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Are Patients and Relatives the Better Innovators? The Case of Medical Smartphone Applications

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Abstract

Prior research has shown that users are a valuable resource for identifying new product or service innovations. However, few scholars have analyzed how different user types such as intermediate and end users are interacting along the value chain of an emerging new product and how they contribute to innovation. Further, user innovation success in the market is often unclear, since very few innovations diffuse directly to customers from the user innovators. We analyze different innovative contributions of intermediate and end users that have been sold and evaluated within the healthcare sector.

Several studies in the healthcare sector have shown that healthcare professionals are an important source of innovation. Yet, to date, companies and scholars have paid little attention to the end users of medical devices: patients. We focus on the innovative behavior of patients and their relatives, their motivations, and their contributions to improving the quality of their own and ultimately of other patients' therapy. We analyze innovations of producers, healthcare professionals, patients, and relatives in the German, UK, and U.S. markets for medical smartphone apps (Apple App Store) and conduct 16 semi-structured interviews.

Our findings show that users develop around 46% of all medical smartphone applications (apps). We analyzed 510,229 user ratings and found that apps designed by patients, relatives, and healthcare professionals are rated significantly better by App Store customers than apps created by professional software companies. Apps developed by patients' relatives achieve significantly more downloads and generate on average three times higher revenues per year. The initial medical smartphone app developments in the early days of the Apple App Store were mainly triggered by healthcare professionals. The interview data shows the extensive medical knowledge of patients and their relatives, particularly those with chronic diseases.

The overall findings are in line with a current literature stream that indicates that patients are gaining more influence on their treatment, are better informed, and are taking more actions to increase their quality of life. Commercial healthcare companies should take advantage of this and should consider including patients and relatives into their product development.

Keywords: User innovation, patient, relative, healthcare professional, m-health, medical, smartphone applications, app, apps

1 Introduction

Using external knowledge in a company's innovation process is a widely established approach to identifying new product or service concepts today (West and Bogers 2014; Salge et al. 2013). Firms are inviting users to actively contribute their knowledge to leverage their R&D efforts (von Hippel 1988). Prior research has shown that healthcare professionals, i.e. people who provide health-related products/services, are a primary source of innovation (Lettl et al. 2006; Lüthje and Herstatt 2004). However, to date, very little is known about innovative patients, i.e. people who receive health-related treatments as well as products. This very large group of users has largely been excluded from innovation by scholars and companies. Yet, it seems promising and valuable to integrate patients and their relatives into companies' product development: Patients are highly intrinsically motivated to innovate, and often have complementary knowledge to that of a healthcare professional about certain aspects of their disease (Elberse et al. 2011; Wilson 1999).

We focus on the innovative behavior of patients and relatives, their motivations, and their contributions to improving the quality of their own and ultimately of other patients' therapy. We compare innovations of patients and relatives with innovations of healthcare professionals and companies with two complementary datasets: First, we use publicly available data to detect and evaluate a large user innovations set. Second, we use interview data obtained from 16 interviews with innovative patients, relatives, and healthcare professionals. As an empirical field, we chose the medical smartphone applications (apps) market. Thus, we analyze innovations that are already diffused to the App Store and that are available to millions of potential customers. These customers download and rate medical apps with very limited knowledge about the origin (user innovator vs. professional software developer) and therefore have unbiased opinions, which we will evaluate. Our dataset consists of 510,229 user ratings and download numbers of 1,233 smartphone apps developed by 878 developers. Thus, we not only analyze the inventions, but also their exploitation (cf. Roberts 2007) in the market.

We have two major findings: First, we show real-world data on user innovations that are available in the marketplace. In the medical smartphone apps market, users account for 46.5% of all developers. These apps account for 43.8% of total yearly revenues. The largest subgroup is healthcare professionals, followed by patients, healthcare associations, and relatives. The remaining 53.5% of non-users were professional software companies and independent developers. The quality (operationalized by user ratings) of user-developed apps is significantly higher than that of non-users-developed apps. User seem to understand the market needs better as this *sticky* knowledge (von Hippel 1998) is difficult to transfer to professional developers. Download numbers and revenues of apps designed by professional developers are slightly higher, indicating a somewhat higher market penetration by those apps. One reason for this are average lower prices of producer-developed apps as those are often co-financed by established manufacturers of medical devices. However, for paid apps, patients' relatives receive significantly more downloads and create on average three times higher revenues.

Second, our study shows the emergence of a new industry sector – medical smartphone apps – since the opening of the App Store in 2008. We see that early innovations were developed mostly by healthcare professionals, subsequently followed by professional developers. Established manufacturers rather fear new and uncertain markets and waited until users pioneered with first apps. Contradicting extant literature, we find that increasing numbers of user-developers, particularly patients and relatives, have recently entered the market for medical smartphone apps. We show, for the two subsamples diabetes and hypertension management, that patients and relatives account for more than 33% of all newly released apps in 2013. Our interview data suggests that most entered the market with a differentiation strategy after the basic functionalities had been developed – for instance by introducing gamification, an app for a specific target group, or a peculiar design.

In net, we find that patients and relatives often discover needs during their daily routines associated with a disease earlier than professional developers of medical smartphone apps. Thus, the dual knowledge of needs and solutions knowledge might be one reason for the significantly superior quality of apps developed by patients and relatives compared to companies. Particularly relatives develop apps that are also commercially more successful than those developed by companies.

Our paper contributes to user innovation theory and practice: While preceding studies in user innovation literature analyzed small samples of user-generated ideas or concepts, we analyzed a large real-world sample of user innovations that already diffused to the marketplace. Thus, we not only examine the current state, but also the emergence of medical smartphone apps after the App Store opened. To remain competitive, professional developers should carefully analyze the medical smartphone apps market and should include patients and relatives into their innovation activities. Users might be particularly beneficial in new and emerging fields, as producers are afraid of pioneering in those markets.

The remainder of this paper is structured as follows: In Section 2, we discuss the study's theoretical background and derive our research questions. In Section 3, we outline methodology and the dataset. In Section 4, we present the empirical findings and, in Section 5, we discuss these findings and propose implications for further research and practice.

2 Theoretical background and research questions

2.1 User innovation, user groups, and diffusion

As von Hippel (2009) notes, users are firms or individual consumers that expect to benefit from using a product or a service. In contrast, manufacturers expect to benefit from selling a product or a service. User innovators are users who innovate in relation to their own needs (Baldwin and von Hippel 2011). The lead user method is a proven approach to identify user innovators (von Hippel 1986). Lead users are users with two primary characteristics: They face needs that become general in the marketplace earlier than other users, and they personally benefit considerably by solving this need (Herstatt and von Hippel 1992). There is a rich body of literature that indicates that user innovation is prevalent across a variety of industries such as sports (Hienerth et al. 2014; Tietze et al. 2015; Franke and Shah 2003), healthcare (Chatterji et al. 2008; Chatterji and Fabrizio 2007; Lettl et al. 2006; Lüthje and Herstatt 2004), scientific instruments (Riggs and von Hippel 1994; von Hippel 1976), banking (Oliveira and von Hippel 2011), software (von Krogh and von Hippel 2006; Franke and von Hippel 2003), within companies (Schweisfurth and Raasch 2014), and across different continents (von Hippel et al. 2011).

So far, scholars have mostly considered only single user groups. Yet, there are cases where intermediate users and end users were interacting along a product's value chain (Bogers et al. 2010). This is the case if a product is purchased by one party and then used by another party, or when the product is used in altered ways by different user groups. One example is medical devices that are purchased and prescribed or implanted by healthcare professionals (intermediate user) and then used by patients (end users) (Shah and Robinson 2008). User innovation might occur in all user groups. Generally speaking, a successful innovation requires two knowledge types: information about the problem (need knowledge) and about how to solve this problem (solution knowledge) (Schweisfurth and Herstatt 2016; von Hippel 1994). Different user groups possess different knowledge bases – end users have need knowledge and lack solution knowledge, while producers have solution knowledge and need to absorb external need knowledge (Block et al. 2016). Adams et al. (2013) argue that intermediate users are key players in innovation owing to their unique knowledge base. However, to date there have been no studies of the interactions between (several) intermediate users and the end users.

Studies that analyze the diffusion of user innovations show that users often reveal their innovations freely as they benefit from using the innovation rather than from selling it (Harhoff et al. 2003). Free revealing of user innovations has been shown in several industries, such as sports equipment (Franke and Shah 2003), library information systems (Morrison et al. 2000), semiconductor production (Harhoff et al. 2003), and open source software (Füller et al. 2013; Balka et al. 2010; von Hippel and von Krogh 2006). Not only user innovators, but also manufacturers might have reasons to reveal some – carefully selected – innovations freely (Henkel 2006). However, some user innovators might not want their innovations to be revealed freely, for instance, if they are seeking to commercialize their idea and to become an entrepreneur (Bogers and West 2012).

2.2 User innovation and user entrepreneurship

Most user innovators require professional help to commercialize and diffuse their innovations at some point, particularly if the innovation is not diffused freely peer-to-peer, but on a commercial level (Gambardella et al. 2014). In this case, the innovation is often licensed to an established producer already present in the market (de Jong et al. 2015).

User entrepreneurship literature has been extending user innovation theory by outlining the commercialization process of user innovators (Shah and Tripsas 2007). However, this young research stream is still limited to a few cases in a few industries. According to Shah and Tripsas (2007), enjoyment during the development and commercialization process as well as low opportunity costs have been identified as primary drivers of user entrepreneurship. In contrast to these propositions, we seek to extend user entrepreneurship theory by discussing the case of innovative patients and relatives – persons that develop medical devices according to their own or their relatives' needs.

Furthermore, very little is known about the ability of user-innovated products to compete with producer-innovated products in real-world settings, since it is difficult to obtain reliable quantitative data. In an experimental setting, user-generated ideas were rated to be superior concerning novelty and customer benefit and lower concerning feasibility (Poetz and Schreier 2012). Kristensson et al. (2004) found similar results: ideas developed by ordinary users were superior concerning originality and value compared to professional developers. Also for idea evaluation, users have been proven to be capable to screen ideas in conformity with professional experts (Magnusson et al. 2016). One of the few studies to show the market performance of user-generated designs was published by Nishikawa et al. (2013): User-generated designs (n = 6) were significantly more successful than professional-generated designs (n = 37) along financial parameters such as sales volume and profit margin. Yet, these designs were further developed, manufactured, and sold by an established company. To date, we do not have large-scale and real-world data of innovations that have been commercialized by user entrepreneurs.

2.3 User innovation in healthcare

The phenomenon of healthcare professionals as user innovators has to some extent been analyzed by prior research (Chatterji et al. 2008; Lettl 2007; Lettl et al. 2006; DeMonaco et al. 2006; Lüthje and Herstatt 2004; Shaw 1985). In his study, Lüthje (2003) found that 39% of surgeons were users with innovation ideas. Innovative surgeons are limited by conventional technologies and are thus motivated to look for more effective solutions (Lettl 2007). Additionally, physicians not only develop medical devices, but also (surgical) techniques that subsequently trigger product innovation (Hinsch et al. 2014). Companies can benefit from involving these users: By including healthcare professionals into their research, they gain insights into “user needs, experience & ideas, improvements in medical device designs and user interfaces” (Shah and Robinson 2007).

Although they are one primary user group of medical devices and services, patients and their relatives have to date mostly been neglected as a source of innovation by the academy and industry. Scholars have only recently identified the innovative potential of patients and relatives (Oliveira et al. 2015; Habicht et al. 2013; Bullinger et al. 2012). Regarding the shift to chronic diseases, patients are acting increasingly proactively and are becoming experts in their health issues. Habicht et al. (2013) argue that patients have a strong incentive to innovate, since they generally expect to benefit from using self-developed solutions. First findings indicate that patients mostly develop innovative behavioral patterns, treatments, and therapies, while only a small fraction of their innovations relates to medical devices (Oliveira et al. 2015). Analyzing medical device innovations, software innovations dominate, followed by hardware innovations, service innovations, and media innovations (Bullinger et al. 2012).

Our initiative is supported by current developments in healthcare: There is a shift from acute to chronic diseases that require long-term commitment from healthcare professionals towards their patients (Holman and Lorig 2004; Mascie-Taylor and Karim 2003). Furthermore, patients seek to increase quality of life and wellbeing, rather than to increase life expectancy (Steptoe et al. 2015). Patients are better informed, as they are increasingly using the Internet to learn about their diseases and to explore alternative treatments (Hartzband and Groopman 2010).

2.4 Empirical field: E-health, m-health, and medical smartphone apps

In a traditional patient-physician relationship, the patient is highly dependent on the information obtained by the healthcare professional. Assuming that physicians dominate medical encounters, Bodkin and Miaoulis (2007) describe physicians as gatekeepers of healthcare information. Several scholars have identified the emergence of the Internet to be a major factor in challenging these traditional roles (Hartzband and Groopman 2010; Mukherjee and McGinnis 2007).

Electronic healthcare (e-health) services can be defined as “health services and information delivered or enhanced through the internet” (Eysenbach 2001). Subsequent studies found evidence that the Internet has become a significant source of health information (Hartzband and Groopman 2010; Camacho et al. 2010; Khechine et al. 2008; Bodkin and Miaoulis 2007; Mukherjee and McGinnis 2007; Dickerson and Reinhart 2004). Today, patients actively use the Internet to get access to medical information and thus become informed patients that no longer only depend on their local healthcare providers (Budych et al. 2012; Camacho et al. 2010; Khechine et al. 2008). For health professionals, the Internet also serves as a significant source of information (Hartzband and Groopman 2010).

The mobile health services (m-health) trend is closely related to e-health and telemedicine. As stated by Istepanian et al. (2004), m-health "represents the evolution of e-health systems from traditional desktop 'telemedicine' platforms to wireless and mobile configurations". The continuously growing amount of smartphones has leveraged a wide range of new, app-based medical devices and services (Agu et al. 2013). This ecosystem allows non-professional developers to actively design solutions that correspond to their medical needs and to invite others to use these apps. As indicated by Terry (2010), utilization fields for medical smartphone apps are very diverse, ranging from patient communication, point-of-care documentation, and disease management to public health and ambulance services. Currently, about 48% of all available medical apps target chronic conditions (Research2Guidance 2015).

While there are several stores available for smartphone apps, the Google Play Store and Apple App Store offer by far the largest number of available apps. Our study considered only the Apple App Store. Developers are able to make their apps available at a small annual cost to a huge audience. The store owner offers toolkits (software development kits (SDK)) to their developers that facilitate user participation by creating an ecosystem for development (Franke and von Hippel 2003; von Hippel 2001). Apple keeps 30% of all revenues and distributes 70% of the app revenue to the developers.[1] Currently, about 1.4 million apps are available in the Apple App Store.[2] Medical apps make up a fraction (2% of all available apps) compared to larger groups such as games (> 21%)[3]. More than 30,000 medical apps are available online. It is estimated that in 2014 alone, developers earned US $10 billion selling apps via the Apple App Store.[4]

To date, there are no mandatory regulations for medical smartphone apps (Visser et al. 2013), although some of these apps can be seen as medical devices, according to EU-Directive 93/42/EEC (2007). Thus, it is much easier to diffuse a medical smartphone app than a tangible medical device that requires clearance by a regulatory body. Approval for market launch is only required from the platform provider (i.e. Apple), but not by the regulatory bodies such as the Food and Drug Administration (FDA) in the U.S. or European notified bodies. To date, very few apps are being regulated on a voluntary basis (Hussain et al. 2015; Kamerow 2013). However, regulatory agencies in Europe and the U.S. are currently

[1] Source: Apple. Accessed April 4, 2015. Available from: https://developer.apple.com/programs/ios/distribute.html

[2] Source: Apple. Number of available apps in the Apple App Store from July 2008 to January 2015. Statista. Accessed May 26, 2015. Available from www.statista.com/statistics/263795/number-of-available-apps-in-the-apple-app-store

[3] Source: 148Apps.biz. Most popular Apple App Store categories in March 2015, by share of available apps. Statista. Accessed May 26, 2015. Available from www.statista.com/statistics/270291/popular-categories-in-the-app-store

[4] Source: Kosner (2015). Apple App Store Revenue Surge and The Rise Of Freemium App Pricing. Forbes.com. Accessed April 4, 2015. Available from: www.forbes.com/sites/anthonykosner/2015/01/11/apple-app-store-revenue-surge-and-the-rise-of-the-freemium

evaluating proper means to regulate smartphone apps in order to ensure user safety (Brooke and Thompson 2013).

Recently, analytics data such as user ratings and smartphone app prices have already been investigated in different medical disciplines, such as obesity (Stevens et al. 2014), orthopedics (Franko and Bhola 2011), hernia repair (Connor et al. 2013), and surgery (O'Neill and Brady 2012; Dala-Ali et al. 2011). To our best knowledge, ours is the first attempt to identify user innovations in the field of medical smartphone apps. We seek to contribute to a novel research stream about the innovativeness of patients and relatives by analyzing the medical smartphone apps of patients, their relatives, and healthcare professionals, compared to manufacturers' apps. In the medical smartphone apps market, all three types of developer groups (*intermediate users* – here, relatives as well as healthcare professionals and associations; both develop for the needs of their patients, *end users* – here, patients as well as healthcare professionals and associations; both develop for healthcare professionals, and *producers*) are present. A smartphone app's developer type is not directly visible for the customer. Thus, the decision to download or to rate an app is not influenced by developer type. We will evaluate the de facto market behavior of user innovations in an unbiased setting in the healthcare sector.

2.5 Research questions

We aim to assess users' ability to compete with professional developers in a large-scale and real-world setting. To evaluate the performance of user innovators in the field of medical smartphone apps, we developed two research questions:

First, we want to assess if user-developed products can compete (or outpace) producer-developed products in the marketplace.

It is not easy to assess the success of user-developed products, since most user-generated ideas remain in the prototype stage and are later (if at all) commercialized together with a manufacturer. To date, little is known about actual market behavior of user-developed and commercialized products vs. manufacturer-developed and commercialized products (Ogawa and Piller 2006). First evidence about the performance of user-generated ideas was provided by Poetz and Schreier (2012): In an experimental setting, experts rated user-generated ideas (n = 52) to be superior concerning novelty and customer benefit, and lower concerning feasibility when compared to manufacturer-generated ideas (n = 51). This indicates the potential performance of user-generated ideas, although this study only evaluated ideas, not products that are available in the market. A study by Nishikawa et al. (2013) revealed that user-generated designs that were subsequently commercialized by an incumbent company yielded significantly better financial results compared to entirely in-house developed designs. Thus, we should also include a financial parameter should in our analysis.

Second, we investigate whether the early development of medical smartphone apps was triggered by user-developers.

Users innovate because they face unmet needs months or years before other users (Herstatt and von Hippel 1992). In a study about the development of scientific instruments, Riggs and von Hippel (1994) show that early development of new scientific instruments (with high scientific importance) is driven by users, while manufacturers step in later in the process and mainly develop devices of high commercial importance. Since patients, relatives, and healthcare professionals are users of medical devices, we assume that some of them also face needs earlier than the general market and therefore are the first to develop novel medical smartphone apps. Healthcare professionals have already been proven to be lead users and are able to develop medical devices earlier than manufacturers (Lettl et al. 2006; Lüthje and Herstatt 2004). The Apple App Store was opened to developers in 2008. At the time, few professional software developers were developing mobile smartphone apps. Barriers for patients, relatives, and healthcare professionals to diffuse their apps are very low – there is as yet no mandatory regulatory process for medical smartphone apps (Visser et al. 2013).

It is critical that scholars and professionals address these two research questions, since they provide first evidence of the performance of user-developed vs. producer-developed products on a large scale in the real world.

3 Methodology

The phenomenon of innovative patients and relatives is as yet unexplored. We take a phenomenon-based approach (von Krogh et al. 2012) to derive implications for the user innovation literature as well as health policy. The healthcare sector has been subject to several studies and has proven to be a field with high innovation potential, particularly for user innovation (Hinsch et al. 2014; Braun and Herstatt 2008; Lettl et al. 2006; Shaw 1985). For this study, we used two data sources: Analytical data about medical smartphone apps and interviews with user innovators (patients, relatives, and healthcare professionals) in the field of medical smartphone apps.

3.1 Analytical app data

Our study focuses on apps for the Apple iPhone only, as at the time of data acquisition, many more medical apps were available for iOS (Apple) than for Android (Google) (Pramann et al. 2014). In the meantime, the number of medical apps for Android has increased substantially. Currently, the Apple App Store and the Google Play store both have about 30,000 medical smartphone apps available (Research2Guidance 2015).

We used the software WebSundew 4 Professional (Sundewsoft) to collect and extract data from five websites[5] that provide publicly available analytical data about smartphone apps. We collected 30 parameters such as name, app ID, initial release date, download numbers, and ratings, which have been used to measure app success (Garg and Telang 2013). The initial collection took place on May 26, 2014; data was collected for some parameters weekly and for others monthly until August 28, 2014. Although we measured data over about three months, we will use only the most recent values obtained in August 2014 for further analysis here.

All data was stored in a MySQL database (release 5.6.16) using an Apache web server (release 2.4.7) and was accessed using the web-browser based software phpMyAdmin (release 4.1.6). The database was accessed using Microsoft Access 2010 and evaluated using IBM SPSS Statistics 22 and Microsoft Excel 2010.

First, we analyzed all apps within the group top 1,000 medical apps in the German, UK, and U.S. Apple App Stores within the three categories: free, paid, and grossing[6]. Since some apps appear in several markets and some in several categories, this first search yielded n = 4,550 apps. Further, we selected only apps with a true medical purpose and that can thus can be classified as a medical device according to a medical device regulation (cf. EU-Directive 93/42/EEC 2007)[7]. This led to 1,233 apps published by 878 developers. This classification was done according to Armstrong et al. (1997) by two of the authors independently. We applied Cohen's κ (Cohen 1968), which yielded an agreement of 89.2%.

In a next step, we categorized the apps according to the developer type into six groups: We differentiated between user-developers, namely patients, patients' relatives, healthcare professionals, healthcare associations, and non-user-developers (i.e. professional developers, namely companies and independent developers). A healthcare association is defined as a community of healthcare professionals that share information and assistance with other group members. Franke and Shah (2003) found that these *user communities* provide users with access to resources for their innovative endeavors.

For each app, we did a brief Internet search about each developer's group affiliation. This information was mainly obtained from the *About us* section of the company's website, the iTunes website, linkedin.com, websites with media releases, and other websites. For each user innovator, we have proof

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[5] www.applyzer.de, www.apptrace.com, www.distimo.com, www.xyo.net, iTunes lookup.
[6] The category *grossing* lists the applications by revenue generated per application.
[7] "A medical device means any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, including the software intended by its manufacturer to be used specifically for diagnostic and/or therapeutic purposes and necessary for its proper application, intended by the manufacturer to be used for human beings for the purpose of: diagnosis, prevention, monitoring, treatment or alleviation of disease, diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap, investigation, replacement or modification of the anatomy or of a physiological process, control of conception, and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means" (EU-Directive 93/42/EEC 2007).

of his or her affiliation. This work was done by two of the authors separately so as to ensure rigorous results. Cohen's κ for the classification of user-developer vs. non-user-developer yielded 82% (κ = 0.820), for the classification of all six developer types 78.5% (κ = 0.785). Two of the authors then double-checked all classifications together and agreed on one developer type. For developer groups with more than one person, we evaluated the app's founder or idea originator. In 92 cases, the information could not be obtained from the Internet. We sent a clarification email to these developers; 55 answered, yielding a 59.8% return rate. To ensure that we were on the conservative side concerning this classification, we classified apps for which the group affiliation could not be identified to our best knowledge as non-user-developers.

3.2 Interviews

In a second step, we conducted 16 semi-structured interviews with developers from Germany, Austria, Switzerland, the U.S. and India to find out about the motivations for their innovative endeavors, their specific knowledge of and experience in the topic, supportive and required contextual factors from their perspective, and their roles and activities in the innovation process. We developed these themes using prior research (Franke et al. 2006; Lüthje and Herstatt 2004; Franke and Shah 2003; von Hippel 1988) and produced an interview guideline. We contacted 22 user-developers from our abovementioned dataset; 15 were willing to conduct an interview. Additionally, one developer was interviewed who released his app in early 2015. We sought to reach app developers that vary concerning user group, professional experience, app age, and the app's business model. We conducted the first set of interviews between May and July 2013, and the second set in March 2015. We interviewed six patients, seven relatives, and three healthcare professionals.[8] The developers were between 18 and 55 years old (average age: 39). We interviewed one female and 15 male developers. The interviews lasted between 23 and 49 minutes, with an average length of 35 minutes. We transcribed and coded all interviews using MAXQDA 11. For data reduction, we used a threefold approach: first-order analysis, second-order analysis, and aggregation (Gioia et al. 2012; Miles et al. 1994). Concerning data triangulation, we interviewed three different participant groups: patients, relatives, and healthcare professionals. Concerning investigator triangulation, two authors performed parts of the interview analysis independently and then cross-checked each other.

[8] While one interviewee was a healthcare professional, he developed the app in his role as a MS sufferer, not as a heart surgeon.

4 Findings

Our findings consist of the analytical App Store analysis and interview data with user developers of medical smartphone apps.

4.1 Analytical App Store data analysis

4.1.1 Descriptive developer analysis

During our study, we analyzed 1,233 apps developed by 878 developers; 470 developers (53.5%) were professionals: 350 companies and 120 independent developers. They account for 53.8% of all developed apps. The remaining 408 developers (46.5%) were users: 41 healthcare associations, 299 healthcare professionals, 44 patients, and 24 patients' relatives. As shown in Table 1, the number of developers and the number of developed apps correlate across the sample.

Table 1: Number of developers and number of developed apps

	Company	Independ. developer	Association	Healthcare professional	Patient	Patients' relative
	Non-user-developers		User-developers			
No. of developers	350 (0.398)	120 (0.137)	41 (0.047)	299 (0.341)	44 (0.050)	24 (0.027)
No. of developed apps	512 (0.415)	151 (0.122)	48 (0.039)	441 (0.358)	52 (0.042)	29 (0.024)

Smartphone apps can be released to the App Store as a free app or as a paid app. The app's price can be set by the developer in predefined price tiers (i.e. US $0.99, $1.99, $2.99). The analysis of the developers' business models revealed that 57.9% of all companies released their apps for free, but only 39.2% of healthcare professionals, 42.3% of patients, and 41.4% of patients' relatives did the same (see Table 2). Mean prices for paid apps vary from US $5.07 (independent developer) to US $5.34 (company) for non-user-developed apps and from US $4.06 (associations) to US $5.35 (healthcare professionals), US $8.06 (patients), and US $10.69 (patients' relatives) for user-developed apps. Looking at mean, standard deviation, and median values for prices (Table 2) reveals that for patient and patients' relative-developed apps, there was a high variance, with few very expensive apps and the majority of apps priced between US $1.99 and US $2.99. Some apps offer *in-app purchases*, i.e. the basic version of the app is provided for free or at low cost, and additional features can be unlocked by additional payments. This so-called *freemium* business model (Baden-Fuller and Haefliger 2013) is positively related to increased downloads and revenue of apps (Liu et al. 2012). We find that 29% of all relatives and 23% of independent developers offered in-app purchases, followed by patients (14%) and companies (11%). Of all non-user-developers, 14.1% offered in-app purchases, compared to 9.8% of all user-developers.

Table 2: Pricing of apps

	% of free apps	Mean price paid apps (US $)	S.D. price paid apps (US $)	Median paid apps (US $)	% of in-app purchases
1 Company	0.570	5.34	9.96	2.99	0.115
2 Independent developer	0.497	5.07	8.66	2.49	0.231
3 Association	0.729	4.06	4.03	1.99	0.091
4 Healthcare professional	0.392	5.35	9.04	2.99	0.083
5 Patient	0.423	8.06	19.27	2.49	0.140
6 Patients' relative	0.414	10.69	30.80	2.99	0.286

n = 1,233.

4.1.2 Performance assessment

We identified three primary criteria for evaluating a smartphone app's performance: number of downloads (i.e. the app's popularity), annual revenue (i.e. financial benefits), and user ratings (i.e. the app's quality). Since the users of these apps do not know the developer type (this information is not directly available on iTunes), we assume that decisions about downloading and rating the app are unbiased concerning this attribute. User ratings are "peer-generated product evaluations posted on company or third party websites" (Mudambi and Schuff 2010) and have been used by scholars to evaluate a smartphone app's quality (Kranz et al. 2013; Obiodu and Obiodu 2012). Users can rate a smartphone app from one to five stars (with one star being the worst and five stars the best rating). Additionally, users can add a text-based review of the app.

We find that apps developed by patients were rated best, with an average value of 3.94 stars (Table 3), followed by associations (3.83 stars), patients' relatives (3.75 stars) and healthcare professionals (3.73 stars). Companies and independent developers ranked last, with 3.44 stars and 3.32 stars respectively. Companies had significantly lower ratings ($p = 0.001$) compared to patients and healthcare professionals ($p < 0.001$); however, there is no significant difference to patients' relatives. Independent developers had significantly lower ratings than healthcare professionals ($p = 0.001$) and patients ($p = 0.002$).

Table 3: Ratings: mean, S.D., median, and p-values

	Mean	S.D.	Median	1	2	3	4	5
1 Company	3.45	0.996	3.5					
2 Independent developer	3.31	1.173	3.5	0.382				
3 Association	3.83	0.849	4.0	0.028	0.023			
4 Healthcare professional	3.74	0.987	4.0	0.000***	0.001*	0.767		
5 Patient	3.94	0.871	4.5	0.001*	0.002*	0.485	0.230	
6 Patients' relative	3.75	0.875	4.0	0.153	0.102	0.739	0.880	0.281

* p < 0.05;

*** p < 0.001;

n = 1,010; 223 apps without ratings were excluded from this analysis. We used Mann-Whitney U-tests, since the data was not normally distributed.

We evaluated a total of 510,229 user ratings; the mean rating per app was 505, and the median was 22.[9] On average, companies had 804 (27) user ratings, relatives 480 (26.5), and patients 334 (28.5). Healthcare professionals reached a mean of 296 (15.5) ratings, independent developers 261 (19.5), and associations 45 (20.5).

Next, we obtained and evaluated secondary data about sentiments of written reviews of smartphone apps. Although it provides valuable feedback for app developers, qualitative analysis of user comments about smartphone apps has to date gained very little attention (Guzman and Maalej 2014). Thus, automated sentiment analysis (Pang and Lee 2008) of user comments has been performed, analyzing for instance restaurant reviews (Ganu et al. 2009) or movie reviews (Pang et al. 2002). Since review occurrence declines exponentially with decreasing app rank (Fu et al. 2013), we evaluated only 19.3% of apps with user reviews within our sample within this analysis. Thus, we analyzed only the non-user and user-developer bases.

The sentiment for positive user comments (Table 4) is 5.6 percentage points higher, the sentiment for addictive user comments 5.2 percentage points higher for user-developed apps. Accordingly, the sentiment analysis for crashes and negative comments were 4.4 percentage points respectively 5.1 percentage points lower. A Mann-Whitney U-test revealed that all p-values are below 0.05, indicating a significant difference for non-user vs. user sentiment means.

Table 4: User sentiments: mean, S.D. and p-values

	Mean non-user	Mean user	S.D. non-user	S.D. user	p-value
Positive	0.446	0.502	0.172	0.150	0.027*
Addictive	0.166	0.218	0.087	0.097	0.000***
Crashes	0.109	0.062	0.102	0.057	0.000***
Negative	0.152	0.095	0.134	0.867	0.001**

* p < 0.05;
** p < 0.01;
*** p < 0.001;
n = 238; 995 apps without rating were excluded from this analysis. We used Mann-Whitney U-tests, since the data was not normally distributed.

Download numbers are a measure of a smartphone app's popularity (Garg and Telang 2013; Abroms et al. 2011). Analyzing download numbers requires a differentiation between apps concerning their business models: Since free apps have substantial (up to 10 times) more downloads (Garg and Telang 2013), we will distinguish between free and paid apps. Since Apple does not publish any download numbers, we use publicly available estimations of total cumulative downloads[10] and divide this by the age of the app (in years) to receive average annual downloads per app.

[9] In this paragraph, median values are shown in brackets behind the mean value.
[10] Provided by www.xyo.net

Like Garg and Telang (2013), we found that a few apps are responsible for the majority of downloads. The 20 most downloaded paid app account for 52% of all downloads, and the 20 most downloaded free apps for 53%. Analyzing the upper 20% of all apps, we find that they account for 81% of all paid app downloads and 82% of all free app downloads. Thus, the results show a high variance ranging from 1,000,000 downloads to less than 500 downloads per app and year.

For paid apps, patients' relatives have an average annual download rate of 8,534 (median = 6,436), followed by companies (mean = 6,608; median = 1,197) and independent developers (mean = 4,081; median = 1,232). As shown in Table 5, patient-developed paid app have an average of 3,615 downloads per year (median = 1,453) and healthcare professionals 2,402 downloads per year (median = 908). A Mann-Whitney U-test shows that patients (p = 0.004) and relatives (p = 0.002) have significantly higher numbers of downloads compared to healthcare professionals. Additionally, patients' relatives have significantly more downloads than companies (p = 0.015) and independent developers (p = 0.019).

Table 5: Annual download estimations (paid apps): Mean, S.D., median, and p-values

	Mean	S.D.	Median	1	2	3	4	5
1 Company	6,608	27,763	1,197					
2 Independent developer	4,081	10,323	1,232	0.537				
3 Association	3,150	4,539	1,568	0.467	0.629			
4 Healthcare professional	2,402	7,226	908	0.097	0.067	0.176		
5 Patient	3,615	4,725	1,453	0.106	0.189	0.685	0.004**	
6 Patients' relative	8,534	10,519	6,436	0.015*	0.019*	0.154	0.002**	0.231

* p < 0.05;

** p < 0.01;

n = 593; 30 apps had to be excluded owing to too small download numbers. We used Mann-Whitney U-tests, since the data was not normally distributed.

Analyzing free apps only (Table 6), patient-developed apps had the highest average download rate per year, 43,905 (median = 12,858), followed by patients' relatives (mean = 33,450; median = 6,622) and companies (mean = 33,278; median = 5,876). Patients had significantly more downloads compared to associations (p = 0.011), companies (p = 0.036), and healthcare professionals (p = 0.005). Associations, healthcare professionals, and independent developers followed, with 26,840, 23,223, and 18,910 downloads per year respectively.

Table 6: Estimations of downloads (free apps) per year: Mean, S.D., median, and p-values

	Mean	S.D.	Median	1	2	3	4	5
1 Company	33,278	113,634	5,876					
2 Independent developer	18,911	35,113	6,436	0.283				
3 Association	26,840	105,012	5,25	0.292	0.059			
4 Healthcare professional	23,223	78,75	5,381	0.304	0.050	0.577		
5 Patient	43,905	84,493	12,858	0.036*	0.115	0.011*	0.005**	
6 Patients' relative	33,450	63,293	6,622	0.302	0.671	0.144	0.210	0.477

* p < 0.05;

** p < 0.01;

n = 546; 62 apps had to be excluded owing to too small download numbers. We used Mann-Whitney U-tests, since the data was not normally distributed.

Next, we analyzed the revenue generated by the different user groups (Table 7). We multiplied app price and annual download numbers of paid apps for calculating the revenue. We could not assess the revenues generated by in-app purchases, since this data is not publicly available. However, only 11.6% of all apps used in-app purchases. The apps developed by patients' relatives generate by far the highest average revenue per year (US $82,230), followed by companies (US $26,850) and patients (US $18,560). Patients' relatives generated significantly more revenue than independent developers and healthcare professionals. The overall revenue of all apps per year is about US $11.14 million, of which 42.8% is generated by user-developed apps.

Table 7: Revenue estimations in US $1,000 (paid apps): Mean, S.D., median, and p-values

	Mean	S.D.	Median	1	2	3	4	5
1 Company	26.85	133.58	3.44					
2 Independent developer	9.62	12.46	3.57	0.933				
3 Association	17.30	29.61	6.06	0.838	0.718			
4 Healthcare professional	11.28	36.44	2.98	0.171	0.388	0.556		
5 Patient	18.56	32.32	4.71	0.284	0.294	0.640	0.066	
6 Patients' relative	82.23	21.47	15.66	0.052	0.030*	0.337	0.012*	0.296

* $p < 0.05$;

n = 593; 30 apps had to be excluded owing to too small download numbers. We used Mann-Whitney U-tests, since the data was not normally distributed.

Last, we calculated the values for ratings, downloads, and revenues again, contrasting only performance for users vs. non-users. Users received significantly better ratings ($p < 0.001$) than non-users, while download numbers (paid and free apps) and revenues were on average slightly higher for non-users. The similar median values indicate that a few very successful apps dominate the field, although the majority of apps have comparable results for downloads and revenue.

Table 8: User vs. non-users – ratings, downloads (paid and free), and revenues (in US $1,000): Mean, S.D., median, and p-values

	Users			Non-users			
	Mean	**S.D.**	**Median**	**Mean**	**S.D.**	**Median**	**p-value**
Ratings	3.77	.960	4.0	3.42	1.04	3.5	0.000***
Paid downloads	2,828	7,246	997	5,964	24,535	1,206	0.330
Free downloads	26,232	82,148	6,000	30,281	102,466	5,904	0.382
Revenue (in US $1,000)	15,531	59,224	3,160	22,465	115,742	3,453	0.507

Notes: *** $p < 0.001$;

$n_{Ratings}$ = 1010, 223 apps without ratings were excluded from this analysis. $n_{Downloads(paid)}$ = $n_{Revenue}$ = 593; 30 apps had to be excluded owing to too small download numbers. $n_{Downloads(free)}$ = 546; 62 apps had to be excluded owing to too small download numbers. We used Mann-Whitney U-tests as the data was not normally distributed.

4.1.3 User group analysis

Several studies about users' motivations to innovate conclude that users mainly develop their innovations in relation to their own needs (Lüthje et al. 2005; Lakhani and von Hippel 2003). We find that patients and relatives developed 98% and 93% of their apps for patients' needs, while healthcare professionals developed 34% for (presumably their) patients and 56% for healthcare professionals' needs (see Table 7). Associations developed about half of their apps for patients and the other half for healthcare professionals. Independent developers focused mainly (67%) on patients as a target group. Very few apps target both healthcare professionals and patients.

Table 9: Target groups for app users

	Apps for patients	Apps for healthcare professionals	Apps for both
1 Company	310 (0.605)	179 (0.35)	23 (0.045)
2 Independent developer	101 (0.669)	39 (0.258)	11 (0.073)
3 Association	23 (0.479)	22 (0.458)	3 (0.063)
4 Healthcare professional	149 (0.338)	258 (0.585)	34 (0.077)
5 Patient	51 (0.981)	1 (0.019)	-
6 Patients' relative	27 (0.931)	1 (0.034)	1 (0.034)
Total	**661 (0.536)**	**500 (0.406)**	**72 (0.058)**

n = 1,233.

Next, we analyzed whether group affiliation impacts on product quality (e.g. ratings). We compared intermediate users (here, relatives as well as healthcare professionals and associations that both develop for their patients' needs) with end users (here, patients who develop for themselves as well as healthcare professionals and associations that both develop for healthcare professionals) and producers (here, companies and independent producers). All remaining apps were neglected for this analysis. The results (see Table 8) revealed no significant difference in ratings between intermediate and end users (3.75 stars for intermediate user and 3.78 for end users). However, ratings for all producers were significantly lower (3.42 stars) compared to intermediate users ($p < 0.001$) and end users ($p < 0.001$).

Table 10: Intermediate users vs. end users analysis: Number of apps, ratings (mean, S.D., and p-values)

	Number of apps	Mean	S.D.	1	2
1 Intermediate user	160 (0.143)	3.75	0.955		
2 End user	275 (0.263)	3.78	0.968	0.744	
3 Producer	564 (0.594)	3.42	1.037	.000***	0.000***

*** $p < 0.001$;
n = 981; 223 apps without ratings and 29 apps that were designed for both healthcare professionals and patients were excluded from this analysis. We used Mann-Whitney U-tests, since the data was not normally distributed.

4.1.4 The emergence of medical apps

The Apple App Store was initially opened on July 10, 2008 for developers to upload their smartphone apps. Analyzing the release date of the apps within our sample reveals that healthcare professionals initially uploaded 67% of all apps, followed by 24% of companies, two relatives, and one independent developer (Table 9). The first eight patients released their apps in 2009. Still, the absolute number of released apps is fairly low owing to the low diffusion of smartphones at that early stage. The amount of newly released apps rose within the next few years: In 2010, companies accounted for 45% of all released apps, followed by healthcare professionals (37%) and independent developers (12%). The percentage of apps released by user-developers is almost constant over the years. The compound annual growth rate (CAGR) of all newly released apps is 56.3%.

Table 11: The emergence of medical smartphone apps

	2008	2009	2010	2011	2012	2013
1 Company	8 (0.242)	44 (0.411)	88 (0.454)	97 (0.449)	120 (0.435)	114 (0.37)
2 Independent developer	1 (0.030)	12 (0.112)	23 (0.119)	21 (0.097)	27 (0.098)	56 (0.182)
3 Association	-	2 (0.019)	4 (0.021)	10 (0.046)	13 (0.047)	12 (0.039)
4 Healthcare professional	22 (0.667)	37 (0.346)	71 (0.366)	77 (0.356)	100 (0.362)	102 (0.331)
5 Patient	-	8 (0.075)	6 (0.031)	8 (0.037)	9 (0.033)	15 (0.049)
6 Patients' relative	2 (0.061)	4 (0.037)	2 (0.010)	3 (0.014)	7 (0.025)	9 (0.029)

n = 1,134 99 apps released in 2014 were excluded from this analysis.

For further analysis of smartphone app release dates, we focused on two subsets of disease-specific smartphone apps: diabetes and hypertension management. Diabetes and hypertension are widespread diseases that require constant tracking of health-related data (glucose level or blood pressure) that can be facilitated by a smartphone app. The first diabetes-related app was released by a healthcare professional shortly after the App Store was established (see Table 10). An app developed by a patients' relative followed a few months after. In 2009, seven new apps were uploaded, three by companies, three by healthcare professionals, and one by an independent developer. In 2012, six user-developed apps were released to the App Store (37%); in 2013, this was the case for 13 apps (50%).

Table 12: The emergence of diabetes apps

	2008	2009	2010	2011	2012	2013
1 Company	-	3 (0.429)	7 (0.700)	7 (0.700)	8 (0.500)	9 (0.346)
2 Independent developer	-	1 (0.143)	1 (0.100)	-	2 (0.125)	3 (0.115)
3 Association	-	-	1 (0.100)	-	-	1 (0.038)
4 Healthcare professional	1 (0.500)	3 (0.429)	-	-	3 (0.188)	2 (0.077)
5 Patient	-	-	1 (0.100)	3 (0.300)	2 (0.125)	8 (0.308)
6 Patients' relative	1 (0.500)	-	-	-	1 (0.063)	3 (0.115)

n = 71; 13 apps were suited for diabetes and hypertension management and were thus included in Table 10 and Table 11.

The analysis of hypertension-related apps yields a similar picture: early development in 2008 was initiated by two patients' relatives, one healthcare professional, and one independent developer (Table 11). In 2009, four companies, one patient, and one additional independent developer uploaded a hypertension-related smartphone app to the App Store. In 2012, 40% of all new apps were developed by users, and in 2013, about 42%.

Table 13: Emergence of hypertension apps

	2008	2009	2010	2011	2012	2013
1 Company	-	4 (0.667)	4 (0.667)	6 (0.600)	3 (0.300)	4 (0.333)
2 Independent developer	1 (0.250)	1 (0.167)	1 (0.167)	2 (0.200)	3 (0.300)	2 (0.167)
3 Association	-	-	-	-	-	1 (0.083)
4 Healthcare professional	1 (0.250)	-	1 (0.167)	1 (0.100)	2 (0.200)	1 (0.083)
5 Patient	-	1 (0.167)	-	1 (0.100)	1 (0.100)	1 (0.083)
6 Patients' relative	2 (0.500)	-	-	-	1 (0.100)	3 (0.250)

n = 48; 13 apps were suited for diabetes and hypertension management and were therefore included in Table 10 and Table 11.

4.2 Interview data

After gathering analytical data about user innovation in the field of medical smartphone apps, we conducted 16 semi-structured interviews with user-developers (six patients, seven relatives, and three healthcare professionals). We group this section into three main clusters and a concluding section, where remaining aspects will be presented and summarized. The product category of interviewees' apps are listed in Table 12.

Table 14: Characteristics of interviewees' medical smartphone apps

ID	Category	ID	Category
Patient 1	Diabetes	Relative 3	First aid
Patient 2	Hypertension	Relative 4	Poisoning treatment
Patient 3	Diabetes	Relative 5	Diabetes
Patient 4	Diabetes	Relative 6	Diabetes
Patient 5	Multiple sclerosis (MS)	Relative 7	Diabetes
Patient 6	Diabetes	Healthcare professional 1	Anesthesia management
Relative 1	Hypertension	Healthcare professional 2	Acupressure
Relative 2	Speaking aid	Healthcare professional 3	Bruxism

4.2.1 Triggers for innovative endeavors

The initiations of the innovations differed, as patients were directly confronted with a disease, while relatives only indirectly suffered from the health issue. Patients showed strong personal motivations concerning their level of suffering, particularly those suffering from chronic conditions such as diabetes and hypertension. Five of the interviewed patients were diabetics and received their diagnoses at a young age. They dealt with those health issues for many years and sought to help themselves in order to bring relief. Therefore, their personal needs were at the origin of their innovative endeavors. In most cases, there was a daily demand for a solution. For instance, a diabetic needs to document food intake and must calculate insulin injections to regulate his or her blood glucose level. Hypertension patients need to regularly monitor their blood pressure:

> *"Whenever I measured [my blood pressure] at work, I wrote an email home in order to put the values into a table, but that was very annoying." (Patient 2)*

The described health issues involve daily obligations that are very time-consuming. A patient's motivation to meet such obligations might change from time to time. Thus, the need for a solution emerges, and becomes stronger every day.

In the case of relatives, the innovative endeavors related to someone else's personal needs. However, we find that curiosity and fun about the development were two additional major motivational aspects that drove their development process.

> *"Initially, I had the intention to develop any kind of app; I just wanted to try it. Then my father was diagnosed with high blood pressure. […] This brought me to the field of hypertension management quickly." (Relative 1)*

The triggers of the participating healthcare professionals were operational – they tried to simplify time-consuming tasks in their daily activities, such as dose calculation. Others aimed to inform patients about certain health topics to improve the medical encounter, which is hampered by time constraints during daily activities.

In the early days of the App Store, users could choose between a few apps available online. However, the number of available apps increased rapidly. The interview data revealed that patients and relatives who uploaded their app more recently already had a concept for the software in mind and then checked which existing solutions were available online. However, in all cases, the interviewees stated that they were dissatisfied with existing apps. This dissatisfaction – combined with their severe need – were the major triggers for their product development. Thus, all interviewees match the conceptual description of lead users, as defined by von Hippel (1986).

It remains unclear why, between 2011 and 2013, particularly patients and relatives developed more new apps, although a large number of apps for their diseases already existed in the market. This pattern was observed particularly for apps targeting diabetes and hypertension (see Section 4.1.3).

We find that all participants' apps released after 2011 had some kind of novelty compared to existing solutions. One developer connected existing PC software to a mobile app and thereby developed the first cross-platform diabetes management app; another interviewee designed an app for children and thereby opened a new market segment. One patient intended to make a very flexible app with many tracking possibilities to suit his needs, while one relative wanted to make a very streamlined and simple piece of software for his sister. Although the basic functions of all apps in our sample were comparable to existing solutions, we find that every single new app had some kind of novelty – for instance in terms of design, connectivity, target group, or by introducing gamification and thereby making diabetes monitoring a game. Thus, all interviewees had good reasons to develop their own software, because there was no fitting solution available at the time.

4.2.2 Product development

Most of the analyzed apps were developed privately, i.e. without external support. Only two healthcare professionals collaborated with a partner during the development process owing to a lack of programming skills. All other 14 interviewees possessed the skills and knowledge to develop a smartphone app; some were trained software architects, while others had a high affinity to software development and improved their skills during the development process.

Depending on the app's scope and complexity, the development timeframe varied tremendously. It ranged from a few days to several months to finalize the app. The intensity expressed in hours per day or week also differed. At one extreme, a participant worked full-time in order to finish the development.

The majority estimated the time they spent on developing the app to between 10 to 20 hours per week over several months.

"Of course this development process takes time and therefore costs you money." (Patient 6)

Owing to personal preferences, current knowledge, and limited resources, only a few apps have been recreated for the Android operating system. Although the regulation of the app as a medical device demonstrates trustworthiness to its customers (Cortez et al. 2014), only two apps had been regulated. The majority did not pursue this option, as current regulatory frameworks bore too many administrative, financial, and procedural efforts.

4.2.3 Commercialization and outcome

Investigating commercialization, we find that some participants initially did not intend to upload their app to the App Store, but changed their decision during the course of private utilization. Mostly, these developers recognized their app's usefulness; therefore, every participant uploaded the own app to offer it to millions of smartphone users worldwide.

"If it helps me, why should it not help the others as well?" (Patient 3)

Most of the developers have set a price for downloading their app. However, owing to relatively low download rates, these fees were not a major revenue stream, but allowed them to compensate for their development costs (hardware, Apple developer account, etc.). Only two of the interviewees started a commercial startup. Even though return on investment is relatively low in financial terms, most participants had lists of suggestions for future improvement and ideas on how to further develop their app. Generally speaking, these suggestions mostly originated directly from users' feedback. In addition, half of the participants had ideas for new apps that they want to pursue in the near future; however, a prerequisite is that there are resources and no time constraints. Nonetheless, some participants will not invest any further effort into their app, owing to a lack of stimuli and time.

4.2.4 Summary interview data

The investigated phenomenon can be described by considering the findings on triggers for innovative endeavors, the development process, commercialization, and outcomes.

Before the participants started developing a medical app, several and varying triggers fostered the planning and final realization of the app. Subsequent to the creation of the app, participants experienced its usefulness via private utilization. Commercialization introduces the medical app to millions of iOS users worldwide. Although many apps for their disease were already available, users were dissatisfied and developed their own software, introducing some kind of novelty to the market.

Additionally, the data showed that certain attributes fostered innovative endeavors, for instance, a high affinity for smartphones may positively influence the desire to develop an app. The likeliness that someone with a high affinity for IT will develop an app seems much higher than someone who does not have such affinity. Furthermore, the participants expressed their personal attitudes. The data implied that there is a connection between innovative endeavors and personal attitudes. One participant did not perceive healthcare professionals as valuable problem-solvers concerning his diabetes. Similarly, he perceives large medical device manufacturers as "resistant to innovation". These attitudes clearly strengthened his desire to build an app to best satisfy his needs.

Participant's prior competencies and knowledge played an key role. A sound body of medical knowledge about the disease in question was present in all three user-developer groups. Healthcare professionals were well informed about their medical specialty, but all patients were able to discuss their condition with their healthcare professional at a high level.

> *"Often a general practitioner possesses less knowledge on diabetes than the patient himself." (Patient 4)*

Those who developed a medical app by themselves had some prior programming knowledge. Most of these participants also worked in IT-related jobs and therefore possessed various competencies.

> *"A long time ago, I did some research in the field of genetics and […] those huge datasets are only manageable by using IT. Therefore, I took some classes in bioinformatics and taught myself to use the programming language PERL." (Healthcare professional 1)*

Two healthcare professionals instructed someone else to realize their idea. They represent an exception in our dataset. This external software developer is a critical prerequisite to be fulfilled in order to realize the app.

5 Discussion and implications

5.1 Summary

Our study is to our best knowledge the first to analyze user innovation in different user groups in a large-scale and real-world setting. We identified four different user groups (healthcare professionals, patients, relatives, and healthcare associations) and two non-user groups (companies and independent developers). In the field of medical smartphone apps, the amount of user-developed apps is as high as 46.5%. In a preceding study by Lüthje (2003) in the healthcare sector, 22% of the participating surgeons were innovating. Oliveira et al. (2015) found that 36% of all patients with a chronic condition or their relatives innovated in relation to their needs. These findings are in line with a growing body of literature that indicates that patients are gaining increased medical expertise in relation to their disease (Budych et al. 2012; Hartzler and Pratt 2011; Greenhalgh 2009; Thorne et al. 2000).

Assessing product quality, we find that patients and healthcare professionals received significantly better ratings compared to companies and independent developers. Additionally, reviewer comments about user-developed products are significantly more positive. The product quality does not differ between intermediate and end users, but both groups received significantly better ratings than companies and independent developers. In this study, intermediate users are relatives as well as healthcare professionals and associations (who develop for their relatives or their patients, respectively). End users are patients who develop for themselves as well as healthcare professionals and associations who develop for themselves or other healthcare professionals.

Download numbers for free apps are significantly higher for patients compared to companies, while paid apps from patients' relatives received significantly more downloads than companies. About 60% of all apps developed by healthcare professionals are designed for healthcare professionals – a much smaller target group than patients. Therefore, apps developed by healthcare professionals have significantly lower download numbers than those of patients (paid and free apps) and relatives (paid apps).

Unexpectedly, it was also found that apps developed by patients' relatives yield on average highest revenues, followed by companies and patients. Extant user innovation theory suggests that users are interested in using a product than in its commercialization (von Hippel 2009). Yet, particularly relatives seem to develop more commercially successful apps. One reason might be that those developers experience their relatives' needs before others do, but also discover the commercial opportunities associated with the idea. They offer their apps for a higher average price and also use in-app purchases more often. Thus, we conclude that relatives as intermediate users are seeking to maximize profit (Bogers et al. 2010), in contrast to patients and healthcare professionals.

Thus, user-generated products are significantly more successful concerning quality and partly more successful concerning diffusion and revenue. Regarding the first research question, we conclude that user-generated products are outpacing producer-developed products concerning quality and partly concerning amount of downloads. These findings support the results of Poetz and Schreier (2012) and (Nishikawa et al. 2013), who found that user-generated ideas compare well with manufacturer-generated ideas.

Preceding studies about pricing of user innovations found that users reveal their innovations freely more often (Franke and Shah 2003; Morrison et al. 2000) and even benefit from this information spillover (Harhoff et al. 2003). In contrast, we find that only 42.5% of all user-developed smartphone apps are offered for free, compared to 55.4% of all apps developed by companies and independent developers. On average, user-developed apps are more expensive than non-user-developed apps. These results must be discussed in relation to the characteristics of the App Store: Medical device manufacturers sometimes offer smartphone apps for free to their clients because they are connected to a medical device – for instance, a blood sugar diary that interacts with a blood glucose meter. Apps might act as a marketing tool for complementary products (e.g. a pill reminder for certain pharmaceuticals) or might add new features to existing devices (e.g. viewing X-ray images on the go). The interview data suggests that user-developers do not want to earn money with their apps, but seek to get compensated to some extent for their development costs. A report about the economics of mobile apps reveals similar results: about 53% of all developers state that their primary goal was to help others; likewise, 67% of developers received no or less than US $10,000 in revenue from their sales (Research2Guidance 2015).

Besides, many more non-user-developers (14.1% compared to 9.8% user-developers) release a free version of their smartphone app, but require an in-app purchase for the full functional range. This has been proven to increase revenue (Liu et al. 2012) and seems to be used more frequently by commercial developers. The lower average price of non-user-developed apps is most likely one reason for the higher download rates compared to most user-developed apps. Yet, apps developed by relatives have significantly more downloads, despite being more expensive. This might be an indication of a higher perceived quality concerning those apps, compared to company-developed apps.

Our analysis of the emergence of medical smartphone apps revealed the dominance of user-developers in the early stage of the App Store. In the first six months after opening, about two-thirds of all apps were developed by a healthcare professional. In the following years, this share dropped to about 35% and subsequently remained constant until 2013. From 2009 on, companies account for about 40% of all newly released apps. We find that the distribution of user groups is relatively constant over time. In contrast, Riggs and von Hippel (1994) find that for scientific instruments, the amount of user-developed innovations was high at the outset and then decreased over time, while producer-developed innovations increased over time.

Subsequently, we examined two subgroups of disease-specific apps (diabetes and hypertension management) and observed an even more extreme pattern: The early innovations in the market were developed by users, shortly followed by an increasing number of producers publishing their apps. Between 2011 and 2013, even more user-developers (mainly patients and relatives) entered the market with a new app, accounting for more than 33% of all newly released apps in 2013.

In our view, the App Store is a very dynamic environment that undergoes constant change – hardware and software improvements add new functionalities and thus new opportunities to developers several times a year. Owing to the large customer base, many developers who entered the market after the basic functionalities have been developed chose a differentiation strategy – for instance by developing for another target group (e.g. children), making design changes, or merging specific innovations (e.g. gamification or cross-platform connectivity) with existing functionalities. New functionalities introduced by the platform provider (e.g. cloud-based data storage or smartwatches) amplify this pattern. Thus, all developers – user-developers and non-user-developers – have good reasons to initiate new development projects, although a set of established products is already available in the market.

Overall, we can confirm that user innovators triggered the early development of the market for medical smartphone apps, thereby answering our second research question.

5.2 Implications for user innovation research

This study contributes to user innovation theory in at least two ways: First, we showed real-world market data of user-innovated products on a large scale. The existing literature has been limited to fairly small-scale data and product ideas (Poetz and Schreier 2012). We operationalized product quality by analyzing user ratings and product popularity by app downloads. User-innovated medical smartphone apps received significantly better ratings; particularly patients, relatives, and associations are outpacing companies and independent developers. Analyzing popularity, company-developed apps are partly excelled by patients (free apps) and patients' relatives (paid apps). We support the findings of Lettl et al. (2006) as well as Lüthje and Herstatt (2004) that healthcare professionals are a primary source of innovation. In our study, healthcare professionals were the largest user group, accounting for about 36% of all developed apps. This is particularly interesting, since medical doctors generally do not have software development knowledge. We find that some trained themselves in writing software programs, while others hired a third party to develop an app according to their concept.

Second, we evaluated innovations by intermediate and end users. We found no significant differences in product quality between apps developed by intermediate and end users. Thus, both subgroups have significantly better product quality compared to producer-developed apps.

For the development of a medical smartphone app, medical knowledge and technical knowledge is needed. While some healthcare professionals had to rely on external knowledge for the software's implementation, patients and relatives possessed a dual knowledge base: technical and medical knowledge. Prior research has shown that solution knowledge is mostly prevalent within companies, while need knowledge is often found among users (von Hippel 1994). Particularly in the healthcare sector, patients with long-lasting – often chronic – diseases have high usage experience in time-consuming routines (Oliveira et al. 2015; Holman and Lorig 2004; Davis et al. 2000). During these enduring treatments, patients, patients' relatives, and healthcare professionals gain information about the disease and the treatment that are costly to acquire and to transfer (von Hippel 1998). Previous research has shown that healthcare professionals use this so-called *sticky* information for instance to develop off-label drug therapies (DeMonaco et al. 2006). We propose that patients and relatives also develop needs during their caring activities that may not yet been envisioned by medical smartphone app developers. Thus, the dual knowledge base might be a reason for the significantly superior quality of apps developed by patients and relatives compared to companies. Since we could not find significant differences in end user vs. intermediate user innovation quality, both groups seem to have similar knowledge, independent of whether the app was designed for themselves or for a related party.

5.3 Managerial implications

It is valuable for companies to integrate innovative users into their R&D process, since it helps to reduce information asymmetries and increases the innovation process efficiency (Henkel and von Hippel 2005). Our study shows that both user types – intermediate users and end users – innovated successfully with high quality. Commercial mobile app publishers and healthcare companies should take advantage of this and should consider including patients, patents' relatives, and healthcare professionals into their R&D process. Depending on the task and the required knowledge set, involving patients and patients' relatives might be superior to involving healthcare professionals. A study by Oliveira et al. (2015) revealed that quality of life is increasing significantly for patients and their relatives after an own medical innovation has been used by the patient. This indicates that relatives and other caregivers are affected similarly by a medical condition as patients. However, they might have better access to solutions to enhance health outcomes. In our sample, several tech-savvy people developed an app for their relatives who suffered from a chronic condition. In these cases, where no relative with a certain set of solution knowledge is available, companies or public entities such as universities might step in and might help to match needs and solutions, for instance by using an online platform.[11] Furthermore, sophisticated user toolkits for smartphone app development might help to leverage new software ideas (von Hippel 2001).

In our study, we focused only on smartphone apps. Other areas, where tangible medical devices are in place, certainly require more effort, owing to complex product development and regulatory processes. Again, medical device manufacturers could amplify patients' and relatives' endeavors by providing access to certain knowledge bases or co-working spaces, or by inviting them to jointly develop an innovation further.

5.4 Limitations and outlook

Our results have great originality and validity, but also limitations: The findings of our interview series are limited to 16 individuals and need quantitative validation. Further, only the 1,000 apps with the highest rank in three categories for each country could be considered in our study, owing to technical limitations. We assume that the amount of patient-developed apps is much higher; however, they are not downloaded as often as very popular commercial apps and therefore do not appear in the top 1,000 ranking. The revenue generated by in-app purchases could not be measured, but these additional sales are a meaningful way to increase the overall sales volume. Next, some developers generated several apps based on a similar functionality or even copy existing apps (Arnhold et al. 2014; van Velsen et al. 2013). We could not quantify the improvement level on an individual level for each app. In a subsequent study, the functionalities of each app could be recorded, coded, and analyzed concerning developer type. A study by Ventola (2014) found that healthcare professionals tend to own iPhones rather than Android-based smartphones. We should confirm our analytical analysis using data from the Google Play Store and should compare it to our dataset, which is derived from the Apple App Store.

Despite limitations, our study provides valuable insights into the phenomenon of user innovation in the area of medical smartphone apps. It contributes to the innovation literature by analyzing real-world market data on user innovations on a large scale and suggest further research avenues.

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[11] First initiatives such as www.patient-innovation.com – led by Prof. Pedro Oliveira (Católica-Lisbon School of Business and Economics, Portugal) – are available.

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