand-related and supply-related newness. For example, Ardichvili et al. (2003) distinguish between 'value sought opportunities' (seen from the perspective of prospective customers) and 'value creation capability opportunities' (starting from new technologies, capabilities, or unemployed resources) and propose that their combined presence contributes to successful business formation (p.117).

Thus, high degree of product newness is expected to be associated with increased first adoption of innovations, provided there is general use value. Regardless of the innovator's diffusion effort, innovations with high product newness are more likely observed and adopted basically because they are a better match given what first adopters generally like, and what is needed for successful opportunity pursuit. We hypothesize

H2b. The relationship between general use value and first adoption of consumer innovations is moderated by the degree of product newness of the innovation. At higher product newness first adoption of generally valuable innovations is more likely.

2.2.3. Community engagement

We define a community as a social group of any size who share common behaviours, values or habits. Community engagement is a moderating variable primarily derived from the user innovation literature. Baldwin and von Hippel (2011) proposed that the open-collaborative mode of innovation is better for diffusion than single-user innovation (i.e. consumer innovators working on their own). Examples are found in open-source software and open design projects, but also in practitioner communities concerned with a specific problem, hobby or interest (e.g., a rare disease patient community).

Community engagement increases the odds that there has been earlier communication about the innovation with others. This raises general awareness which is the first step of any adoption process (Rogers, 2003). User innovation scholars have identified that in a community of like-minded individuals knowledge is more likely to be exchanged (Franke and Shah, 2003). Receiving help, inputs or feedback from others also reduces development costs, so diffusion thresholds are lowered. Moreover, community norms of reciprocity and consistency will stimulate consumers to do an effort to inform other community members (Cialdini, 2001). Likewise, entrepreneurship studies showed that communities can help individuals to identify opportunities and to commercialize their innovations in a venture. So-called user entrepreneurs recognize opportunities after receiving positive feedback and suggestions to improve the innovation from other members (Shah and Tripsas, 2007).

We should point out that our argument for community engagement basically comes down to communication, which is a well-known determinant of diffusion (e.g., Choi et al., 2010; Valente, 1995). In previous studies, however, the focus was on communication between individuals as part of the adoption process rather than innovation development. Diffusion studies do provide additional arguments for the moderating role of community engagement. Engagement implies interpersonal communication, which enhances similarity and shared attitudes between community members, and this will enhance the rate of adoption (Michaelson, 1993).

Accordingly, we anticipate that with community engagement the relationship between general use value and first adoption will be strengthened. Our reasoning is that potential adopters are more likely to be aware of the innovation and develop application-related knowledge. Moreover, the innovator may be more inclined to do an effort to inform others for reasons of reciprocity or after receiving positive

feedback from other community members. We hypothesize

H2c. The relationship between general use value and first adoption of consumer innovations is moderated by engagement in communities during the innovation process. With community engagement first adoption of generally useful innovations is more likely.

3. Data

3.1. Participants and procedure

We conducted a survey of 164 consumer innovators in Germany. In line with von Hippel's (2017) definition of consumer innovation, all respondents were citizens who had developed an innovation at private cost during their unpaid discretionary time. Their innovations were developed up to a prototype that was used or applied in everyday life. Thus, consumers in our sample had developed technically viable solutions, not premature ideas in need of an existence proof. Their reported innovations covered a range of objects including household fixtures, software, child- and education-related products, car equipment, medical applications, and garden-related products. These objects were in line with the innovations reported previous studies (e.g., de Jong et al., 2015; von Hippel et al., 2012).

A sampling frame of consumer innovators does not exist, and screening consumer innovators in broader samples is costly as the frequency of consumer innovation in broad populations is low (de Jong, 2016). We therefore collected data from a convenience sample of consumer innovators. Data were collected in the summer of 2013 in a period of three months. We mobilized engineering students at a German university. They identified potential consumer innovators in their social networks and/or by means of Internet search. For this purpose each student was equipped with a guideline including: definition of consumer innovation, examples of consumer innovations (including pictures/visualizations) and information on our study design. Students were asked to identify respondents in different age groups (20%: < 30 years; 60%: 30– < 60 years; 20%: 60 years are over) to avoid selection effects with regard to students' age.

The students found 800 individuals who might be consumer innovators. They were contacted by phone or in person with screening questions taken from previous consumer innovation surveys (e.g., von Hippel et al., 2012). First, a respondent was familiarized with consumer innovations by providing a list of verbal examples and showing pictures of exemplary innovations from different fields. Then it was asked if they had innovated themselves. If yes, the respondent was asked to describe the innovation, and to explain why s/he developed it. We excluded innovations that respondents had developed for their employers. This resulted in a sample of 221 consumer innovators; all others refused to participate or did not pass the screening.

The 221 consumer innovators were asked to take a survey with questions about our key variables. (We had first consulted a few peer researchers for feedback on the survey questions, then tested the questions with five early-identified consumer innovators who are not included in the final dataset.) Full responses were obtained from 164 consumer innovators. Along with the survey we asked respondents to return photos, videos and other supportive materials that would enable us to better code the general use value of their innovations. Examples of their reported innovations are shown in Table 1.

Eighty-five percent of the innovators in our sample were male. Fifty-two percent had a bachelor/master/PhD degree. These demographics are in line with previous surveys where consumer innovators were mainly male and well-educated (de Jong, 2016). Seventy-four percent was employed or self-employed, while 26% was unemployed, retired, student or housekeeper. The age of our consumer innovators ranged from 19 to 83 years, with an average of 45.1 years. As for their reported innovations, these were mostly recent, but some innovations were older ones. The average age of the reported innovations was 6.1 years (range 0–33 years).

To obtain an independent measure of general use value, we asked three independent coders to assess all reported innovations. The coders were research master students from a different German university. Their age was 23–24 years. They all had a degree in engineering or industrial design, and taken a course in open/distributed innovation. Thus, the coders were trained within the domain of our research. Drawing on the open-ended descriptions of reported innovations, and supportive photos and videos, they rated all 164 innovations on multiple items (see hereafter).

3.2. Variables

In previous consumer innovation survey the key constructs were measured with single or few items. Here we could apply more extensive, multiple-item measures. All measures satisfied common reliability standards (Table 2).

First adoption was measured with two items regarding the extent to which the respondent observed other users applying his or her solution. Reliability was good (Alpha = 0.97; mean corr = 0.94; IRCs ≥ 0.94).

General use value was rated by three independent coders. They rated the innovations on three items: problem scope, potential market size, and expected utility to other users. To assess interrater reliability, we computed two-way mixed average-measure ICC-values indicating absolute agreement (McGraw and Wong, 1996). The ICCs were 0.43 (for general utility), 0.77 (potential market size) and 0.77 (problem scope), indicating fair to excellent absolute agreement. (Cicchetti (1994) suggests 0.40, 0.60 and 0.75 as thresholds for fair, good and excellent agreement.) To obtain a single score for each item, we computed its average score over three reviewers. These three items were sufficiently reliable, so a single score for general use value was obtained by taking the average. To illustrate, a sample innovation with the highest general use value (score 3.00) was *"A vacuum cleaner attachment. It can detach deep-seated finest particles from the floor. In contrast to traditional vacuum cleaners that exert constant force, my enhancement uses additional motors integrated in the vacuum cleaner nozzle. These motors create different air pressures that cause dirt particles to vibrate"*. An example of an innovation with the lowest general use value (score 1.00) was *"Developed a 'Book of Capacitance and Resistance' which looks like an antique book. However, once opened the reader realizes that it does not contain any paper-based book pages. Instead it gives a clear overview of electronic circuit boards, arranged informatively"*. To assess criterion validity, we correlated general use value with a three-item measure rated by the innovator: *"The solution I invented is useful for other users"*, *"…is valuable to other users"* and *"… is practical for other users"*. Answers ranged from 1 (*"agrees not at all"*) to 7 (*"fully agrees"*). Cronbach's Alpha was 0.86. The Pearson correlation coefficient with self-rated general use value was 0.33 (p = .000) indicating criterion validity.

With regard to our interaction variables, willingness to commercialize and willingness to reveal were indicated by six and four items, based on a review of the user innovation literature (e.g., Baldwin and von Hippel, 2011; Hienerth et al., 2014). Entrepreneurial experience was measured with a dummy indicator for respondents who, before they developed the solution, had founded a business. For product newness we asked our coders to provide an independent measure. They coded all innovations on functional novelty, technical novelty, and originality. Two-way mixed average-measures ICC-values were 0.71 for functional novelty, 0.69 for technical novelty, and 0.79 for originality, indicating good to excellent absolute agreement (Cicchetti, 1994). To assess criterion validity, we correlated the measure with a six-item measure developed by Im and Workman (2004). Sample items are *"The solution I invented is really out of the ordinary"* and *"…provides radical differences from existing solutions"*. Answers ranged from 1 (*"agrees not at all"*) to 7 (*"fully agrees"*). Cronbach's Alpha was 0.82. The Pearson correlation coefficient between independently coded and self-rated degree of newness was 0.39 (p = .000) suggesting criterion validity.

Table 1
Examples of reported consumer innovations.

Category	*Example*
Medical	Inhalation game that helps the inventor's son to regularly inhale in a playful and focused manner to strengthen his lungs. Based air pressure measures, a hot-air balloon ascends or descends on the screen. Players of the computer game need to overcome several hurdles and obstacles.
Car equipment	Foldable car trailer that can be fold up flat in order to solve the inventor's capacity issue. Placed upright, the new trailer saves a lot of space in the garage. Thanks to the easy handling of the solution, it only takes 30 s to stow the trailer.
Garden	Comfortable and back-protecting spade. By the means of a second handle, the user can easily dig with little effort, even if the person is suffering from back problems.
Household	Flexible mop stick that can be easily used to wipe below furniture, without having to bend over or pushing away furniture items. The solution is based on flexible spring steel elements enabling the user to bend the stick.
Parenting	Children's watch, based on an existing wall clock. By replacing the clock face with several appealing pictures representing activities and obligations of the respective time (e.g., after-lunch sleeping, teeth brushing, etc.), the inventor's children learn to organize themselves in an autonomous manner.
Software	Forecasting Excel tool that predicts national league sport results in order to increase the accuracy rate regarding sport bets. The software solution is based on different data basis than existing forecasting tools in order to increase objectivity and, in turn, accuracy rate while placing a bet.
Furniture	New type of shelves that can be installed on roof pitches and thereby suit the inventor's room conditions in the top floor. The shelves can be installed at walls of different inclination angles.

Table 2
Variables.

Variable	*Description*	*Statistics (n = 164)*
First adoption	mean score of two items (Alpha = 0.97; mean corr = 0.94; IRCs ≥ 0.94) coded 1 ('agrees not at all') to 7 ('fully agrees') other users already used and/or adopted my solution. the solution has already been applied by other users.	M = 3.97, SD = 2.41
General use value	mean score of three independently coded items (Alpha = 0.92; mean corr = 0.79; IRCs ≥ 0.85): general utility: 'This innovation is useful to … other users than the respondent' (1 = no, 2 = few, 3 = many) potential market size: 'After further development, the innovation can serve …' (1 = no potential market, 2 = a niche market, 3 = a mass market) problem scope: 'Regard of its solution quality, this innovation addresses a problem that applies …' (1 = only to the innovator, 2 = to few others, 3 = too many others)	M = 1.92, SD = 0.52
Willingness to commercialize	mean score of six items (Alpha = 0.89; mean corr = 0.58; IRCs ≥ 0.64) coded 1 ('agrees not at all') to 7 ('fully agrees'). To what extent would you be willing to disseminate your solution? I could imagine very well … … to sell my solution to other users. … to protect the solution in order to commercialize it. … to help other users to apply the solution for payment. … to help visitors of a relevant Internet platform applying the solution for payment. … to commercialize the solution jointly with a company. … to help a company to apply my solution for payment.	M = 3.60, SD = 1.80
Willingness to reveal	mean score of four items (Alpha = 0.84; mean corr = 0.57; IRCs ≥ 0.66) coded 1 ('agrees not at all') to 7 ('fully agrees'). To what extent would you be willing to disseminate your solution? I could imagine very well … … to share this solution with other users for free. … to actively help others to adopt the solution. … to freely share the solution within an internet community. … to help users of an Internet platform for free to apply the solution.	M = 3.91, SD = 1.76
Entrepreneurial experience	dummy for respondents who, before they developed the solution, ever founded a business (0 = no, 1 = yes)	M = 0.34, SD = 0.48
Product newness	mean score of three independently coded items (Alpha = 0.80; mean corr = 0.57; IRCs ≥ 0.64): functional novelty: This innovation … (1 = basically replicates an existing function, 2 = adds a new function on top of an existing one, 3 = enables an entirely new function) technical novelty: The technology embodied in this innovation … (1 = is an incremental improvement of an existing solution, 2 = definitely improves an existing situation, but is not a leap, 3 = is a leap compared to previous solutions in this field) originality: This innovation … (1 = is of a type I (would expect to) see quite often, 2 = is neither obvious nor very original − somewhere in between, 3 = is one of a kind/very original)	M = 1.60, SD = 0.44
Community engagement	dummy for respondents who used and/or participated in an online community to develop and discuss their ideas and/or solutions (0 = no, 1 = yes)	M = 0.16, SD = 0.37
Complexity	mean score of seven items (Alpha = 0.85; mean corr = 0.65; IRCs ≥ 0.61) coded 1 ('agrees not at all') to 7 ('fully agrees'). The solution I invented… … is high in need of explanation. … is very complex. … is hard to evaluate without expertise.	M = 2.55, SD = 1.53
Gender	dummy for female respondents (no = 0, yes = 1)	M = 0.15, SD = 0.36
Education	dummy for respondents with a bachelor, master or PHd degree (no = 0, yes = 1)	M = 0.52, SD = 0.50
Age of respondent	age of the respondent, in years	M = 45.1, SD = 16.0
Age of innovation	age of the innovation, number of years since the innovation was developed	M = 6.1, SD = 7.3

Notes: M = mean score, SD = standard deviation.

Finally, community engagement was measured with a dummy indicator if respondents had used or participated in an online community to develop their innovation.

We also included control variables. We adapted Homburg et al.'s (2011) measure to control for the complexity of reported innovations. We recognized that at high product newness, innovations may be perceived as complicated and less aligned with existing practices, which can hinder adoption (Rogers, 2003). Controlling for perceived complexity better ensures that the interaction effect of product newness reflects the arguments discussed at H2b. We also controlled for respondent's gender, educational attainment and age. Finally, we included the age of the innovation as older innovations have already

Table 3
Descriptive statistics and correlations (n = 164).

	M	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) First adoption	3.97	2.41											
(2) General use value	1.92	0.52	0.14ˆ										
(3) Willingness to commercialize	3.60	1.80	0.26**	0.19*									
(4) Willingness to reveal	3.91	1.76	0.18*	−0.11	−0.13ˆ								
(5) Entrepreneurial experience	0.34	0.48	0.19*	0.18*	0.34**	−0.12							
(6) Product newness	1.60	0.44	0.18*	0.53**	0.37**	0.00	0.29**						
(7) Community engagement	0.16	0.37	0.15ˆ	−0.05	0.16*	0.24**	0.23**	0.15ˆ					
(8) Complexity	2.55	1.53	−0.01	0.04	0.20*	0.00	0.14ˆ	0.19*	0.29**				
(9) Female	0.15	0.36	−0.13ˆ	0.04	−0.17*	−0.01	−0.12	−0.13	−0.18*	−0.23**			
(10) BSc/MSc/PHd degree	0.52	0.50	−0.02	−0.07	−0.10	−0.02	−0.04	−0.08	−0.13ˆ	−0.05	−0.10		
(11) Age of respondent	45.1	16.0	0.00	0.08	0.03	−0.07	0.10	0.02	−0.14ˆ	0.02	−0.01	−0.11	
(12) Age of innovation	6.1	7.3	0.07	0.02	−0.13	−0.01	−0.09	−0.11	−0.21**	−0.20*	0.05	−0.04	0.36**

Notes: M = mean score, SD = standard deviation. Two-tailed significance ** $p < 0.01$; * $p < 0.05$; ˆ $p < 0.10$.

diffused more likely.

4. Results

Table 3 provides descriptive statistics and correlations between our variables. No correlation coefficient was > 0.60 in absolute value, indicating no multicollinearity concerns. Variance inflation factors of the regression models presented hereafter did not exceed 1.70.

4.1. Market failure

We applied ordinary least squares regression analysis to test our proposed relationships. To ease interpretation we centred all continuous predictor variables around their means. Interaction terms were created by multiplying the mean-centred variables. Our findings regarding the analysis of market failure are shown in Table 4.

Model 1a is a baseline model with our control variables. Model fit was acceptable (R^2 = 15.3%, F = 2.96, $p < 0.01$). Willingness to commercialize was significantly related with first adoption (b = 0.25, $p < 0.05$), as was willingness to reveal (b = 0.28, $p < 0.05$). The age of the innovation was positively related with first adoption, with marginal significance (b = 0.05, $p < 0.10$).

Model 1b answers RQ1 regarding the relationship between general use value and first adoption. As expected we found no direct relationship (b = 0.29, p = n.s.). Model 1c provides a test of H1 by including the interaction term of general use value and willingness to commercialize. The interaction term was positive and significant (b = 0.42, $p < 0.05$) and in line with H1. Model 1d provides an answer to RQ2 by testing the interaction effect of willingness to reveal. The coefficient was not significant (b = 0.07, p = n.s.). Model 1e provides a robustness check by adding both interaction terms at once, with basically the same finding. The higher an innovator's willingness to commercialize, the stronger the association between general use value and first adoption − while the overall relationship is not significant, and willingness to reveal provides no moderation effect. Our findings replicate the results of de Jong et al. (2015) with an independent measure of general use value.

4.2. Alleviating factors

With models 2a–2e (Table 5) we tested our hypotheses regarding the moderating role of innovator, object and process variables.

Model 2a enters the interaction term for prior entrepreneurial experience. It was positive and significant (b = 1.62, $p < 0.05$). Model 2b tests the moderating role of product newness. Again, the interaction term was positive and significant (b = 1.96, $p < 0.05$). Model 2c tests the moderating role of community engagement − also positive and significant (b = 2.10, $p < 0.05$). Acknowledging that testing interaction effects one-by-one enhances the risk of omitted variable bias, model 2d enters the three interaction terms together. Only community engagement was significant. In model 2e we estimated a parsimonious

Table 4
Regression models of the first adoption of consumer innovations (market failure) (n = 164).

	1a		*1b*		*1c*		*1d*		*1e*	
	b/β	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*
Effect parameters:										
Intercept	3.78/–	0.32	3.67/–	0.33	3.62/–	0.34	3.68/–	0.33	3.65/–	0.34
Complexity	−0.16/−0.11	0.13	−0.16/−0.11	0.13	−0.16/−0.10	0.12	−0.16/−0.10	0.12	−0.15/−0.10	0.12
Female	−0.45/−0.07	0.54	−0.50/−0.08	0.57	−0.52/-0.08	0.56	−0.53/−0.08	0.57	−0.57/-0.09	0.55
BSc/MSc/PHd degree	0.04/0.01	0.38	0.04/0.01	0.38	0.04/0.01	0.38	0.03/0.01	0.39	0.02/0.00	0.38
Age of respondent	−0.00/−0.03	0.01	−0.00/−0.02	0.01	−0.01/−0.04	0.01	−0.01/−0.03	0.01	−0.01/−0.03	0.01
Age of innovation	0.05/0.15ˆ	0.03	0.05/0.15ˆ	0.03	0.05/0.16ˆ	0.03	0.05/0.15ˆ	0.03	0.05/0.15ˆ	0.03
Willingness to commercialize (WC)	0.25/0.19*	0.12	0.25/0.19*	0.12	0.27/0.20*	0.12	0.25/0.19*	0.12	0.26/0.20*	0.12
Willingness to reveal (WR)	0.28/0.20*	0.11	0.26/0.21*	0.11	0.29/0.21**	0.11	0.29/0.21**	0.11	0.30/0.22**	0.11
Entrepreneurial experience	0.45/0.09	0.45	0.46/0.09	0.45	0.40/0.08	0.44	0.46/0.09	0.45	0.39/0.08	0.44
Product newness	0.31/0.06	0.45	0.12/0.02	0.57	−0.07/−0.01	0.58	0.13/0.02	0.57	−0.07/−0.01	0.58
Community engagement	0.81/0.13	0.61	0.83/0.13	0.61	0.94/0.14	0.59	0.85/0.13	0.63	0.99/0.15	0.61
General value (GV)			0.29/0.06	0.49	0.26/0.05	0.48	0.28/0.06	0.49	0.23/0.05	0.48
GV*WC					0.42/0.15*	0.21			0.44/0.16*	0.22
GV*WR							0.07/0.02	0.24	0.14/0.05	0.24
Model fit:										
R-square	0.153		0.153		0.174		0.153		0.176	
F-value	2.96**		2.76**		4.03**		2.56**		3.71**	

Notes: Continuous independent variables were mean-centred before entering them into the regression equations. Unstandardized (b), standardized (β) and robust standard errors (S.E.) are shown. Significance ** $p < 0.01$; * $p < 0.05$; ˆ $p < 0.10$.

Table 5
Regression models of the first adoption of consumer innovations (alleviating factors) (n = 164).

	2a		*2b*		*2c*		*2d*		*2e*	
	b/β	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*	*b/β*	*S.E.*
Effect parameters:										
Intercept	3.66/–	0.33	3.41/–	0.36	3.72/–	0.33	3.52/–	0.37	3.49/–	0.37
Complexity	−0.17/−0.11	0.13	−0.16/−0.11	0.12	−0.15/−0.10	0.12	−0.16/−0.10	0.12	−0.15/−0.10	0.12
Female	−0.64/−0.10	0.57	−0.62/−0.10	0.54	−0.48/−0.07	0.56	−0.65/−0.10	0.56	−0.58/−0.09	0.55
BSc/MSc/PHd degree	−0.01/0.00	0.39	0.12/0.02	0.39	−0.09/−0.02	0.38	−0.03/−0.01	0.39	−0.01/0.00	0.39
Age of respondent	−0.01/−0.06	0.01	−0.01/−0.04	0.01	−0.01/−0.06	0.01	−0.01/−0.07	0.01	−0.01/−0.06	0.01
Age of innovation	0.05/0.16^	0.03	0.06/0.17^	0.03	0.06/0.17^	0.03	0.06/0.18*	0.03	0.06/0.18*	0.03
Willingness to commercialize	0.23/0.18^	0.12	0.23/0.17^	0.12	0.28/0.21*	0.12	0.24/0.18*	0.12	0.26/0.19*	0.12
Willingness to reveal	0.29/0.21**	0.11	0.30/0.22**	0.11	0.33/0.24**	0.11	0.33/0.24**	0.11	0.34/0.24**	0.11
Entrepreneurial experience (E)	0.52/0.10	0.46	0.49/0.10	0.44	0.49/0.10	0.44	0.54/0.11	0.44	0.51/0.10	0.44
product newness (PN)	0.06/0.01	0.56	−0.21/−0.04	0.64	0.02/0.00	0.58	−0.22/−0.04	0.63	−0.24/−0.04	0.64
Community engagement (C)	0.80/0.12	0.60	0.81/0.13	0.58	0.88/0.14	0.58	0.84/0.13	0.56	0.86/0.13	0.57
General value (GV)	−0.27/−0.06	0.56	0.18/0.04	0.49	−0.07/-0.02	0.50	−0.38/−0.08	0.58	−0.11/−0.02	0.51
GV*E	1.62/0.20*	0.79					0.96/0.12	0.82		
GV*PN			1.96/0.18*	0.89			1.37/0.13	0.94	1.64/0.15^	0.51
GV*C					2.10/.19*	0.84	1.49/0.14^	0.87	1.77/0.16*	0.85
Model fit:										
R-square	0.178		0.179		0.180		0.205		0.197	
F-value	4.28**		4.33**		4.72**		4.86**		4.90**	

Notes: Continuous independent variables were mean-centred before entering them into the regression equations. Unstandardized (b), standardized (β) and robust standard errors (S.E.) are shown. Significance ** p < 0.01; * p < 0.05; ^ p < 0.10.

model (omitting entrepreneurial experience, which was the least significant in the previous model). We then found that the interactions for community engagement and product newness were significant. Altogether, we find empirical support for H2c, and tentative evidence for H2a and H2b.

4.3. Probing significant interaction effects

To interpret the significant interaction effects we did a simple slope analysis (Aiken and West, 1991). We estimated the regression coefficient between first adoption and general use value at specific values of each interaction variable. See Fig. 2. Simple slopes for continuous interaction variables (willingness to commercialize, product newness) were evaluated at increments of a standard deviation (SD) around their mean scores, and at their highest and lowest observed values in our dataset. Simple slopes for the dummy variables (entrepreneurial experience, community engagement) were estimated at their presence and absence.

When willingness to commercialize is evaluated at its mean score, the relationship between general use value and first adoption is not

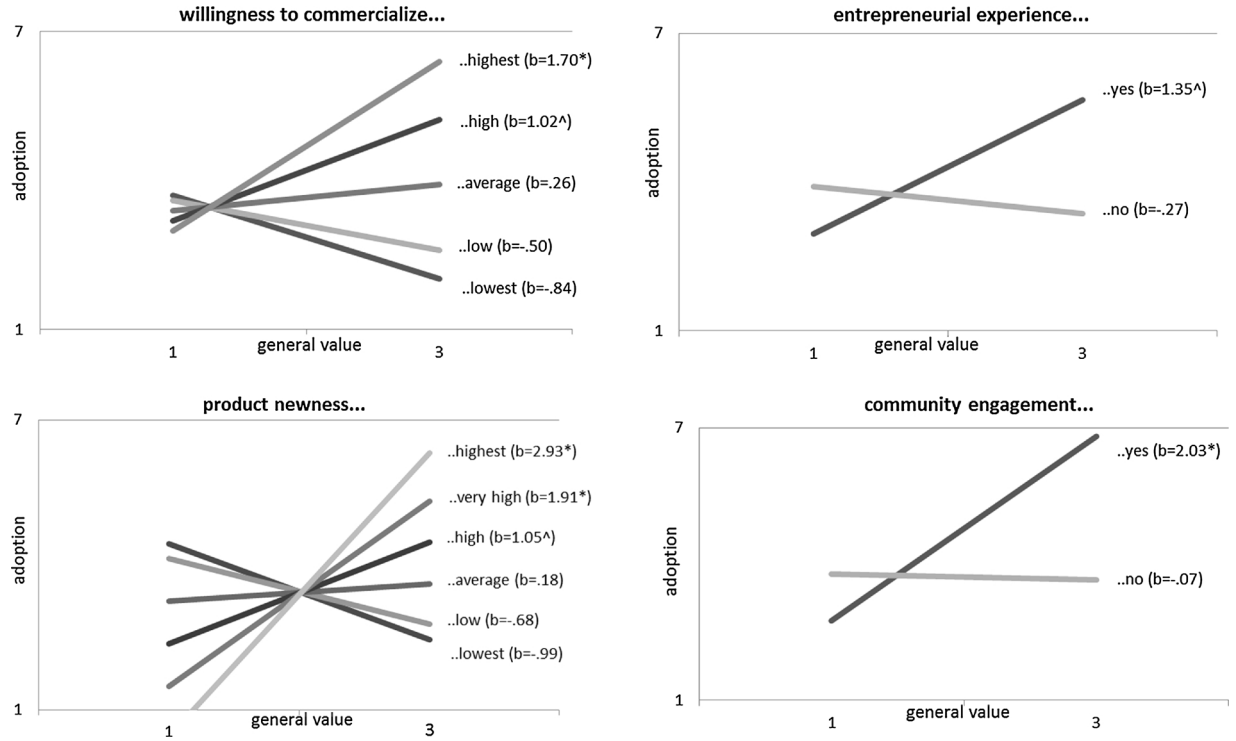

Fig. 2. Simple slopes for significant interaction variables (n = 164).
Notes: Unstandardized effect parameters (b) are shown with two-tailed significance (* p < 0.05; ^ p < 0.10). Willingness to commercialize and product newness are evaluated at increments of a standard deviation (SD) from their average score, and at their lowest and highest values. A high score is at M + 1*SD, a very high score is at M + 2*SD, etc.

significant (b = 0.26, p = n.s.). Only at high values of willingness to commercialize does the simple slope become significant. Apparently, it takes rather exceptional levels of willingness to commercialize for generally useful innovations to be adopted by others.

In the presence of prior entrepreneurial experience the relationship between general use value and adoption is marginally significant (b = 1.35, p < 0.10). The relationship vanishes if prior entrepreneurial experience is absent.

For product newness, again a significant relationship between general use value and adoption is obtained only at high values. This can be interpreted as first adoption being likely only if, on top general use value, the innovation is highly novel and original. These simple regressions must however be interpreted with care, as we only found tentative empirical evidence for a significant interaction effect.

If a community was engaged during the innovation process, generally useful innovations were more likely to see first adoption (b = 2.03, p < 0.05). Without community engagement the relationship was insignificant (b = −0.07, p = n.s.). In line with what theorists have proposed about accidental entrepreneurship and open collaborative innovation, community engagement seems helpful to stimulate diffusion. In the discussion section we will elaborate on these findings and offer suggestions for future research.

5. Discussion

The results of our study confirm von Hippel's (2017) lack-of-diffusion hypothesis. From a theoretical point of view this is an important matter. In a world of producer innovation (innovators who benefit primarily from innovation diffusion) market failures include lack of appropriation, asymmetric information, uncertainty about market demand, and indivisibility of innovation investments. In these circumstances producers may be deprived to innovate, and their innovation investments may fall short from the viewpoint of social welfare (Arrow, 1962). As a consequence, it is legitimate to offer policies to stimulate producer innovation investments – for example R&D subsidies and intellectual property rights.

In contrast, the lack of relationship between general use value and first adoption can be explained by a disconnect between adopter benefits and the effort required to diffuse consumer innovations. We found that only when consumers were willing to pursue commercial pathways the relationship was restored. This creates a situation in which diffusion effort is compensated by anticipated monetary benefits. Thus, beyond the initial finding reported by de Jong et al. (2015) we replicate with more robust evidence a market failure – previously not recognized in the economics of innovation literature. This finding legitimizes a different kind of policy: to stimulate diffusion efforts practiced by consumer innovators so that first adoption can occur.

To explore new variables that may alleviate lack of first adoption, we proposed a framework of individual, object and process moderators. We reported strong evidence for the significance of community engagement, while tentative evidence was found that first adoption of generally valuable consumer innovations occurs if the innovator has prior entrepreneurial experience, and for innovations with a high level of product newness (in terms of function, technology and/or originality). For entrepreneurial experience and product newness we only found a significant effect if the interaction term was tested in isolation, so strong conclusions cannot be drawn. Nevertheless, when considered together with the significant moderation effect of willingness to commercialize (an individual-level variable) our findings suggest that the I-O-P framework is useful as a basis for identifying and exploring potential moderating variables alleviating the market failure. As such our study expands the user innovation literature with a framework for future investigation.

Moreover, the proposed framework expands previous diffusion of innovation studies in which the individual innovator and innovation process are not considered. For a producer perspective, i.e. a change agent in Rogers' (2003) terminology, the step from innovation to diffusion is trivial, and the lack-of-diffusion pattern we observed will not exist. For consumer innovators, however, it is neither evident that consumer innovations become available to first adopters, nor can we expect the individual innovator to be eager to try. Our study shows that the step from innovation to diffusion effort is only taken in specific circumstances. To better understand innovation diffusion, in particular the initial step in which the innovation becomes available to a social system, it is worthwhile to study the preceding phase of innovation development, and the characteristics of the innovator including his/her motives and abilities.

Recalling that the interaction term for willingness to reveal was not significant, it seems that adopter benefits are an externality for consumers who are willing to freely share (but not commercialize) their knowledge. This raises the question if commercialization motives are a necessary condition for first adoption. For user innovation theory this is an important question, as the pursuit of commercial pathways basically implies that consumer innovators at some point become classical producers pursuing monetary interests. In other words: do consumer innovators have to become producers in order to diffuse? Our finding that community engagement alleviates lack of first adoption suggests that the answer is 'no'. In communities a broader range of diffusion motives is applicable. For example, the literature on online knowledge sharing platforms offers altruism, community identification, ideology, reputation/status, and even career motives as reasons for individuals to reveal knowledge (e.g., Baruch et al., 2016; Bucher et al., 2016). Thus, the moderating role of community engagement suggests that specific non-commercial circumstances can also alleviate the market failure. We therefore recommend further research to study consumers' diffusion motives (see hereafter).

Finally, we remark that the investigated alleviating factors apply to only a fraction of all consumer innovations. Von Hippel (2017) summarizes survey evidence that one out of ten consumer innovators are driven by commercial motives, and that the share of innovations developed in collaboration is only 10–20%. Single innovators who are not willing to commercialize will be the majority of all consumer innovators. This implies that in practice first adoption of generally valuable innovations will fail. Continued attention from researchers and policy makers to explore when and how market failure can be alleviated, is merited.

5.1. Implications

For innovation policy the market failure with regard to diffusion legitimizes new interventions. Policy concerned with the diffusion behaviour of innovators, rather than innovation development, is a leap compared to most policy practices. It makes sense to be focus initially on individual consumer innovators with no interest in commercialization. To these innovations the lack-of-diffusion problem is most likely applicable.

First adoption can be improved by restoring the lack of benefits that keep consumers from doing a diffusion effort. People's willingness to commercialize can be influenced, e.g., by enhancing current policies to support nascent and early-stage entrepreneurs, and by facilitating technology licensing. Consumer innovators can be more proactively informed and educated about the opportunities offered by such policies. This may elicit their willingness to commercialize innovations they now keep to themselves, especially when the required diffusion effort would be modest. From this perspective, we have better expectations from interventions to facilitate consumer innovators' entry to technology licensing schemes. Consumers might rather sell their knowledge to commercial producers (for a license fee, royalty or other compensation) than going through the more elaborative process of starting a business.

Policies can also focus on establishing collaborations during the innovation process. Recalling that lack-of-diffusion is alleviated if communities are engaged, policies may stimulate and ease consulting

others for help, information, advice or feedback. For example, facilities that involve social interaction, like Fab-labs and Makerspaces, can be stimulated in many ways. With regard to general use value community ratings and feedback systems might help consumer innovators to get meaningful assessments of the demand for their innovations, thereby increasing their awareness about its potential scope and likeliness that other people will adopt.

From an economic point of view we expect it will be helpful to lower the overall cost of diffusion. Surveys of consumer innovators show that overall sharing effort is low (de Jong, 2016) and facilitating online sharing may help. Online knowledge sharing platforms for specific consumer innovation domains can provide a common 'language' to communicate about innovations, and provide a uniform format in which knowledge can be shared. Also, these platforms help to visualize and develop latent demand by counting numbers of visitors and showing relevant statistics (e.g., number of downloads). For example, 3D printing designs can be diffused on online platforms like Thingiverse and Youmagine, while patients with specific diseases can share their experiences with new treatments on dedicated platforms (like Crohnology does for people suffering from Crohn's disease). Policy makers can also offer subsidies for websites or social media platforms where people report the problems they face in everyday life. Also prizes or contests can be initiated to articulate particular needs which some consumer innovators might have solved already.

5.2. Suggestions for research

Our study had a few limitations which directly create opportunities for future research. A first concern is that our resources enabled us to sample only 164 consumer innovators. For the kind of moderation hypotheses investigated here, this is a rather low number. Testing interaction effects generally requires substantial samples (Aiken and West, 1991) and our analyses probably suffered from diminished statistical power. This might have been the reason that entrepreneurial experience and product newness lost their significance when tested simultaneously with community engagement. Replicating our analyses with more observations would be worthwhile.

Related to this issue, our convenience sample was unlikely to be representative for all consumer innovators. Selection bias may be present in our sample, in the sense that we suspect that relatively many of respondents had done an effort to diffuse their innovations to others. The more innovations have already diffused, the more likely that our students have detected them. Although regression estimates primarily require sufficient observations at the tails of variable distributions (Hair et al., 1998), we stress that especially our descriptive statistics (as reported in Tables 2 and 3) have limited generalizability. External validity should be explored with a probability sample. With sufficient resources one can collect a random sample of consumer innovators; it requires a large-scale screening effort. Second best but still worthwhile would be a sample of consumers innovating on a specific object. For example, one could start with the members of a product community (e.g., surfing equipment) and survey them to measure if they innovated and tried to diffuse.

The I-O-P framework seems useful. However, our first application only included three moderating variables based on recent insights from the three literatures about what may help to alleviate the market failure. We can think of many other moderators. One that comes to mind is the type of innovation: software versus hardware. This O-factor seems relevant, as some innovation types are easier to diffuse. (Diffusing software code generally takes less effort than hardware.)

Regarding P-factors, an example may be intellectual property rights. During the innovation process consumers sometimes infringe on existing patents. Does it diminish the diffusion of generally valuable innovations? Another P-factor is the involvement of, or collaboration with, *individual* others rather than community members. In the current paper we followed Baldwin and von Hippel's (2011) distinction between single and open-collaborative innovators, and analyzed the moderating role engagement with a community of like-minded individuals. A broader perspective would be to investigate if the involvement of *any* individual collaborator is sufficient for first adoption. A range of surveys, summarized by de Jong (2016), show that around 20% of all consumer innovations is developed collaboratively with others, and we recommend to investigate if this influences first adoption of valuable consumer innovations.

With regard to I-factors we recommend to go beyond innovation motives and focus on *diffusion* motives. Consumers may, for example, try hard to diffuse to enhance their status or reputation. Although status/reputation is rarely observed, we suspect it will help to alleviate the market failure. Likewise, consumers may be driven altruism, community identification or ideological considerations. Each of these diffusion motives may partly explain why the observed market failure vanished when a community was engaged in the innovation process.

Finally, a next step would be to investigate diffusion patterns *after* the stage of first adoption. With regard to our hypothesis on product newness, we reasoned that innovations high on new functions, technology and originality are received better by highly venturesome, risk-taking first adopters. In subsequent phases of the adoption process, however, this may change. The characteristics of the innovator and the preceding innovation process may have implications for broad diffusion; maybe community engagement will no longer be sufficient, while commercial motives and abilities might be more important for diffusion on a larger scale. Research into the diffusion of consumer innovations has only just started.

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