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Market failure in the diffusion of consumer-developed innovations: Patterns in Finland

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ABSTRACT

Empirical studies have shown that millions of individual users develop new products and services to serve their own needs. The economic impact of this phenomenon increases if and as adopters in addition to the initial innovators also gain benefits from those user-developed innovations. It has been argued that the diffusion of user-developed innovations is negatively affected by a new type of market failure: value that others may gain from a user-developed product can often be an externality to consumer-developers. As a result, consumer innovators may not invest in supporting diffusion to the extent that would be socially optimal. In this paper, we utilize a broad sample of consumers in Finland to explore the extent to which innovations developed by individual users are deemed of potential value to others, and the extent to which they diffuse as a function of perceived general value. Our empirical analysis supports the hypothesis that a market failure is affecting the diffusion of user innovations developed by consumers for their own use. Implications and possible remedies are discussed.

1. Introduction and overview

Empirical research finds that tens of millions of citizens spend tens of billions of dollars annually developing and modifying consumer products to better serve their own needs (von Hippel et al., 2011). Driven by the ever-increasing quality of freely available design and communication tools, single and collaborative user innovation is expected to become even more prominent in the future (Baldwin and von Hippel, 2011).

The social welfare benefits of single and collaborative user innovation by citizens will be considerably enhanced if citizen-developed innovations of general value diffuse to others who can benefit from them. However, from microeconomic theory, there is reason to hypothesize that free, peer-to-peer diffusion of user innovation will be inefficiently low from a social welfare perspective. As von Hippel et al. (2014) have argued, when innovation diffusion involves free revealing rather than market transactions, innovators will find the benefits that accrue to adopters to be partially or entirely an externality from their point of view. As a result, user innovators can be expected to invest less than might be socially desirable to inform or assist others to adopt, even when their innovations would be highly valuable to others – a market failure. In the specific circumstances focused upon here, we say that a market failure exists if user innovators and adopters, taken together, would have higher net benefits from the user innovation if the user innovator invested more in diffusion. This type of market failure is novel in the innovation literature.

In this paper, we empirically explore the market failure hypothesis just described via a sample of 176 innovations developed for personal use by individual consumers in Finland. In overview, we found that 85% of the consumer developers report that what they had developed highly satisfied their own needs. Moreover, drawing on multiple questions, we concluded that, in our respondents' view, 61% of their innovations are deemed useful to some or many others. Still, actual commercial and/or peer-to-peer diffusion only occurred for 19% of the innovations.

We further find that effort exerted to achieve peer-to-peer diffusion is not affected by the innovators' assessment of the general

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value of the innovation, and consequently, innovations with higher perceived value to other users are not more likely to spread to peers than are low-valued ones. In contrast, commercial diffusion effort exerted is related to perceived general value. These findings are in line with the existence of a market failure of the type hypothesized by von Hippel et al. (2014).

Our concluding discussion increases our understanding of its inner workings and points out avenues for future research as well as practical implications for policy and business.

2. Review of the literature

In this section, we review the literature on the frequency and importance of innovation and innovation diffusion by users, the pathways by which user innovations diffuse, users' incentives to diffuse their innovations, and the likelihood of diffusion-related market failure.

2.1. Extent of product development and modification by consumers

Representative national surveys of citizens above age 18 in the UK, US, and Japan, show that millions of individuals in each of these nations develop or modify consumer products to better serve their personal needs (von Hippel et al., 2011). In the UK, the fraction of user innovators was found to be 6.1% of the population, in the US it was 5.2%, and in Japan it was 3.7%. The scope of consumer innovation in all three nations was found to be very broad, ranging from improvements to vehicles, to products used in patient home care, to improvements in sporting products.

In the UK, von Hippel et al. (2012) estimated that consumer-developers on average spent 7.1 days and £1098 out-of-pocket costs per year. At the macro-level and when evaluating person-days at average UK workforce salaries, total annual spending by consumers on innovation was estimated to £3.2 billion. In comparison, estimated annual R&D expenditures by companies on consumer products were £2.2 billion. Similar findings have been reported for the US and Japan (von Hippel et al., 2011). These findings show that both the scale and scope of user innovation is substantial.

2.2. Diffusion pathways

Consumers as user innovators are motivated to create innovations to serve their own needs – not those of others, and consumer needs have been shown to be heterogeneous (Franke and von Hippel, 2003). At the same time, what one consumer requires may fit what another wants better that commercially-available products, and so some user innovations may prove to be of general value. When user innovations are valuable to others, diffusion enhances social welfare (Gambardella et al., forthcoming). User innovations are especially likely to be of general value when they have been developed by 'lead users', who are characterized by needs that foreshadow general demand. Producers who purposefully seek out innovations developed by lead users as a basis for commercial products have found this to be a profitable practice (Lilien et al., 2002).

The diffusion pathways user innovations might follow are as shown in Fig. 1 (Baldwin et al., 2006; de Jong and von Hippel, 2013). At the top of Fig. 1, we see that users who innovate may choose to reveal information regarding their innovations without charge to other users (peers) interested in adopting them. This diffusion may be purposeful, or simply be the result of spillovers of unprotected information, as when a novel product is used by a user innovator in a public setting (Strandburg, 2008).

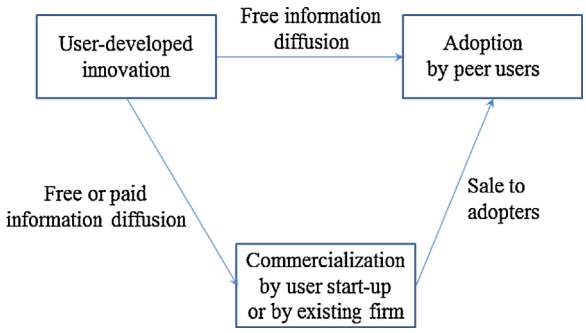

Fig. 1. Pathways via which user-developed innovations diffuse.

Diffusion can also be accomplished less directly, with producers obtaining information from user innovators so that they can adopt the innovation (and further develop it if needed) and then offer it to a broad audience for general sale. As can be seen at the left side of Fig. 1, the information may be freely revealed to the producers on the same terms as it is revealed to adopting users: freely revealed information has no restrictions upon who may access it. Or, some user innovators may choose to not freely reveal their innovation-related information but instead receive some kind of compensation (e.g., pay, royalties, and favors) (de Jong and von Hippel, 2009). Or alternatively, they may start their own firm for that same purpose (Shah and Tripsas, 2007). In any of these commercial pathways, the innovation ends up being offered for general sale, and in that way diffused.

2.3. Prevalence of innovation diffusion by individual users

It has been empirically documented that user innovators may freely reveal what they have developed, for others to examine, imitate, or modify without any compensation to the innovator. The practices visible in open source software development were important in bringing this phenomenon to general awareness. In these projects it was clear policy that project contributors would routinely and systematically freely reveal code they had developed at private expense (Raymond, 1999). However, free revealing does not imply that others will adopt what has been freely revealed. In the case of innovations by individual users, survey evidence shows that diffusion exists in only a fraction of the identified cases. As can be seen in Table 1, the diffusion rate, via commercial and/or peer-to-peer channels, varies from 5.0% to 17.1%. This is the case even though, as can also be seen in Table 1, only a small percentage of individual consumers have legally protected their innovation-related knowledge as intellectual property.

Note that, on their own, the figures for diffusion shown in Table 1 are not evidence for under-diffusion. Although, this matter was not studied prior to the empirical study we will report on here, many or even most of the innovations in earlier studies 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

Table 1
Protection of and diffusion of user innovations developed by consumers.

Source	Country	Data year	Sample	Protection with IPRs	Diffusion
von Hippel et al. (2012)	United Kingdom	2009	104 innovations by consumers ≥ 18 years	1.9%	17.1%
Ogawa and Pongtanalert (2011)	USA	2010	114 innovations by consumers ≥ 18 years	8.8%	6.1%
Ogawa and Pongtanalert (2011)	Japan	2011	83 innovations by consumers ≥ 18 years	0.0%	5.0%

innovator: it simply is a reflection of the expected lack of adopter interest. Obviously, diffusion is useful only to the extent that user innovations have value to others.

2.4. Potential market failure

In general, a market failure exists when another possible outcome can make at least one economic actor better off without making someone else worse off (Krugman and Wells, 2006). Market failures are a form of inefficiency that may call for remedy.

The type of possible market failure that might be associated with the diffusion of individual, freely-revealed innovations is that individual users, with no mechanism in place to share the benefits others might reap from adopting their innovations, would view potential adopters' benefits as an externality and so underinvest in innovation diffusion from the perspective of social welfare. To understand the level of diffusion investment that it would be socially useful for user innovators to expend, consider the innovating user and the pool of potential adopters who could benefit from his or her innovation as an integrated system for which a benevolent dictator seeks to maximize the aggregate surplus. Assume that investments in the diffusion of innovation-related information by innovators will lower the costs for all potential adopters. Assume also that additional investments by the innovator would lower adopters' costs at a declining rate. Aggregate surplus is then maximized at the point where an additional dollar of investment by the innovator in diffusion produces an increase of exactly a dollar of benefit for the entire pool of potential adopters. In other words, that social optimum obtains if the marginal cost of diffusion equals the marginal benefit derived from it. Of course, individual innovators may obtain non-priced diffusion benefits such as help with innovation development, or reputational benefits, or altruism (Franke and Shah, 2003; Lakhani and Wolf, 2005). If these are sufficiently high, they could offset the lack of direct financial reward that a market provides. Whether they do so is a matter requiring empirical investigations of the type conducted in this paper.

This novel form of market failure was first described by von Hippel et al. (2014), and an existence proof was provided within the medical field. Here, it was found that clinicians' efforts to diffuse valuable discoveries made during their clinical practice was very low, and unrelated to the general value of those discoveries. In this paper, we broaden the exploration of this potentially very fundamental form of market failure to a much more general category of user innovators – a broad sample of citizens in Finland. We also explore more deeply the details of cause and consequence.

3. Research methods

3.1. Sample identification

Our research was supported by a grant from Finland's national innovation agency, Tekes. To obtain an initial and representative sample, we first contacted 10,000 individual citizens aged 18–65 years by telephone to invite them to take an electronic survey. These citizens were randomly drawn from Finland's Population Register Centre. In order to increase our subsample of validated user innovations (see later), we also sought to build a convenience sample consisting of people whose attributes, based on previous studies, made it more likely that they were innovators: highly educated, technical workers, and males (von Hippel et al., 2011). To this end, we invited members of several labor unions whose members had these characteristics to participate in our survey (The unions whose memberships we contacted were: The Union of Professional Engineers in Finland, the Finnish Inventors National Federation, Academic Engineers and Architects in Finland, the Trade Union of Education, AKAVA, SEFE, and The Finnish Metalworkers' Union).

All invitations were issued between August, 2012 and January, 2013. Each invitee was sent a hyperlink so that she/he could find the survey and participate. To avoid duplication, respondents were asked to fill in the surveys at their home address. Each respondent was allowed to complete the survey only once; to ensure this, our software recorded each respondent's IP address.

Completed questionnaires were obtained from 2048 Finnish citizens. The representative and likely user innovator subsamples contained 993 and 1055 respondents, respectively. We combined these into an overall sample, as exploratory t-tests and χ^2-tests showed that none of the key variables in our study (reported later) significantly differed between the two samples. With respect to demographic characteristics, 58% of the respondents in the overall sample were male. Forty one percent had a bachelors, masters or Ph.D. degree, and 46% worked in a technical job or business (e.g., engineering, medicine, natural sciences, design, and IT). Respondents' average age was 44.9 years at the time of the survey, and 86% were employed (including self-employed and business owners).

3.2. Sample screening

To identify respondents who had engaged in user innovation, we applied a refined version of a procedure initially developed in the United Kingdom (von Hippel et al., 2012). The screening procedure first casts a broad net to increase the chance of capturing any product developments or modifications of respondents. Then, careful screening is applied to eliminate any false positives captured.

At the start of our questionnaire we stated: "*The following questions relate to any creative activities in your leisure time. You may have created any products or applications for personal use, to help other people, to learn or just for fun*". Respondents' recall was assisted by offering a list of nine specific cues: had they created any (1) computer software; (2) household fixtures or furnishing; (3) vehicle-related; (4) tools or equipment; (5) sports, hobby or entertainment; (6) child or education-related; (7) health, care or medical; (8) food or clothing; or (9) any other items. We asked if respondents had created any of these items for personal use in the past three years.

Out of the 2048 respondents, initially 624 reported at least one creation with respect to the nine aforementioned cues. We next applied two screening questions as one step in our validation process. We asked (1) whether the respondent knew of an equivalent product available on the market that he/she could have bought; and (2) whether the innovation had been developed as part of the respondent's job. A positive answer to either question eliminated the claimed innovation from further consideration. We were not interested in replications of existing products, but rather aimed for creations/modifications that were at least new to the consumer him/herself. We also wanted to include only innovations that individuals had developed as consumers rather than as business sector employees. Application of these screens reduced our 624 affirmative replies to 251 potential innovators.

Next, the survey script asked respondents to describe their development and its intended function. These open-ended descriptions were examined and discussed by two members of the research team. Cases regarded as false positives due to lack of novel, user-developed content such as: "*I installed a [manufacturer-developed] software upgrade on my personal computer*" were removed at this stage. When no description was provided, we took the respondent's claims as correct (e.g., "*I am too afraid to reveal it. [But] the problem I had almost on a daily basis is now solved*!").

Finally, we only included innovations into our sample that produced some level of functional novelty. This included developments that were a customized version of existing products that were not

Table 2
Objects of validated user innovations, and examples ($n = 176$).

Object	Freq.	Examples
Tools & equipment	20%	A tool that helps to change tyres with less back pain. There are no similar products on the market. This one is for personal use.
Household fixtures & furnishing	20%	A foldaway bathtub. I am having a small bathroom and wanted to avoid big and expensive renovation work.
Sports, hobby & entertainment	17%	New device for bee keeping, helps lifting the compartments of the beehive. This is usually heavy lifting which needs to be done by two persons, but not anymore.
Food and clothing	12%	A hamburger mold that I could not find in the shops. I wanted extra large hamburgers, but the tools were not available.
Transport & vehicle	11%	I have made my own stunt bike foot rests. They are much stronger, lighter and safer than available commercial products
Help, care & medical	7%	Tools to help my brother who is disabled and who can only use one arm. He can now peel, dice and slice and work with anything from bread to fruit with one hand.
Computer software	6%	Software that is able to take screenshots simultaneously from several cameras. I like to see what happens in my street.
Children & education	4%	A seat belt control that guides the belt to come down over the collarbone/shoulder and not for example over the throat. My child does not get frustrated anymore when the seatbelt is in his face. He no longer wears it only partly, e.g. only on the hip, so it is safer.
Other	3%	A cylinder woven of acid-proof steel net to neutralize well water. The cylinder is filled with dolomite lime grains and lowered down into the well. The pH-value of the well water rises and therefore the life of the piping and plumbing fixtures will increase. Existing products did not match with my situation.
Total	100%	

available on the market, and that provided important value for the developer. It excluded purely aesthetic improvements, as in: "*I painted a picture more appropriate to my setting than any available*". (This is a restriction that future researchers may want to revisit: in effect, all purely artistic innovation is excluded). After the completion of our screening process, we had a sample of 176 validated innovations. Table 2 provides their frequencies and some examples.

3.3. Variables

As we explained earlier on, our major goal is to explore the relationships between the value associated with product innovations developed by citizens for others, the extent to which respondents had made an effort to diffuse their innovations commercially and/or peer to peer, and how often commercial and/or peer-to-peer diffusion had been observed. Table 3 provides an overview of the variables in the analyses we will present later.

First, in the survey we asked respondents if, as far as they could assess, diffusion of their innovation had occurred. Commercial diffusion was measured with a dichotomous indicator – 'yes' if the innovation was commercialized either by a venture or an existing commercial producer – otherwise 'no'. Similarly, peer-to-peer diffusion was measured with a dichotomous indicator – 'yes' if the innovation was adopted by other individual users, – otherwise 'no'. Next, we asked whether the innovator had made an effort to diffuse his/her innovation. Diffusion effort via commercial pathways was indicated if he/she had shown the innovation to a business or entrepreneur. Diffusion effort to peers was indicated if he/she had revealed the innovation to other individuals.

With respect to value created by the innovations, we first asked respondents whether or not their innovation had served their own needs. Next, we asked four questions (shown in Table 3) to determine to what extent each innovator thought his or her innovation could also serve the needs of others. A principal component analysis then was applied (details available on request). This showed that the four questions could be condensed into a single dimension, and we saved the resulting factor-score as an indicator of perceived general value.

As an independent check on the validity of innovators' self-assessment of general value, we provided three independent coders with the open-ended descriptions of all innovations in our validated sample. Based on these descriptions, each of these individuals coded the innovations as having value to: no, few, or many other consumers. Cohen's kappa was calculated to be 0.45, indicating fair or moderate agreement among the coders (Landis and Koch, 1977; Cicchetti, 1994). We next computed the average score of the three coders to obtain an independent measure of general value. This measure was positively and significantly related to self-rated general value provided by the innovators ($r = .37$, $p < .001$).

Our independent coders thus provide support for the validity of the self-rated general value measure provided by our sample of innovators. However, of the two available measures, we elected to use the innovators' self-rating in further analyses. We reasoned that the self-rating, although suffering from potential biases to be discussed in Section 5.2, is likely to be the most accurate one. Consider that, for most innovations, the open-ended descriptions relied upon by the independent coders were not very detailed. By comparison, the innovators themselves have much richer information on the nature of their innovations. In addition, the innovators' assessment of general value was made after their innovations were completed, put to use, and perhaps also observed by others. Self-rating accuracy should therefore be additionally enhanced by this post-innovation information – which was available to the innovators but not to the independent coders.

Other variables in Table 3 were included in the regression analyses we present later to investigate the correlates of diffusion via commercial pathways or peer-to-peer. We included respondents' educational attainment (dummy for those with at least a bachelor degree). We also included motives for innovating, which were measured by distributing 100 points over five pre-defined motives (taken from Hienerth et al., 2014). Three dummy variables were included indicating collaboration partners if they were involved, reasoning that such innovations more likely diffuse. We also added respondents' willingness to freely share their innovation-related knowledge with at least some others, and, likewise, a dummy indicating if the respondent was willing to share for some kind of compensation. Finally, we included two count variables regarding the innovator's perception of the cost and difficulty for others to adopt their innovation. Adoption may require that adopters invest from a little to a lot of time or money to understand, replicate, and apply an innovation.

Table 3
Variables.

Variable	Description	Values
Commercial diffusion	Innovation was commercialized in a venture or adopted by a producer for general sale	0 = no; 1 = yes
Peer diffusion	Innovation was adopted by other users for non-commercial purposes	0 = no; 1 = yes
Diffusion effort: commercial	Innovator showed the innovation to a business or entrepreneur	0 = no; 1 = yes
Diffusion effort: to peers	Innovator revealed the innovation to other individuals	0 = no; 1 = yes
Personal value	Response to the item, 'this innovation worked for me, it solved my personal need.'	1 (barely/not at all)–4 (perfectly)
General value	Factor-score of four indicators listed below (standardized alpha = .75; mean r = .42, IRCs > = .50; variance explained 57%) ..This innovation would be of value to other people (1 = to none, 2 = to few, 3 = to many, 4 = to (nearly) all) ..I think this innovation can become a valuable commercial product (1 = not, 2 = to a small market, 3 = to a reasonable market, 4 = to a substantial market) ..My innovation would enable other people to do something they could not do before (0 = no, 1 = yes) ..My innovation would help other people to save money (0 = no, 1 = yes)	Range: −1.48–2.25
Education	Dummy variable for those with at least a bachelor degree	0 = no; 1 = yes
Motives:	Innovator's motives to develop the innovation, with importance indicated by distributing 100 points across. . .	
Personal need	..I personally needed it	0–100 points
Sales	..I wanted to sell it/make money	0–100 points
Learning	..I wanted to learn/develop my skills	0–100 points
Helping	..I was helping other people	0–100 points
Enjoyment	..I did it for the fun of doing it	0–100 points
Collaboration:	Innovation was developed in collaboration with others. . .	
Relatives/friends	..Relatives/friends	0 = no; 1 = yes
Business	..Businesses/producers	0 = no; 1 = yes
Club/community	..Members of a community or club	0 = no; 1 = yes
Willingness to freely reveal	Innovator is willing to freely share his/her innovation-related knowledge	0 = no; 1 = yes
Willingness to trade	Innovator is willing to reveal his/her innovation-related for a compensation (e.g., money, royalties, favors, and discounts)	0 = no; 1 = yes
Commercial adoption barriers	Count variable of three types of adoption costs for commercial adopters (required learning effort, time/money investment, or any other)	0–3 barriers
Peer adoption barriers	Count variable of three types of adoption costs for peers/other users (required learning effort, time/money investment, or any other)	0–3 barriers

4. Findings

We start with overall study findings (Section 4.1). We next explore the value that innovating consumers derive from their innovations, and from the process of developing them, as well as perceived value to others (Section 4.2). We then explore levels of diffusion across different levels of perceived general value of the innovations (Section 4.3). Next, our main analysis is concerned with the factors associated with commercial and peer-to-peer diffusion (Section 4.4).

4.1. Frequency and nature of user innovation by consumers in Finland

Our first analyses focused on our subsample of 993 respondents who had been drawn at random and recruited on the phone. We estimate that in Finland, 5.4% of the consumer population aged 18–65 years has engaged in user innovation in the past three years (5.9% in the unweighted sample—see Table 4 notes).

With respect to diffusion-related matters, we see in Table 4 that only a small fraction of consumer innovators protect their innovations from copying via intellectual property rights. We also see that only 19% of the consumer-developed innovations diffuse. As can be seen in Table 1, these findings are similar to findings obtained in the UK, the US, and Japan. Recall that, on their own, the figures for diffusion shown in Table 1 are not evidence for under-diffusion. Consumer innovators that seek to serve their own needs may only sometimes develop innovations that are of potential interest to others as well. Diffusion is beneficial only to the extent that user innovations have value to others.

Table 4
Extent of consumer innovation and diffusion in Finland.

	Finland[a] (n = 993)
Percentage of consumers who developed or modified a consumer product in the previous three years. . .	
. . .In the general population aged 18 and over (for Finland, aged 18–65)	5.4%
. . .Amongst highly educated (at least bachelor degree)	7.7%
. . .Amongst those in a technical job or business	8.8%
. . .Amongst males	6.3%
Estimated number of consumer innovators aged 18 and over (for Finland, aged 18–65)	0.17 million
Diffusion: percentage of consumer innovations. . .	
. . .Protected with IPRs	4.7%
. . .Actual diffusion to peers and/or commercially	19.0%

[a] Via a comparison with population statistics for 2012 obtained from Statistics Finland, we found that males, younger citizens aged 18–24, and those with only primary education were under-represented. This sampling bias was corrected for by computing weights for all respondents across all combinations of gender, education and age classes (details available on request).

4.2. Personal and general value of innovations

With respect to personal utility, most respondents reported being highly satisfied with the use value of their innovation. In our combined sample of 176 validated innovations, 85% of the developers reported that their innovation very well or perfectly solved their own personal needs. More specifically, their response distribution to the statement. 'The innovation worked for me, it solved

Table 5
Perceived general value of user innovations by consumers.

General value	This innovation...			
	...Helps other people to save money (yes)	...Enables people to do new things (yes)	...Would be valuable to others (many or nearly all)	...Can become a valuable commercial product (to a reasonable/substantial market)
Cluster I: valuable to many (17%)	70%	67%	74%	93%
Cluster II: valuable to some (44%)	66%	68%	42%	0%
Cluster III: valuable to none (39%)	0%	0%	0%	3%

Note: Percentages in cells based on 30, 77 and 69 validated innovations for cluster I, II and III, respectively.

Table 6
Diffusion of innovations and diffusion effort across clusters of general value.

Perceived general value	Diffusion of innovations			Diffusion effort	
	Any type	Peer-to-peer	Commercial	To peers	Commercially
Cluster I: valuable to many	19%	12%	15%	23%	19%
Cluster II: valuable to some	25%	19%	9%	21%	6%
Cluster III: valuable to none	15%	15%	0%	12%	0%
Total	19%	16%	6%	18%	6%

my personal need' was 'barely or not at all' (3%), 'somewhat' (12%), 'very well' (43%) and 'perfectly' (42%).

We next asked innovating respondents about the extent to which they thought that others would find their innovations valuable. Recall from Section 3 that four indicators, shown in Table 5, were used to assess general value. Utilizing data collected for these indicators, we applied cluster analysis to our sample. Classification was obtained using the two-step cluster procedure suggested by Milligan and Sokol (1980). First, hierarchical clustering based on Ward's method with squared Euclidian distances was applied to group the reported innovations into homogeneous clusters. To assess the robustness of various cluster options, we saved a range of initial solutions with two to five clusters. In a second step we proceeded with *k*-means cluster analyses, using the initial hierarchical solutions as starting values. Coefficient Kappa (chance-corrected coefficient of agreement) between each initial and iterated solution (cf. Singh, 1990) then indicated that a three-cluster solution was optimal ($k = .94$).

Note from Table 5 that 17% of the innovation cases are self-assessed by the innovators 'likely to be useful to many' (Cluster I) and 44% are 'likely to be useful to some' (Cluster II). This is a very interesting finding – first of kind – with respect to the social welfare potential of consumer innovation. It is in principle possible that very few consumer-developed innovations would be of interest to others, due to high heterogeneity of user need that has been found among consumers (Franke and Reisinger, 2003; Franke and von Hippel, 2003). Or, it is possible that, despite high heterogeneity of need, user-developed innovations will in many cases be a good or better fit to the needs of others than available commercial options. Empirical findings such as the ones described here are needed to understand this matter.

An illustrative example of an innovation in Cluster 1, 'likely to be useful to many', is "*I am suffering from aching feet. My device is different from the ones available on the markets. It gives massage on 80–100 pressure points, simultaneously or as a wave, based on simple processor-guided program. The novelty value is based on massage that can be adjusted easily according to my needs. It can imitate acupuncture without puncturing my skin*". An example of an innovation in Cluster 3, 'likely valuable to none beyond the innovator' was "*I work in the garage and there is often need for tools that are not available on the markets. For example, I developed a drill and sleeve combination that helps in getting broken 8 mm bolt out of a 5 cm deep hole. Hardly newsworthy, these novel tools assist me in my own activities*".

4.3. Levels of diffusion

In Table 6, we see initial evidence compatible with a market failure with respect to the peer-to-peer diffusion of innovations developed by individuals in Finland. Overall, as can be seen, only a minority of innovations deemed to be of value to others did in fact diffuse, and diffusion effort was seldom exerted by innovating individuals.

In the case of peer-to-peer diffusion, we find that there is no significant relationship between the likelihood of diffusion and the general value of the innovation ($\chi^2 = .8$ with $df = 2$, $p = .646$). In addition, there was no significant relationship between the likelihood that innovators were making an effort to diffuse to peers (by revealing their innovation to other potential users) and the general value of the innovation ($\chi^2 = 2.5$ with $df = 2$, $p = .285$). Both findings are in line with the presence of a market failure in the case of peer-to-peer diffusion. If the value of an innovation to others is entirely an externality for individual innovators, there is no reason that diffusion effort should be correlated with the general value of the innovation.

In the case of diffusion to commercial firms, things are different. Here, we find a significant relationship between the likelihood of diffusion and the perceived general value of an innovation as assessed by the individual innovator ($\chi^2 = 8.0$ with $df = 2$, $p = .018$). There is also a relationship between effort to diffuse commercially and higher perceived general value ($\chi^2 = 12.2$ with $df = 2$, $p = .002$).

These findings are in line with the existence of a market failure affecting peer-to-peer diffusion effort and diffusion accomplishment in the case of innovations developed by individual user innovators. In contrast, the failure appears to be mitigated in the case of commercial diffusion effort of innovations developed by individuals.

4.4. Factors distinguishing diffusing from non-diffusing innovations

Next, we explore whether the relationships between perceived general value, diffusion and diffusion effort are confirmed in a more elaborative multivariate framework. As will be seen, in this framework we included as control variables educational attainment, innovation motives, external collaboration indicators, willingness to freely reveal or trade innovations, and perceived adoption barriers. This increased richness enabled us to more broadly assess factors distinguishing diffusing from non-diffusing innovations.

Table 7 provides descriptive statistics and bivariate correlations. We estimated four probit regression models, as shown in Table 8, which due to the cross-sectional nature of our data should be interpreted in correlational and not causal terms. To ease the interpretation of significant effects we report marginal effect parameters. Variance inflation factors of the probit models did not exceed 2.0, indicating that multicollinearity was not present.

The first regression was significant and helpful to explain diffusion via commercial pathways ($\Delta\chi^2 = 28.8$ with $\Delta df = 12$, $p = .004$). We excluded willingness to trade as an independent variable: for all cases that had diffused commercially the innovator was willing to transfer his/her knowledge for a compensation. This suggests that such willingness is a necessity for commercial diffusion to occur. The marginal effect estimates showed that after including the control variables, general value is still positively related with commercial diffusion. In addition, educational attainment was marginally significant.

With respect to the effect of general value on commercial diffusion, our estimates suggest that one additional unit of general value (i.e., a standard deviation, as general value is a standardized factor-score) increases the probability of commercial diffusion by 5.8%. Given the estimated baseline probability of 6.3%, at high levels of perceived general value the probability of commercial diffusion almost doubles.

The third model in Table 8 explores the correlates of innovators' effort to diffuse commercially. Again, willingness to trade was not included, as it perfectly correlated with the dependent variable. Overall model fit was even stronger compared to the first model ($\Delta\chi^2 = 35.6$ with $\Delta df = 12$, $p = .000$). After entering the control variables the relationship between perceived general value and commercial diffusion effort was still significant.

At high levels of general value (one standard deviation above its mean score) the probability of exerting commercial diffusion effort increases by 4.5%. Moreover, we found that innovators were more likely to exert commercial diffusion effort when their innovation motive was sales related, when the innovation was developed in collaboration with club or community members, and at high levels of personal use value. Overall, these observations confirm that innovations with high general value are more likely to spread if a market incentive is operating.

The second model in Table 8 explains the correlates of accomplished diffusion to peers, that is, to other users. After including the control variables we find that perceived general value is not related with peer-to-peer diffusion, echoing Table 6. Only innovators' willingness to freely reveal their innovation seems to increase the probability that innovations spread to other users. However, overall model fit is not significant ($\Delta\chi^2 = 15.0$ with $\Delta df = 13$, $p > .10$) indicating that our ability to explain peer-to-peer diffusion is limited.

Model fit was acceptable in the fourth model, in which peer diffusion effort was the dependent variable ($\Delta\chi^2 = 23.7$ with $\Delta df = 13$, $p = .032$). Here, we again find that a relationship between general value and peer diffusion effort is lacking, which is in line with the market failure we proposed. Rather, innovations developed in collaboration with others are more likely to be shown to other individuals.

5. Discussion

In this study, we have extensively analyzed the relationship between the perceived general value of user innovations, the extent to which they diffuse, and the extent to which effort is exerted by user innovators to support diffusion. Our goal has been to investigate the merit of the "under-diffusion of user innovation due to market failure" hypothesis (von Hippel et al., 2014), and to explore

Table 7
Descriptive statistics ($n = 176$).

Variable	*M*	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1. Commercial diffusion	.06	.24																		
2. Peer diffusion	.16	.37	.12																	
3. Diffusion effort: commercial	.06	.24	.15^	.17*																
4. Diffusion effort: to peers	.18	.38	.08	.30**	.02															
5. Personal value	3.23	.78	-.01	.04	.09	.09														
6. General value	.00	1.00	.30**	.02	.29**	.08	.08													
7. Education	.46	.50	.17*	−.06	−.03	−.01	.03	.08												
8. Motive: personal need	51.1	30.5	−.05	−.04	−.16*	−.10	.05	−.22**	.04											
9. Motive: sales	3.4	8.1	.18*	-.01	.31**	.00	.00	.37**	.11	−.28**										
10. Motive: learning	12.2	13.5	.05	.03	.03	.12	.04	.16*	.17*	−.47**	.14^									
11. Motive: helping	13.3	23.0	−.01	.03	.09	.00	−.04	.08	−.15*	−.61**	−.08	−.08								
12. Motive: enjoyment	19.9	16.7	−.02	.01	−.01	.08	−.07	−.03	−.05	−.47**	.03	.09	−.16*							
13. Collaboration: relatives/friends	.22	.42	−.02	−.03	−.08	.09	−.07	−.11	.05	−.04	−.02	−.04	.04	.06						
14. Collaboration: business	.05	.21	.18*	.14^	.18*	.19*	.08	.16*	.08	−.02	.18*	−.10	.02	.00	.02					
15. Collaboration: club/community	.04	.20	.07	.16*	.20*	.14^	−.06	.07	.11	−.15^	−.05	.18*	.11	.01	−.04	.09				
16. Willingness to freely reveal	.84	.37	−.24**	.10	−.17*	.02	.04	−.32**	−.05	.13	−.46**	−.13	.07	−.01	−.07	−.13	−.07			
17. Willingness to trade	.91	.28	.08	−.06	.08	.07	.06	.12	.02	.06	−.04	−.07	.13	−.21**	−.09	−.03	.06	.23**		
18. Commercial adoption barriers	.18	.39	.14^	.11	.08	.07	−.08	.15^	.00	−.11	.10	.15^	.00	.03	−.14^	.11	.21**	−.06	.09	
19. Peer adoption barriers	.26	.47	.08	.07	.08	−.06	−.01	.17*	.06	−.19*	.12	.14^	.01	.16*	−.03	.18*	.21**	−.15^	−.06	.44**

Table 8
Probit regression models of diffusion, and diffusion effort ($n = 176$).

	Diffusion observed				Diffusion effort			
	Commercial		Peer-to-peer		Commercial		Peer-to-peer	
	dy/dx		dy/dx		dy/dx		dy/dx	
Baseline estimate	.063		.164		.060		.176	
Effect parameters:								
Education	.055^	(.033)	−.064	(.054)	−.045	(.031)	−.043	(.058)
Motive: sales	−.001	(.003)	.002	(.005)	.005*	(.002)	−.001	(.004)
Motive: learning	.000	(.001)	.002	(.003)	−.001	(.001)	.005*	(.002)
Motive: helping	−.000	(.001)	.000	(.001)	.000	(.000)	.000	(.001)
Motive: enjoyment	−.000	(.001)	.000	(.002)	.000	(.001)	.003	(.002)
Collaboration: relatives/friends	−.005	(.041)	.009	(.069)	−.027	(.033)	.141*	(.069)
Collaboration: business	.059	(.077)	.248	(.178)	.002	(.044)	.442*	(.175)
Collaboration: club/community	−.024	(.041)	.336	(.212)	.448*	(.187)	.362	(.215)
Willingness to freely reveal	−.050	(.062)	.157**	(.047)	.002	(.045)	.080	(.082)
Willingness to trade			−.175	(.138)			.100	(.091)
Commercial adoption barriers	.047	(.035)			−.029	(.036)		
Peer adoption barriers			.027	(.063)			−.121	(.072)
Personal value	−.006	(.018)	.012	(.035)	.057**	(.021)	.041	(.034)
General value	.058*	(.023)	.007	(.033)	.045*	(.018)	.045	(.031)
Model fit:								
Wald χ^2 (Δdf)	28.8 (12)		15.0 (13)		35.6 (12)		23.7 (13)	
Significance (Wald p-value)	.004		.304		.000		.032	
Pseudo R^2	.299		.090		.415		.170	

Note: Robust standard errors in parentheses. For innovation motives, personal need is the reference group. Two-tailed significance ** $p < .01$, * $p < .05$, ^ $p < .10$.

factors affecting it. Our analyses were based on a broad sample of consumers in Finland.

In the remainder of this section, we discuss the evidence in favor of the under-diffusion of consumer innovation hypothesis. Then, we discuss the limitations of our study and offer suggestions for further research. Finally, we consider whether anything can be done to increase diffusion of generally valuable innovations that consumers develop.

5.1. Evaluating the market failure hypothesis

The market failure hypothesis proposed in von Hippel et al. (2014) offers a reason why generally valuable user innovations might not diffuse. We find that their hypothesis is in line with our empirical findings.

Unlike producers, consumers develop innovations for themselves primarily – and there is no necessary reason why consumer creations would also offer value to others. Nonetheless, we found that 61% of user innovations were believed by their developers to be valuable to at least some other users – and so to be a potential source of broader social and economic value. Of course, this broader value is only realized to the extent that the innovations actually diffuse. In line with the market failure hypothesis we have explored in this paper, we found that few innovators exert an effort to diffuse their innovations commercially or to other users. Only 6% reported that they had exerted effort to show their innovation to an entrepreneur or business for general sale, while 18% had revealed their innovation to other individuals. As for observed diffusion, 16% of the consumer-developed innovations did diffuse peer to peer, while 6% diffused via commercial pathways.

Notably, innovators' reason for not trying to diffuse cannot have been a wish to protect their idea, e.g., for reasons of rivalry with other users. Very few respondents had applied for intellectual property rights, and 84% of the innovators said they were willing to freely reveal their innovation. The situation can be explained by the lack of a connection between the benefits obtained by adopters and any investments by consumer innovators to diffuse their innovations. Adopters' benefits are an externality from the perspective of consumer innovators who freely reveal.

Taking at face value the innovator's subjective assessment of the value of the innovation to others, we can say that the innovator's decision not to share is individually rational, but socially inefficient. Others would benefit, in the innovator's own assessment, if she/he decided to share more; and yet she/he does not do so. Findings from the probit regressions presented above clearly show that diffusion effort to peers, and diffusion accomplished to peers, are not related to perceived general value. No matter what value the innovator believes his innovation to have for others, diffusion is unaffected. This disconnect indicates an externality as the root cause: value to others is not internalized and therefore not factored into diffusion effort decision-making.

By contrast, we find that in the presence of a market incentive, innovators are more likely to put effort into diffusion. In the case of the commercial diffusion pathway, the market failure we have documented in the case of peer-to-peer diffusion seemed reduced in intensity. This is reasonable, given that a market incentives link can then sometimes exist to reward even innovators who freely reveal their innovations.

5.2. Limitations and suggestions for further research

This study has limitations that should be dealt with in future research. We describe three below which all arise from the fact that our research utilized the innovators' own perception of the general value of their innovation, rather than relying upon the evaluations of independent raters. We feel there are benefits from this choice, but it is also true that reliance on innovators' self-evaluations does introduce some potential problems.

On the benefits side, it is important to understand that the innovators' view – however, imperfect – is precisely the one needed for our analysis of possible market failure. The market failure we explore rests on whether innovating users think their innovations are or are not of general value, and whether their view on this matter affects the effort they devote effort to diffusion. As we have seen, this connection is not significantly present in the case of peer-to-peer diffusion, which is consistent with a diagnosis of market failure.

At the same time, the actual social loss resulting from this market failure depends upon the innovators' evaluations of the general value of their innovations being partially or entirely accurate. Innovators' ratings may have built-in biases, such as systematic overestimates of general value arising from self-serving bias. To the extent that is the case, the value of increased diffusion effort by user innovators would be lessened. The literature to date tentatively suggests that user innovators' assessments of general value are valid (Morrison et al., 2000; Poetz and Schreier, 2012), but further research on this issue seems warranted.

A second issue, which should not be confounded with the considerations just above, is that innovators might, due to a social desirability bias, exaggerate the value of their creations in their responses. If this were the case, their diffusion effort might be tied to their true perceptions of general value rather than the general value estimates they report in our survey. Lower true assessments of general value would be an alternative explanation for the low levels of investment that we found in our research, and have attributed to market failure. This effect will occur only if and to the extent that user innovators think it is socially desirable to be known as the developer of a generally useful innovation versus one that is less generally useful. Research on social desirability bias suggests that our data collection approach insulates our findings from this problem. It conveyed a high sense of neutrality as respondents self-administered our online questionnaire without an interviewer being present; they were assured of the full anonymity of their responses, and allowed to backtrack (Nederhof, 1985). Under these conditions distortions due to social desirability have been found to be small (Richman et al., 1999).

A third issue is also related to the relationship we find in our study between diffusion effort and perceived general value: it is conceivable that causality might run at least partially the other way. That is, it may be that when innovations are of general value, innovators will get a signal that this is the case from others. This signal may then stimulate the innovators to increase their diffusion efforts. However, even if this is the case, it is not a concern with respect to our main findings regarding market failure. Recall that, in our exploration of a potential market failure, what we are looking for is evidence for any connection between the innovators' view of marketplace demand and his or her diffusion effort. We are agnostic as to the type of information the innovator uses to assess marketplace demand.

Beyond further in-depth investigation of the market failure hypothesis, it would be worthwhile for future research to quantify the loss the social welfare arising from it. In addition, it would be important to understand mitigating factors and the extent to which they can remedy the market failure. Such mitigating factors need not be market-based, involving financial compensation from consumer or commercial adopters to consumer innovators, but could also involve other rewards in the form of, e.g., recognition or assistance. After all, recognizing a market failure becomes particularly useful if and when we find that there are viable ways to improve the efficiency of the outcome, i.e., mechanisms and measures that will lessen its negative impact on social welfare at a reasonable cost.

With regard to future research on user and open innovation, we suggest that more attention be given to the dissemination and reuse of innovations made by consumers – either by peers or by producer firms. While studying consumer innovation incidence and its antecedents is important, diffusion is a powerful multiplier that is, as yet, comparatively little understood.

5.3. Implications for policy and managerial practice

Despite the relatively low diffusion percentages found in our sample, it is important to note that even such low percentages can be a major contributor to the total pool of commercialized innovations. Specifically in Finland, given our estimated 5.4% of the Finnish population of consumers aged 18–65 who can be considered user innovators, we have 173,000 innovators among 3.2 million Finnish citizens. If 6% of their innovations are commercialized for general sale, this represents 10,380 user-developed products and product improvements commercialized every three years.

With respect to policymaking to address market failures of the type explored in this study, note that it has been shown that user innovation by individuals enhances social welfare (Gambardella et al., forthcoming). Given this, there is clearly a case for policy support. After all, policy has been extensively deployed to address the market failure of spillovers of information from privately financed producer innovation efforts that affect producers. A level playing field would require policymaking to solve market failures in the development and diffusion of consumer innovation as well.

With respect to enhancement of peer-to-peer diffusion, one approach – support of collaborative innovation – seems to us to be especially interesting. Our sample mainly consisted of individual user innovators. An alternative model of innovation revolves around individuals who innovate collaboratively (Baldwin and von Hippel, 2011). When collaboration is involved, investments to diffuse partial and full solutions must be taken 'anyway' to collaborators involved in the work, in the course of the innovation process itself. Receiving help from other users reduces innovation costs, because the entire value of in-house use is captured by each participant, while innovation costs are shared (Baldwin and von Hippel, 2011). For this reason, in the case of collaborative work, diffusion efforts generated to support collaboration may simultaneously serve both innovators and free riding adopters as well.

Recall from Table 8 that our regression findings do show that collaboration is correlated with innovators' efforts to diffuse both commercially and to peers. Ogawa and Pongtanalert (2013) similarly found that when individuals belonged to communities with a shared interest in the innovation they developed, the adoption rate by peers was 48.5%. In contrast, when users did not belong to such communities, the adoption rate was sharply lower at 13.3%. Other literature supports these patterns: community users tend to collaborate with and assist one another (Franke and Shah, 2003; Raymond, 1999) and they tend to share information with other members, including information about innovations they have developed (Morrison et al., 2000; Raasch et al., 2008).

Based on this evidence, practitioners and policy-makers seem well advised to explore how to increase the likelihood that single innovators would join into collaborative innovation projects. Examples of possibly useful measures are increased availability of innovation facilities that involve social interaction like makerspaces. Also likely to be helpful, would be increased availability of on-line community fora where people with similar needs and innovation interests could find each other at low cost. Examples are social sites focused on patients with specific diseases, and sites focused on individuals who share an interest in specific sports.

Finally, our descriptive finding (see Table 6) whereby few innovators undertake an effort to diffuse their innovations commercially deserves attention by managers and policy-makers. It may be that means can be found to increase users' understanding of the general value that their innovations may have and in this way increase their incentives to engage in commercial diffusion. Such market research is a routine part of producer development efforts, but innovating consumers, responding to their own needs, generally do not invest in it prior to innovation development. It may be that general information regarding potential marketplace demand can be organized in a way that is freely accessible to consumer innovators. Established firms seeking to adopt user designs of potential commercial value would seem to have an incentive to make such information available, along with other forms of innovation assistance (Gambardella et al., forthcoming).

5.4. Summing up

The market failure explored in this study – no or "too low" incentives on the part of consumer innovators to diffuse their innovations – appears to be both important and actionable, creating opportunities for additional research, and also for adjustments to innovation policy and practice.

Beyond the specific suggestions made here, there is clearly a great deal of work and learning available on the topic of market failures in user innovation. We greatly look forward to next steps and future learnings regarding theory, policymaking, and practice.

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