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User innovation barriers and their impact on user-developed products

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Abstract

User innovation is a broadly discussed phenomenon in the context of open innovation which describes, for instance, the customer integration into the early phases of new product development). Despite there existing a large body of research in the field of lead users and user innovation, scientific literature provides only a few insights into how barriers are influencing user innovators and their development processes (Braun and Herstatt, 2007). In addition, there is still little research into the effects of user innovation barriers on user-generated products, and how user innovators' personal characteristics remedy or foster the effect of barriers on user-generated products along the user innovation process. Accordingly, this study contributes to lead user and user innovation theory by analyzing quantitative data from 299 respondents in the field of Fab Labs and makerspaces. An empirical model comprising user innovation barriers (technological, social, legal and ownership), user innovators' personal traits (lead userness and openness) and user innovations' product properties (perceived complexity) is analyzed by applying multivariate regression methods. Findings from the study reveal a hierarchical allocation of the barriers' impacts on the dependent variable perceived complexity, along the development stages. Barriers in user innovation processes serve as factors hindering, but also promoting, user innovation activities. It has been found, for instance, that technological barriers in the conceptualization and social barriers in the prototyping phase increase user innovations' perceived complexity. Instead, legal barriers in prototyping even decrease perceived complexity. Furthermore, an influence of openness as a direct and moderating personal trait to overcome user innovation barriers has been confirmed by this study.

Keywords: Open and User Innovation, User Innovation Process, User Innovator Characteristics, Lead User Research, Collaborative Workspaces

1 Introduction

User innovation is a broadly discussed phenomenon in the context of open innovation. Despite there existing a large body of research in the field of lead users and user innovation, scientific literature provides only a few insights into how barriers are influencing user innovators and their development processes (Braun and Herstatt, 2007). In addition, there is still little research on the effects of user innovation barriers on user-generated products, and how user innovators' personal characteristics remedy or foster the effect of barriers on user-generated products along the user innovation process. Initial work was done by Braun and Herstatt (2009). They were searching for user innovation barriers in media, medical and agricultural fields and built up a set of user innovation barriers. Further, they enriched this set by transferring scientific findings from non-user innovation fields. This non-exhaustive cluster of user innovation barriers led to the first suggestions to overcome certain barriers (Braun and Herstatt, 2007, 2008, 2009).

When users innovate their development processes appear often multidimensional, iterative and non-structured. These processes can also be seen as merely linear, comparable to classical corporate innovation processes (Tietz et al., 2005). In these linear processes, users firstly encounter their individual problem statement, then conceptualize possible solutions and finally try to realize their ideas (Tietz et al., 2005). The sequence of these processes is linked to a set of certain preconditions. In user innovation processes, preconditions like general knowledge or experience exist due to the strongly pronounced lead user characteristics of user innovators. In contrast, users often lack access resources such as tools, professional machinery and specific knowledge to apply it. Braun and

Herstatt (2007) found that users additionally face various economical, technological, social, and legal barriers when trying to succeed in their innovating activities. Taking into account various types of constraints users may face when conceptualizing and prototyping their innovation idea, it can be hypothesized that the impact of barriers will lead to changes in the user innovation process. Resulting product property changes with regard to the intended solution cannot be excluded. In worst case, a situation may come up that forces users to give up their innovation projects.

A strong promoter of user innovation is the maker trend and the rise of information technology since the 1980s, which enabled users to develop prototypes that are more sophisticated. These prototypes were going beyond the use of electromechanical components by including electronic steering parts and remote control systems. Today, that users are tinkering on products is relevant for almost all product categories. For instance, in extreme, professional, and leisure sports users developed incremental innovations for rowing boats (Tietze et al., 2015) or complete sailing boats (Raasch et al., 2008), resulting in the founding of new sports disciplines such as mountain biking or kite surfing (Lüthje et al., 2005; Tietz et al., 2005). These user-driven developments also impacted existing, highly commercialized sports markets related to mountaineering and alpine disciplines, such as skiing or snowboarding (Franke and Shah, 2003; Parsons and Rose, 2009; Schweisfurth and Raasch, 2015).

This study focusses on another user innovation field in the household sector. Users innovating in Fab Labs and makerspaces often develop solutions for their everyday life and their home environment. By analyzing such development processes with regard to the occurrence and impact of barriers this study derives a set of contributions. Accordingly, this study contributes to user innovation theory via the development of reliable measurement constructs for user innovation barriers. Furthermore, it includes the first confirmatory analysis of barriers' impact on user ability to innovate. Additionally, the study contributes further developed barrier types, including a distinction between resource-based constraints and a hierarchical allocation of barriers along the development stages. An introduction of openness as direct and moderating personal trait to overcome user innovation barriers will also be conducted in this study. Taking together all these factors comprised with the differentiated analysis for conceptualization and prototyping phase, this study enriches user innovation theory with a better understanding and predictability of the user innovation process. Finally, the study provides implications on how users successfully overcome user innovation barriers. Therefore, the role of workspaces, makerspaces, and Fab Labs in supporting users in such situations is discussed and recommended as a promising field for user innovation studies in the future. User innovation in practice, and the discussion of how it is done in several workspaces worldwide (Mikhak et al., 2002; Stacey, 2014; Walter-Herrmann and Büching, 2013), will have implications for management practice and policymakers.

2 Background

2.1 User innovation and its role for innovation

User innovation takes place in many market segments but shares over user-generated products differ strongly with regard to the product types. Historically viewed, the share of user innovations in the well-known field of trend sports equipment is often very large (Bogers et al., 2010). Studies covering complete populations found significant but smaller shares of user innovators across all business sectors. The proportion of consumers in the

United Kingdom and the United States that can be considered user innovators, is 6% and 5% respectively (von Hippel et al., 2012). They are covering markets like vehicles, homecare as well as sporting equipment (Jong et al., 2015). Other studies indicated a strong underestimation in extant research and found user innovation ratios of up to 40% (Franke et al., 2016).

Early user innovation studies predominantly justified the role of users as innovators across different business sectors and showed first successful cases of cooperation between users and firms (Foxall and Tierney, 1984; Shaw, 1985; Slaughter, 1993). Later, research focussed on determinants of user innovation and implementations of user innovation toolkits (Franke and Piller, 2004; Franke and Schreier, 2002; Jeppesen, 2005; Morrison et al., 2000; von Hippel, 2001). Today, refined user innovation processes (Bosch-Sijtsema and Bosch, 2015; Hyysalo et al., 2016), IP and ownership related topics (Bauer et al., 2016; Tietze et al., 2015) are examined by researchers. Further, the applicability and efficiency of user innovations in different market segments (Bjørkquist et al., 2015; Hienerth et al., 2014; Hjalager and Nordin, 2011) and user entrepreneurship (Chandra and Leenders, 2012; Lettl and Gemünden, 2005; Shah and Tripsas, 2007) are intense fields of research.

When users innovate, they are driven by the objective to generate user value but predominantly for themselves and not for a broad market. When users innovate, they also try to solve problems for their close environment: for themselves, relatives or friends. Thus, developing not too complex products is often important for user innovations. In contrast to producer innovations, the market potential is less important for user innovators. Indeed, corporate innovation and user innovation processes may differ partly with regard to the outcome. Personal traits of innovator instead of corporate characteristics are seen as strong drivers of user innovation, some of them being directly product related. Lead userness (incorporating product needs ahead of the trend and high expected benefits) and use experience (incorporating duration and frequency of product use) are seen as major drivers of user innovation (Tietze et al., 2015). Lead userness is a personal trait of innovative users and strong driver of user innovation in many lead user and user innovation studies are impacting user innovation positively (Franke and Shah, 2003; von Hippel, 1986). The stronger the lead userness, the stronger often is the willingness and the prospect to succeed. Such special product related needs may also arise when a person uses a certain product for a very long time or very frequently.

Recent user innovation literature also adds not directly product related traits to the set of drivers to user innovation and user innovators' characteristics. The "Big Five" personality traits are also found to be significantly related with generating user innovation ideas (Schweisfurth, 2017; Stock et al., 2016). The "Big Five" model allocates the personality of persons to five main dimensions: "openness", "conscientiousness", "extraversion", "agreeableness" and "neuroticism" (Barrick and Mount, 1991; Gosling et al., 2003; Rammstedt and John, 2007). From those "Big Five", the personal trait "openness to experience" recently became increasingly included in user innovation studies' research models. This variable often acts as a proxy for creativity measures in user innovation studies (Schweisfurth, 2017; Shalley et al., 2009; Stock et al., 2016).

To summarize, in an ideal case users are motivated by strong drivers and fulfill the user innovation process via conceptualization and prototyping without facing major barriers. In the end, the user possesses a user innovation product, which is completely adapted towards personal needs, including a high user value and a moderate complexity. Additionally, the user has the opportunity to diffuse the innovation if others face the same needs and if they are able to deal with the innovation. That is why the perceived complexity of a user innovation should not grow too much. Otherwise, third party users may be prevented from using the innovation. Nevertheless, keeping a moderate perceived complexity level may not always be possible as a user innovation is not equal to another user innovation and the outcome of this user innovation process will thus always vary in terms of user innovation properties.

In this study, the analysis of the user innovation product properties will focus on the innovations' property perceived complexity. However, many users either fail before accomplishing their prototype or they have to overcome barriers. Such barriers have rarely been the subject of past analysis. Scientific literature covering "barriers to user innovation" is scarce and literature going beyond a simple collection of barriers by measuring the barriers' impact on user innovation process and outcome is considerably scarcer, let alone measurement constructs to quantify the impact of barriers on user innovation, especially with regard to perceived complexity.

2.2 Barriers along the user innovation process

Few user innovation studies reveal that a significant share of users, having generated innovative ideas, do not manage to convert them into running prototypes (Lüthje, 2004; Tietze et al., 2015). A study in the rowing sport market, observed a user idea generation ratio of 45.0% while only 6.8% of the users implemented at least one of their ideas successfully (Pieper and Tietze, 2012; Tietze et al., 2015). Hence, users are very creative in this environment but not able to bring their creativity on track and to convert it into reality. The main barrier in this specific case is the separation of ownership and control. This case shows that, apart from simple resource constraints, additional barriers impact the development of user innovations during conceptualization and prototyping phase (Braun and Herstatt, 2007; Morrison et al., 2000; Tietz et al., 2005; Tietze et al., 2015). The first introduction and discussion of the term "user innovation barriers" in sense of "barriers innovating users faces" along the user innovation process was developed by Braun and Herstatt (2007), which remains to this day one of few discussions on this subject. They compiled non-exhaustively user innovation barriers and allocated them to "legal", "market/economic", "technological" and "social" clusters of barriers depending on the empirical fields farming and medical devices (Braun and Herstatt, 2007, 2008, 2009). Raasch et al. (2008) discussed those barriers with the example of sailboats, whereby user innovation barriers are mentioned in terms of technological, legal, or regulatory issues which block design space areas and lead users to switch to other fields in order to innovate. Additionally, barriers are seen as factors negatively driving user innovation-related activities during a certain period of time (Raasch et al., 2008). User innovation literature also describes barriers to user innovation in the context of diffusion and that barriers are hindering user innovations' ability to generate social welfare (Svensson and Hartmann, 2018). Nevertheless, the question is unclear in how far barriers hinder and remedy user innovation activities or if it is possible to create a more distinct point of view where barriers impact user innovation processes differently and more dynamically.

When users develop technical products, it seems obvious that technological problems are likely to arise. A user could face problems with components, which should be assembled towards an innovation, not fitting together or that the innovator is not able to disassemble products in order to improve them due to factory settings. Additionally, when innovating users are processing material, it often may be too complex to do so. As a result, the activities may fail due to certain machinery problems or inadequate material properties like, for instance, shape and stability. The worst case for a tinkerer often is that products simply crack under load. When this happens, an innovating user has to procure new material or has to fix the crack and has to start the activity from the beginning. Hence, on a more abstract level technological barriers with regard to product problems range from problems regarding complexity of the intended solution towards material related durability and compatibility problems (Braun and Herstatt, 2007). Further, technological barriers may be incorporated by manufacturers in commercial products and will prevent modifications or repairs to prevent users from tinkering (Braun and Herstatt, 2007). This, for instance, is known from smartphones, which are often built in a very complex way in order to prevent users installing unauthorized batteries or other components without using special tools at hand and without possessing dedicated knowledge (Warner, 2013).

In addition, not only very concrete barriers but also more "soft" barriers show significant influence on user innovation processes. Social barriers like third party skepticism or stigmatizations are also affecting users' innovation behavior and come up often in the close private environment (Braun and Herstatt, 2007). That is why innovating users react on this third-party influence. For example, they show their prototypes to family, friends, neighbors or colleagues and sometimes receive only little support, motivation or approval. Under the influence of those social barriers, users alter their innovating behavior and in worst case abandon their innovation projects (Braun and Herstatt, 2007; Flowers, 2008). Additionally, policymakers and administrations build up legal requirements, liability laws or laws limiting tinkering and hence influence directly user innovators acting in legal grey areas (Braun and Herstatt, 2007). Warranties or guarantee rights on products or components, as well as problems derived from patents, copyrights or secure codes, are relevant in this field and have been studied before (Braun and Herstatt, 2007, 2008; Morrison et al., 2004).

Directly linked to the problem of legal barriers is the previously mentioned discussion about the impact of ownership on user innovation. Only users in private ownership situations possess the right entitling them to modify a product (Tietze et al., 2015). Even if certain equipment is reserved for a user's dedicated use (e.g. in sport clubs, sharing communities, libraries etc.) – the equipment owner can claim damages if the user substantially and irreversibly modifies the product (Pieper et al., 2016). Nevertheless, the trend towards shared products (sharing economy or "shareconomy"), in place of product ownership, is increasing, as is the trend towards product-service systems (PSS) (e.g. car- and bike sharing) and access-based consumption. In those environments, users act more and more in non-private ownership regimes (Belk, 2007; Lawson et al., 2016; Neely et al., 2011; Schultz and Tietze, 2014). The worst-case scenario in these regimes for user innovators would be that experimenting with product modifications leads to complete product failure. In those cases, users would be subject to substantial damage claims from the product owner or the PSS operator. The fear of such a threat of damages would necessitate accounting for additional expenses when approximating innovation costs before initiating a user innovation activity.

Taking together the assumptions from theory, it has been observed that barriers have an impact on the user innovation development either in conceptualization or in prototyping phase of the user innovation process. It may be irrelevant for technological barriers in which phase barriers come up, the users try to circumvent them or downgrade their initial plans and thus, it will be hypothesized that:

(H1): Technological barriers impact perceived complexity in conceptualization and prototyping.

The same assumption applies to social barriers: Innovating users discuss their ideas with close relatives or try to implement ideas from their close relatives, but make the product in some cases more complex. The prototypes the users finally develop include value for both parties; the lead users themselves and the third-party users. Hence, it can be hypothesized, that:

(H2): Social barriers impact perceived complexity in conceptualization and prototyping.

Legal barriers in theory show a significant impact on user innovation (Braun and Herstatt, 2007). When legal barriers arise, before the physical development in conceptualization, the users try to plan smarter solutions. That implies that they may plan a more complex solution in order to circumvent the legal problem. By this smarter circumvention, they try to reach at least as much user value as initially intended. Thus, it is hypothesized that:

(H3) Legal barriers impact perceived complexity in conceptualization and prototyping.

Ownership barriers are strong barriers for user innovation, especially, when users conceptualize their innovation while confronted with third-party ownership. Users try to circumvent these barriers by trying to find solutions that are more complex. Also from theory it can only be deducted, that users raise the effort and try to implement the intended user value by developing their innovation in a smart way (Pieper et al., 2016). Thus, the assumption is that the pattern in conceptualization and prototyping may be the same, which leads to the following hypotheses:

(H4) Ownership barriers in conceptualization impact perceived complexity in conceptualization and prototyping.

The hypothesized impact of barriers on user innovation is supposed to be fostered or remedied by user innovator's personal traits. Often, the stronger the lead userness then the stronger the willingness and the prospect to succeed. From, theory it may be supposed that lead userness per se leads to higher user value while the complexity of lead user innovations may vary to a greater extend. Hence, for the impact of lead userness, the following hypothesis has been formulated applying to both the conceptualization and the prototyping phase:

(H5) Lead userness impacts the relationship between barriers and perceived complexity.

Openness to experience incorporates a person's curiosity, imagination as well as artistic interests. Thus, the person can be seen as a user who is creative and seeking for new experiences and opportunities (George and Zhou, 2001; Zhao and Seibert, 2006). It can be assumed for user innovation that a quite open person may react to external influences in a stronger way than a less open person. Thus, the hypothesis for the impact of openness for both conceptualization and prototyping phase has been formulated:

(H5) Openness impacts the relationship between barriers and perceived.

3 Research approach

3.1 Context and sample

Data was collected via an online questionnaire given to innovative users in Fab Labs. A Fab Lab is an institution where innovating users gain access to tools, machinery and materials in order to tinker on their own developments (Gershenfeld, 2008). Users are able to use, for instance, simple tools from hammers, screwdrivers, and saws up to more sophisticated machines such as 3D printers, PCs, flatbed scanner, laser cutters as well as CNC machines (Blikstein, 2013; Mikhak et al., 2002). Fab Labs have been chosen due to two aspects. First, resource-based constraints should be predominantly excluded in order to achieve a ceteris paribus situation in terms of financial, technological and knowledge-based resources. Hence, the effects of technological, social, legal and ownership barriers are expected to be isolated from resource-based effects on product properties.

Second, Fab Labs were chosen as an empirical field due to the need for a set of 100% innovating users where the majority successfully realizes their innovation implementation. Without successfully implemented prototypes, the measurement of product properties would reveal difficulties. In Fab Labs, all users are innovating or at least tinkering often on household appliances and many users innovate successfully and finalize prototypes, at the very least for personal use. Even in user innovation literature Fab Labs and makerspaces are seen as a clear promoter of user innovations (Svensson and Hartmann, 2018). In addition, the self-selection bias should be minimized by examining an empirical field where all users potentially could take part. Since Fab Labs spread all around the world and are open to anybody to create or modify things, Fab Labs' population is expected to represent the community of user innovators in a representative way.

After a pre-study among Fab Lab members, data was collected via online questionnaire in 2015. For the inquiry, data was obtained from the official list of Fab Labs provided by the Fab Foundation and the International Fab Lab Association (Fab Foundation, 2016; International Fab Lab Association, 2016). The list included data from 66 countries, from which 46 countries have been chosen randomly for a deeper search for Fab Lab contact data. In addition to contact data, provided by official databases, Fab Labs were identified via search in social media (facebook, XING and LinkedIn), online encyclopedias (i.e. different Wikis) and search engines (e.g. Google). The questionnaire for the quantitative study was subdivided into six sections: (1) product properties, (2) barriers in conceptualization phase, (3) barriers in prototyping phase, (4) innovator properties and control variables covering (5) personal and (6) resource variables. Primarily, the questionnaire aimed to collect data for confirmatory regression analyses testing the empirical model. In addition, the questionnaire aimed to collect data to conduct robustness tests.

3.2 Measurement

The number of observations, means and variances of the variables are shown in Table 1 and correlations are shown in Table 2.

Table 1: Sample descriptives

Variable	Obs	Mean	Variance	Minimum	Maximum
Technological barriers - Concept.	116	4.07	1.13	1.00	6.33
Social barriers - Concept.	116	2.86	1.51	1.00	6.50
Legal barriers - Concept.	116	2.81	1.53	1.00	6.33
Ownership barriers - Concept.	116	2.85	1.90	1.00	6.00
Technological barriers - Prot.	116	4.18	1.32	1.00	7.00
Social barriers - Prot.	116	2.59	1.49	1.00	6.00
Legal barriers - Prot.	116	3.00	1.77	1.00	6.67
Ownership barriers - Prot.	116	2.88	2.14	1.00	7.00
Lead userness	116	5.08	0.45	3.25	7.00
Openness	116	5.76	0.54	3.50	7.00
Perceived complexity	103	3.04	2.10	1.00	7.00

Table 2: Correlations

Construct	TB[a]	SB[a]	LB[a]	OB[a]	TB[b]	SB[b]	LB[b]	OB[b]	LU	OP	PC
Technological barriers - Concept.	**.754**										
Social barriers - Concept.	.295	**.880**									
Legal barriers - Concept.	.169	.726	**.888**								
Ownership barriers - Concept.	.165	.544	.636	**n.a.**							
Technological barriers - Prot.	.653	.284	.340	.287	**.833**						
Social barriers - Prot.	.301	.757	.777	.539	.404	**.872**					
Legal barriers - Prot.	.144	.548	.825	.600	.364	.685	**.919**				
Ownership barriers - Prot.	.146	.559	.730	.744	.347	.625	.864	**n.a.**			
Lead userness	.174	-.122	-.048	-.037	.275	-.040	-.024	-.096	**.734**		
Openness	.151	-.143	-.164	-.026	.099	-.166	-.057	-.072	.347	**.714**	
Perceived complexity	.278	.398	.395	.264	.255	.521	.233	.266	-.103	-.137	**.764**

Note: Square roots of AVEs are in bold letters; [a] conceptualization phase; [b] prototyping phase

3.2.1 Dependent variables

The user innovation outcome is described by the variable perceived complexity. The construct perceived complexity describes how far a user of a certain product has the impression that the use of this product is complex to understand or to use. Perceived complexity is operationalized in a modified version based on Schreier et al. (2007). The original construct measures how far the user himself perceives the product as complex. Since in this study, users are rating their own development and not foreign products, it can be assumed that this construct would produce low mean values and low variances. Thus, in this study, the user had to rate the product in terms of complexity for other users. Perceived complexity was measured on a 7-point Likert scale ("1 - strongly disagree"; "2 - disagree"; "3 - disagree somewhat"; "4 - neutral"; "5 - agree somewhat"; "6 - agree"; "7 - strongly agree"). Three items measure perceived complexity be asking the user to indicate how strongly the respondent agrees with statements, if [PC1] getting used to the innovation would require major learning effort for other users, if [PC2] getting used to the innovation would take a long time before other users could fully understand the advantages, and if [PC3] the product concept of the innovation is difficult for other users to evaluate and understand. Factor analysis confirms the operationalization with factor loadings ranging from 0.837 to 0.931 and a Cronbach's Alpha of 0.843.

3.2.2 Independent variables

Users face barriers in their user innovation process. The literature study and a set of pre-interviews among lead users covering this subject, led to four different groups of barriers. All barrier types in quantitative study were measured reflectively on 7-point Likert scales ("1 - strongly disagree"; "2 - disagree"; "3 - disagree somewhat"; "4 - neutral"; "5 - agree somewhat"; "6 - agree"; "7 - strongly agree") including constructs containing up to three items. Furthermore, the barriers were measured per development phase, including the conceptualization phase and the prototyping phase.

The variable technological barriers thus describes how far the user felt influenced by [TB1] problems such as: availability or maturity of technologies or components, [TB2] durability, compatibility or mechanical / electronic problems as well as [TB3] problems including overly complex or extensive material processing. Factor analysis confirms the operationalization by three items with factor loadings ranging from 0.718 to 0.861 and a Cronbach's Alpha of 0.621 (conceptualization) and 0.780 (prototyping). The variable social barriers describes how far the user felt influenced by [SB1] third-party skepticism, societal pressure or stigmatizations or [SB2] fear of idea theft or plagiarism. Factor analysis confirms the operationalization by three items with factor loadings ranging from 0.872 to 0.880 and a Cronbach's Alpha of 0.708

(conceptualization) and 0.685 (prototyping). The variable legal barriers describes how far the user felt influenced by: [LB1] legal requirements, liability laws or laws limiting tinkering, [LB2] warranties or guarantee rights for the product or components the user modifies, and [LB3] patents, copyrights or secure codes. Factor analysis confirms the operationalization by three items with factor loadings ranging from 0.878 to 0.921 and a Cronbach's Alpha of 0.8661 (conceptualization) and 0.908 (prototyping). The variable ownership barriers measures in how far the user felt influenced by [OB1] missing ownership for the product or components a user modifies. Due to the measurement as a single item construct, no factor analysis has been conducted in this case.

3.2.3 Moderating variables

The direct effects of barriers on the user innovation outcome are hypothesized as being moderated by the personal traits of lead userness and openness (Baron and Kenny, 1986). All moderating variables were measured reflectively on 7-point Likert scales ("1 - strongly disagree"; "2 - disagree"; "3 - disagree somewhat"; "4 - neutral"; "5 - agree somewhat"; "6 - agree"; "7 - strongly agree"). Lead userness measures the extent to which a user is [AOT] ahead of the trend and may expect [HBE] high benefits if the user would conduct innovative activities in order to develop own products for personal use (von Hippel, 1986). The construct lead userness is measured reflectively by nine items [three for AOT and six for HBE]. The nine indicators are

Table 3: Measures

Construct	Code	Item
Technological barriers	TB1	I was influenced by problems covering the availability or maturity of technologies or components
	TB2	I was influenced by problems covering the durability, compatibility or mechanical / electronic problems
	TB3	I was influenced by problems covering too complex or extensive material processing
Social barriers	SOC1	I was influenced by third-party skepticism, societal pressure or stigmatizations
	SOC2	I was influenced by the fear of idea theft or plagiarism
Legal barriers	LB1	I was influenced by problems covering legal requirements, liability laws or laws limiting tinkering
	LB2	I was influenced by problems covering warranties or guarantee rights for the product or components I modify
	LB3	I was influenced by problems covering patents, copyrights or secure codes
Ownership barriers	OB1	I was influenced by missing ownership for the product or components I modify
Lead userness	AOT1	I usually find out about new technical products and solutions earlier than others
	AOT2	I have benefited significantly by the early adoption and use of new technical products
	AOT3	In my community I am regarded as being on the "cutting edge" with regard to technical products
	HBE1	I am often confronted with problems that cannot be solved by technical products available on the market
	HBE2	I am dissatisfied with some pieces of commercially available technical products
	HBE3	In the past, I have had problems with my technical products that could not be solved with manufacturers' conventional offerings
	HBE4	In my opinion, there are still unresolved problems with regards to technical products
	HBE5	I have needs related to technical products that are not covered by the products currently offered on the market
	HBE6	I often get irritated by the lack of sophistication amongst technical products
Openness	OP5	I see myself as somebody who has few artistic interests (*reverse item*)
	OP10	I see myself as somebody who has an active imagination
Perceived complexity	PC1	Getting used to the innovation would require major learning effort for other users
	PC2	Getting used to the innovation would take a long time before other users could fully understand the advantages
	PC3	The product concept of the innovation is difficult for other users to evaluate and understand

modified according to the characteristics of the empirical field and based on the studies of Schweisfurth and Raasch (2015), Franke and Shah (2003) and Franke et al. (2006). Factor analysis confirms the operationalization by revealing two factors with factor loadings ranging from 0.531 to 0.852 (AOT) respectively 0.661 to 0.845 (HBE) and a Cronbach's Alpha of 0.803.

Openness is a personal trait of the "Big Five" inventory (Rammstedt and John, 2007). Openness describes the creativity of a user in terms of imaginative power, phantasy and artistic interests. Openness is seen as a driver of innovative activities (George and Zhou, 2001) and measured by the short version construct of the big-five inventory-10 (Rammstedt and John, 2007). The variable is measured reflectively by asking the respondent how far the user sees himself as somebody who has [OP5] few artistic interests and who has [OP10] active imagination. First item is reversed-scored in order to assess inconsistencies in users' response behavior. Factor analysis confirms the operationalization with factor loadings ranging of 0.845 and a Cronbach's Alpha of 0.583. Independent, dependent and moderating measures are depicted in Table 3.

3.2.4 Control variables

The regression model includes gender and age as control measures. Before the original statistical analyses, robustness checks have been applied in control for differences between early and late respondents, differences due to resources with regard to financial, time-related, collaborative resources and structural resources, differences due to nationalities and differences among Fab Labs.

4 Findings

4.1 Direct effects

The regression analyses for the impact on perceived complexity were conducted in two models (Model 1 and Model 2). Each model was calculated in three steps (see Table 4) in order to assess the overall models' significance, indicating if additional variables add a significant R^2-value to the subsequent step. The base model in step 1 includes control variables, step two added the independent and step three the moderating variables. In all models (Model 1 and 2), the control variables explained only 0.9% of the overall models' variance. That indicates that gender and age show no significant influence on the product properties. Adding independent and moderating variable in step 2 and 3 then raised the adjusted R^2-values significantly.

The analyses show well-adjusted R^2 values with R^2=0.218 in compete Model 1 and R^2=0.259 in complete Model 2. Control variables do not significantly influence the results. The independent variable, technological barriers in conceptualization phase, shows slightly significant positive effects on $p>0.1$ level with an effect size of b=0.255. Technological barriers increase perceived complexity in the first development stage. This effect cannot be observed in prototyping phase. Social barriers show an inverted pattern. The statistical analysis cannot indicate direct significant effects for social barriers in conceptualization. However, the significant moderator effect of openness leads to the assumption that a relationship may be confirmed for certain regions of significance. Instead, this relationship shows strong and significant positive effects for the prototyping phase. The effect size for social barrier is b=0.687 on a significance level of $p<0.01$. The occurrence of legal barriers in conceptualization does not significantly affect the dependent variable. However, the significant moderator effect of openness shows that a relationship can be confirmed for regions of significance. In contrast, legal barriers are significantly ($p<0.5$) negatively related to perceived complexity, showing strong effects with b=-0.460.

Table 4: Stepwise OLS regressions

Dependent variable	**Model 1 - Concept. Perceived complexity**		**Model 1 - Concept. Perceived complexity**		**Model 1 - Concept. Perceived complexity**		**Model 2 - Prot. Perceived complexity**		**Model 2 - Prot. Perceived complexity**		**Model 2 - Prot. Perceived complexity**	
	b	SE	b	SE	b	SE	b	SE	b	SE	b	SE
Constant	4.734***	(1.092)	3.744*	(1.536)	4.513*	(1.606)	4.734***	(1.092)	3.266*	(1.447)	3.042*	(1.525)
Gender	-0.836†	(0.494)	-0.645	(0.482)	-0.518	(0.518)	-0.836†	(0.494)	-0.517	(0.438)	-0.232	(0.539)
Age	-0.003	(0.013)	-0.008	(0.012)	-0.017	(0.014)	-0.003	(0.013)	-0.002	(0.011)	-0.010	(0.012)
Independent variable												
Technological barriers			0.289*	(0.125)	0.255†	(0.129)			0.137	(0.118)	0.120	(0.131)
Social barriers			0.190	(0.158)	0.212	(0.172)			0.697***	(0.136)	0.687**	(0.207)
Legal barriers			0.261	(0.164)	0.220	(0.187)			-0.396*	(0.188)	-0.460*	(0.231)
Ownership barriers			-0.053	(0.123)	-0.068	(0.131)			0.141	(0.161)	0.216	(0.186)
Lead userness			-0.173	(0.198)	-0.138	(0.201)			-0.190	(0.193)	-0.130	(0.206)
Openness			-0.104	(0.185)	-0.206	(0.193)			-0.011	(0.172)	-0.057	(0.196)
Moderating variable												
Lead userness x TB					0.027	(0.125)					0.133	(0.130)
Lead userness x SB					-0.286	(0.194)					-0.011	(0.199)
Lead userness x LB					0.258	(0.158)					0.171	(0.259)
Lead userness x OB					-0.016	(0.158)					-0.197	(0.228)
Openness x TB					-0.107	(0.117)					-0.097	(0.128)
Openness x SB					0.471*	(0.208)					-0.117	(0.196)
Openness x LB					-0.628**	(0.235)					-0.146	(0.307)
Openness x OB					0.054	(0.168)					0.085	(0.303)
Model fit												
R^2	0.028		0.249		0.341		0.028		0.333		0.376	
Adjusted R^2	0.009		0.185		0.218		0.009		0.276		0.259	
df	102		102		102		102		102		102	
F-value	1.454		3.897		2.779		1.454		5.857		3.232	
p-value	0.238		0.001		0.001		0.238		0.000		0.000	

Notes: n=102; b-values are un-standardized; all models are linear regressions; interaction variables are z-transformed; statistical significance †p<0.1, *p<0.05, **p<0.01, ***p<0.001

Ownership barriers show no significant effects at all in both phases on perceived complexity. In addition, lead userness and openness show negative but non-significant (p<0.1) direct effects on perceived complexity in both phases.

4.2 Moderating effects

The regression models include moderating variables as well. The assumption was that personal characteristics such as lead userness and openness increase or decrease the impact of barriers on the user innovation outcome. As mentioned above, the analyses reveal such pattern in two cases for the moderating variable openness. Firstly, openness has a significant and strong positive impact (p<0.5) on the relationship between social barriers and perceived complexity in the conceptualization phase with an effect size of b=0.471. Thus, users with higher openness, in combination with the appearance of social barriers, create user innovations with higher perceived complexity than users with lower openness. Second, openness moderates significantly (p<0.01) and negatively the relationship between legal barriers and perceived complexity in the same phase with an effect size of b=-0.628. This effect is strong and shows that the more open an innovative user is, the less complex the solution will be when the user is affected by legal barriers. In the prototyping phase, no significant relationships can be shown by the analysis. However, the effect sizes show the same pattern of decreasing complexity when openness affects the relationships between technological, social and legal barriers on one side and the depending variable on the other.

In detail, openness has a positive effect on the relationship between social barriers and perceived complexity at the conceptualization stage. Slope analysis (Figure 1) shows a more differentiated result. There is a strong positive and significant effect of barriers for high openness (b=0.6190; p<0.05). For medium openness, the effect of barriers is smaller and not significant (b=0.2117; n.s.) while there is a negative and non-significant effect for low openness (b=-0.1954; n.s.). Thus, users with high openness are more strongly affected by social barriers in conceptualization than users with medium or high openness.

Regression Model 1 further shows that openness has a negative effect on the relationship between legal barriers and perceived complexity at the conceptualization stage. Slope analysis (Figure 2) shows a more differentiated result. There is a strong positive

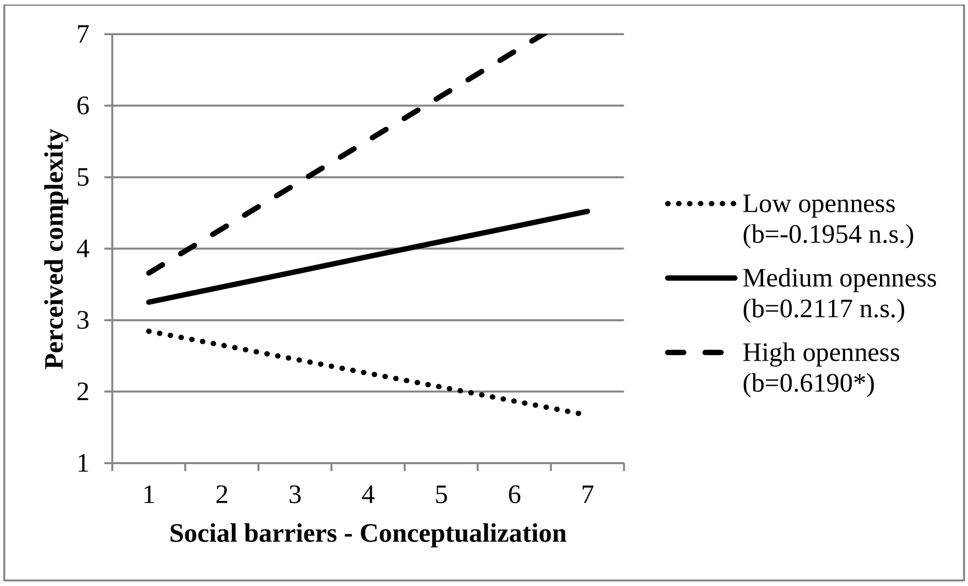

Figure 1: Slopes openness and social barriers

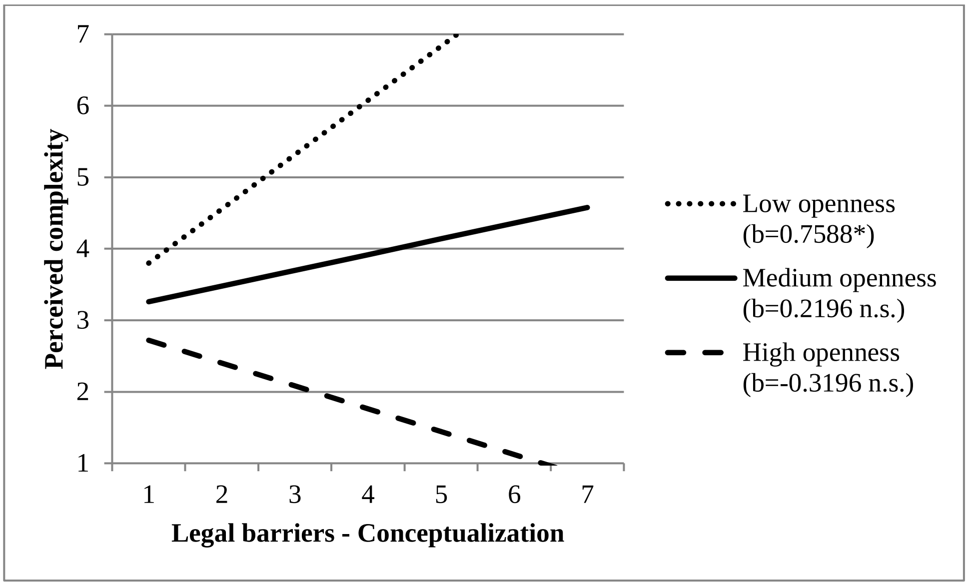

Figure 2: Slopes for openness and legal barriers

and significant effect of barriers for low openness (b=0.7588; p<0.05). For medium openness, the effect of barriers is smaller and not significant (b=0.2196; n.s.) while there is a negative and non-significant effect for high openness (b=-0.3196; n.s.). Thus, users with low openness are more strongly affected by legal barriers in conceptualization than users with medium or high openness.

5 Discussion

5.1 The influence of barriers

When analyzing the technological barriers' impact on perceived complexity on a detailed level, the impact in the conceptualization phase shows slightly significant positive effects while this effect cannot be observed in prototyping phase. In conceptualization, users have technological (design or manufacturing) problems but also have the degrees of freedom and flexibility to change the design and react on this barrier's impact. Thus, they follow the strategy to implement changes in product architecture in order to come to a solution. In prototyping, the effect cannot be confirmed. Thus, an explanation of raising innovation costs for design changes in later development stages completely applies for this case (Kerga et al., 2016; Smith, 2007). When technological barriers arise in prototyping, the users have already begun to build, and minor changes in the framework of the innovation are possible. The users convert technological problems into a challenge they want to accomplish and are willing to put in more effort. Thus, technological barriers are neither killer nor insurmountable barriers. Nevertheless, the technological problems in general may lead to an iterative development process enabling the user to develop superior solutions than initially intended.

Instead, for social barriers, the analyses cannot indicate isolated direct significant effects in conceptualization. However, in interaction with a moderating variable, regions of significance have been identified. Moreover, for the prototyping phase, strong and significant positive effects have been found. Thus, the influence of social barriers is prevalent along the complete user innovation process and stronger in the prototyping phase. Why social barriers predominantly influence in the later process stages may be explained in following way: Social barriers such as skepticism impact as a requirement builder in the conceptualization phase, while external stigmatization takes place mainly in prototyping as others physically see what the lead user is tinkering on. When users plan their innovation project, they are often presenting their ideas to their personal environment. Here, the users sometimes either face skepticism or are delighted with more or less constructive ideas from a third party. Depending on the level of personal ties to these persons, the influence will be comprehended as strong or weak. The assumption is that strong ties on an individual level such as close relatives influence the innovator more than weak ties like nodding acquaintances (Cross and Cummings, 2004; Levin and Cross, 2004). However, weak ties may also have influences on the innovator, like a transfer of the assumptions of the theory of strength of weak ties, which applies on network rather than on individual level (Friedkin, 1980; Granovetter, 1973; Levin and Cross, 2004; Perry-Smith and Shalley Christina E., 2003). Taken together, when users feel influenced by third-parties and think that hints or objections are somehow reasonable, the users will take the influences into account when conceptualizing their project.

Also for legal barriers the analyses cannot indicate isolated direct significant effects in conceptualization. However, in interaction with a moderating variable, regions of significance have been identified where legal barriers influence positively. Moreover, significant negative effects have been found for the prototyping phase. Thus, the influence of legal barriers is prevalent along the complete user innovation process and stronger for the prototyping phase. Legal barriers in conceptualization increase the complexity, but in prototyping legal barriers have the effect that the innovating user generates a less complex product. Legal barriers derive from an external institution. In the case of legal barriers, the institutions who put pressure on the user innovators potentially have the legislative power of forcing the innovators to follow their demurs. Institutions such as state authorities, legal firms, or companies have the power to penalize the innovators for their tinkering. The users seem to consider legal problems when conceptualizing their innovation. In this phase, they are following alternative ways to develop the innovation before they start to tinker physically. In line with these ways, the users include other features or use different products and components where these problems are less invasive. Subsequently, the innovators come to a solution but more complex than initially intended.

For the prototyping phase, the analysis shows a different pattern. The users have already decided on a product or system they would like to tinker. They have already invested effort, time and money in order to develop a solution. When in this case legal problems come up, the users change their innovation strategy. The users are not able to switch to other systems or simply keep on developing. From economic theory, it is commonly known that switching costs, which are part of the theory of transaction costs, are high if standards or products are already existing on the market (Burnham et al., 2003; Williamson, 1983). This may also be a factor in user innovation. When legal problems are, for instance, related to warranties or guarantee rights and the user regards this as a problem, the user intends to use this system or product for a longer time period. In Smart Home environment, for instance the innovators refrain from tinkering invasively on expensive household machines in order not to destroy them. Otherwise, they would have lost their guarantee right to replace the machine or to claim for potential damage compensations. Hence, the users wind down the activities on the product and restricts to the minimum of necessary improvement actions. In line with that a less complex solution would be the result of the user innovation process. Thus, legal barriers in both phases do not lead to project abortion but do strongly influence user innovation properties especially when users have already started to implement.

Legal barriers are related to ownership barriers but ownership shows no influence in this study. It is conceivable that ignoring ownership problems is common practice. User innovators know very early in their development that they could be met by ownership barriers, and take into account that they would have to override the tenures of others. This relates to the research stream in user innovation, which examines so-called "outlaw innovation". Hackers, for instance, conduct very innovative activities in the field of software development, or for specific IT problems. Nevertheless, they are acting above the limit of allowance and thus in an illegal environment (Flowers, 2008). Here, the "innovators" are aware of third-party ownership, stick to their development plan and do not alter the properties of their result due to ownership restrictions. Users have strategies in mind of how to overcome these barriers when stepping into the phase of physical development. Thus, the share of users ignoring this barrier may be decreasing in later process stages as well as the share of users who abandon the project.

5.2 The influence of personal characteristics

Moderating effects of openness have been found in the conceptualization phase for the relationship between social barriers and perceived complexity (positive moderating effect) as well as for the relationship between legal barriers and user innovation outcome (negative moderating effect). That openness moderates the relationship between social barriers and perceived complexity positively; openness reinforces the barriers' impact. The stronger social barriers influence users in conceptualization, the more complex the outcome. In addition, the more open users are the more complex the solution will be in turn. Hence, a very open user is particularly vulnerable to external influences. These results are in line with theory where people with high openness, positively expressed, are characterized as people who have greater perspectives, who are more adaptable to altering circumstances and who have a greater access to ideas. Those open people in corporate environments have more appreciation of new working methods, improvements, or changes of status quo (George and Zhou, 2001). This also matches with findings from user innovation research where users scoring higher on openness are significantly more likely generate innovation ideas (Stock et al., 2016). The moderator analysis revealed that the direct effect of social barriers is only significant for certain levels of high openness. This finding also supports the theoretical explanations. Users do not have to indulge social barriers because social barriers may not threaten the innovation success as severe as technological barriers would do. On the one hand, low ratios for openness may prevent the users to be open for helping ideas and to overcome social barriers. On the other hand, people with low openness ratios are regarded as more conservative, conventional and rather liking ideas, they are more familiar with.

Openness also moderates the relationship between legal barriers and perceived complexity negatively, that means that openness remedies the barriers' impact. Legal barriers influence perceived complexity in conceptualization also positively like social barriers. Thus, the stronger legal barriers influence users in conceptualization the more complex will be the outcome. In addition, the more open users are, the less they are influenced by these barriers, leading to a less complex solution. Hence, a user with higher openness ratios finds ways to overcome legal barriers without increasing the complexity too much and without deviating too far from his initial innovation idea. In extreme cases, very high openness measures lead to insignificance of legal barriers influence and hence, remedies the effect completely. These findings support theory as well. The lead users have an objective what they want to develop and plan very detailed in the conceptualization phase. If then legal problems arise, non-open users may follow conservative strategies to overcome barriers. They somehow may develop bad solutions without adding user value to their product. The product becomes more complex in a negative way, but at the very least delivers a viable solution.

The question of why lead userness also shows no influence moderating on the barriers, can be answered by the fact that this study is not a study comparing lead users and non-lead users. It is a study among lead users with the aim to study in how far lead users and their product development are affected by user innovation barriers. Thus, the mean value of lead userness in the sample is 5.08 on a scale of seven points. When the mean value of lead userness is quite high, the variance quite low and even the minimum value at 3.25, a distinction between lead userness levels is problematic while it indicates that the grand majority of this study's participants could be labeled as lead users. Thus, it was not possible to find statistically significant influences of lead userness.

Further, explanation may be that users who are affected by barriers have to find new approaches, they potentially have to delve into legal topics, and they have to know how to defend themselves from social influence. Thus, innovating users have to be experts in many fields of application and have to be open for external ideas, new information and suggestions. These characteristics are more pictured by the openness construct and less by the lead userness construct. Lead userness measures ahead of the trend and high expected benefits. These are surely related to technical perspectives. However, these two groups of items in turn do not postulate that a lead user is an expert who can easily overcome technical problems. That is why some lead user studies flank the measurement of lead userness by surveying constructs such as technical expertise or use experience (Bogers et al., 2010; Dahlin et al., 2004; Lüthje, 2004; Tietze et al., 2015). Additionally, the construct openness incorporates at least the possibility that a user searches for external help if barriers negatively impact the user innovation project. Searching for external help and somehow applying open innovation methods is also valuable for lead users on the individual level.

5.3 Contribution

This study confirms openness as a personal trait influencing user innovation and furthermore, introduces openness as a direct and moderating personal trait to overcome user innovation barriers. Comprised with the differentiated analysis for conceptualization and prototyping phase, the study enriches user innovation theory with a better understanding and predictability of the user innovation process. The study adds another perspective as to how shortcomings in the process of innovation users may affect user innovation outcome and thus, the possibility to integrate lead users. Beyond contributing constraints and shortcomings to this debate, this study also provides strategies for overcoming these barriers.

It is very useful to include lead users showing high openness ratios. For sure, "ordinary lead users" deliver high-class contributions in lead user projects. However, companies willing to integrate lead users not only develop for long-term projects but also for projects with a medium time-period. Ordinary lead users, even in the household sector, may be too ahead of the trend to generate ideas for the customers of tomorrow and not the customers of the day after tomorrow. Here, lead users with a higher openness may help to take the perspective of other customers into account. The ideas by those users are supposed to provide more user value also for other non-lead users. Additionally, more open lead users may also be open for the perspectives or requirements of the company they are innovating with. It is known from research that firms also try to recruit lead users inside the boundaries of their firm. These so-called embedded lead users take company interests or the corporate abilities more strongly into account than external lead users (Pieper et al., 2014; Schweisfurth and Herstatt, 2014; Schweisfurth and Raasch, 2015). This fact supports the assumption that lead users considering foreign needs are sought after by companies, and thus shows the relevance of these findings.

When companies (in addition to other institutions such as universities, politics etc.) try to support innovating users in their activities, the question arises as to which would be the right way to do so in order to ensure project success. Support has to ensure that users are equipped with enough money in order to acquire materials, components, tools, or to buy or rent machines. In this optimal case, the users could fully concentrate on the challenges of physical product development and not on the acquisition of money for this. Lead users need space and workshops where they are able to tinker, to implement and to discuss their ideas with others. Fab Labs and makerspaces made the first step and grew increasingly thereon. Firms should also follow this direction and support such spaces or go beyond a pure sponsoring and build up own workshops. These workshops could be dedicated to the co-workers or, in an ideal case, be also open to externals willing to collaborate with the company. In addition, firms and institutions can also support in order to overcome technological, social, legal and ownership barriers. Generally spoken, externals should not intervene too strongly in lead users tinkering, because this study shows that they are able to overcome barriers by themselves. With regard to technological problems, technical help for tinkering users will most definitely be welcome. For social barriers, it is important not to address the innovating users with too many wishes and requirements, but to build up an environment where they can develop without the fear of idea theft or plagiarism. Legal barriers should be remedied by helping to get permission to change the properties of products and to use restricted components. Taken together, firms and Fab Labs should shift from providing "pure" collaborative workshops to building up "user innovation incubators".

5.4 Limitations and future research

The generalizability could be limited to the special characteristics of the empirical fields. Lead users today are active in many business sectors from flood resilience over sporting equipment up to airplane industry (Goeldner et al., 2017). These sectors differ strongly with regard to regulations, motives, stakeholders, products and so on. Thus, it is conceivable that not all results are transferable to other sectors or product groups. When focusing on the analytical methods, limitations are possible as well. More than 100 respondents were included in the analysis but to provide more reliable results, a larger sample size would have been favorable. In this case, additional robustness checks and deeper analyses would have been possible. Further, the interpretation of the results is biased due to missing follow-up interviews. The results of the regression thus were partly mirrored with the interview data or with researcher's knowledge from other lead user contacts and projects. However, also in this case, desirable results could have been over-interpreted while undesirable results may have been subconsciously ignored. Despite these shortcomings, there is confidence that the results in general are reliable and valid. The effects are stable over many different analyses along different process stages and have been checked repeatedly in an iterative approach.

The study opens room for a broad variety of future research. Firstly, the role of workspaces, makerspaces and Fab Labs in supporting users in development is a promising field for user innovation studies in the future. Additionally, the fact that universities host many Fab Labs and makerspaces invites in-depth and longitudinal user innovation studies. This links to the suggestion of follow-up interviews in order to assess and further directly develop the results of prevalent study. New approaches for the interpretation of effects or the confirmation of the theoretical discussion's explanations would be very valuable. There are still numerous unanswered questions in this field. The question is, if there are other unexplored barriers in the field, or if there are further personal traits, which fit better to remedy negative barrier effects. Another question is how other dependent and user innovation related variables are affected by barriers and constraints.

The process of user innovation and the influence of barriers has to be analyzed much more granularly and not only based in two development phases. Additionally, it is not clear which barriers come up when lead users and firms are in a direct and fixed collaboration while the corporate and user innovation barriers are interacting. The field of absent ownership is a broad field related to user innovation barriers. The rise of sharing communities leads to more and more situations where users would like to tinker, but are not allowed. How do user innovation strategies in this field evolve? When do users develop permanent and temporary innovations? These are questions which should be answered, as well as the question of how trust in innovation networks evolve when ownership and control is separated between different parties.

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