Finding commercially attractive user innovations: A performance evaluation of the "lead user construct"

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Abstract

The “lead user construct” was developed to preferentially identify commercially attractive innovation-related information developed by users of products and services. In this research, we use data drawn from users of Apache, an open source software project, to assess the association between each of the two components of the lead user construct and the likely commercial attractiveness of innovations developed by users. We find both construct components have significant explanatory value with respect to the likelihood of innovation by users. We also find that one component - being at the leading edge of important marketplace trends - does selectively identify user-developed innovations having higher marketplace potential.

Key words: lead users, innovation, open source software

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1. Introduction and overview

Lead users are defined as having both of two characteristics: (1) they expect relatively high benefits from innovating and (2), they have needs that are at “the leading edge of the market” relative to important marketplace trends. It has been proposed that manufacturers and others might be able use this construct to selectively identify users likely to be experiencing needs for – and perhaps developing prototype solutions for – commercially-attractive, “leading edge” new products and services (von Hippel 1986). In this paper, we conduct a first test of this hypothesis, drawing upon data collected from “webmaster” users of Apache security-related software modules.

We begin by exploring the ability of the two components of the lead user construct to identify users that have developed innovations. We find that both have significant explanatory power with respect to the likelihood of user innovation. We also find that combining the two components into a single construct does not reduce explanatory power. Finally, we find that the second component of the lead user construct – the position of a user relative to marketplace trends – does have a significant ability to selectively identify those users likely to have developed innovations that are or will be attractive to many users in a marketplace. (Figure 1, below, graphically summarizes our study findings regarding the degree of lead user qualities that characterize user-innovators and the commercial attractiveness of the innovations they develop.)

The independent ability of each component of the lead user construct to predict user innovation can be understood in terms of the economics of innovation. With respect to the first, it is reasonable that users’ expectations of significant benefit from a needed new product will be associated with a willingness to invest in obtaining it, whether by innovation or by purchase. The second component of the lead user construct, being “ahead of the market” on important trends, means that the innovations the lead users seek will often not yet exist in the form of commercial products available for purchase. This is because the leading edge of
markets are generally both small and uncertain, and so relatively less attractive to manufacturers from the point of view of innovation investment. If the products lead users need are not yet available from manufacturers, the lead users must develop them for themselves - or go without. It is reasonable that some in this position will decide to innovate for themselves in order to satisfy important in-house needs.

**Figure 1: Attractiveness of Innovations as a Function of the Lead User Construct**

The increased concentration of innovations towards the right indicates that the likelihood of innovating is higher for users having higher lead user index values. The rise in average innovation attractiveness as one moves from left to right indicates that innovations developed by lead users tend to be more “commercially attractive.” Innovation attractiveness is an index variable that is the sum of two components: the novelty of the innovation, and the generality of marketplace demand.

It is also reasonable that the second component of the lead user construct, user position with respect to important marketplace trends, may preferentially identify user-innovators.
likely to have developed innovations with major marketplace potential. By definition, lead users are today facing needs and conditions that will be faced by many users in a marketplace when the general marketplace “catches up” to where lead users are today.

Our paper is organized as follows. In section 2 we review the literature on innovation by lead users, commercial value of lead user-developed innovations, and the lead user construct. In section 3 we describe the research setting for our empirical study and the research methods used. We present our findings in section 4. Finally, in section 5, we discuss those findings.

2. Literature Review

Lead users are defined as members of a user population that display two characteristics with respect to a given novel product or service: (1) they face needs that will be general in a marketplace - but face them months or years before the bulk of that marketplace encounters them and, (2) they are positioned to benefit significantly by obtaining a solution to those needs. Thus, a manufacturing firm with a current strong need for a process innovation that many manufacturers will need in a few years’ time would fit the definition of lead user with respect to that process (von Hippel 1986). In the case of industrial products, lead users would typically be organizations (e.g., firms using process equipment). In consumer goods fields, lead users would typically be individual end users.

Innovation by lead users

Empirical studies in a number of very different fields has found that innovation by users – development of new and modified products – tends to be strongly concentrated among lead users. (Urban and von Hippel 1988, Morrison, Roberts and von Hippel 2000, Lüthje 2002, Franke and Shah 2002, Lüthje, Herstatt and von Hippel 2002). This finding holds in both industrial and consumer good fields, as can be seen below (table 1).

Note that the fraction of users found to have innovated in the table 1 studies does not necessarily reflect the level of innovation in entire user populations. Some studies (notably the study by Morrison et al. (2000) of library automation among Australian libraries) did collect a sample representative of an entire user community. Others, however, were interested in focusing on data rich in user innovations, and so drew samples from user subgroups judged likely to have a higher likelihood of innovating. (For example, Luthje et al. (2002) collected samples of mountain bikers from a region known to be an innovation “hot spot” for that sport.)
Table 1: Proportion of users innovating in diverse product categories

| Innovation Area                        | Number of Users Sampled                                           | % developing and building innovation for own use | Were the innovating users “lead users”? |
|----------------------------------------|-------------------------------------------------------------------|--------------------------------------------------|----------------------------------------|
| **Industrial Products**                |                                                                   |                                                  |                                        |
| 1. Printed Circuit CAD Software (a)    | 136 user firm attendees at PC-CAD conference                      | 24.3%                                            | Yes                                    |
| 2. Pipe Hanger Hardware (b)            | 74 Pipe hanger installation firms                                 | 36%                                              | NA                                     |
| 3. Library Information Systems (c)     | 102 Australian Libraries using computerized library information systems | 26%                                              | Yes                                    |
| **Consumer Products**                  |                                                                   |                                                  |                                        |
| 4. Outdoor Consumer Products (d)       | 153 outdoor specialty mail order catalog recipients               | 9.8%                                             | Yes                                    |
| 5. “Extreme” sporting equipment (e)    | 197 expert users                                                  | 37.8%                                            | Yes                                    |
| 6. Mountain biking equipment (f)       | 291 expert users                                                  | 19.2%                                            | Yes                                    |

Table reproduced from Franke and von Hippel (2002), Sources of Table Data: (a) Urban and von Hippel (1988); (b) Herstatt and von Hippel (1992); (c) Morrison, Roberts and von Hippel (2000); (d) Lüthje (2002); (e) Franke and Shah (2002); (f) Lüthje, Herstatt and von Hippel (2002).

Commercial value of lead user innovations

Findings that innovation by users is concentrated among lead users in itself says nothing about the marketplace promise of the innovations lead users develop. It has been found that innovating users typically can expect to benefit only from the in-house use of their innovations.¹ For this reason, users will have no incentive to devise innovations that suit general marketplace demand – they will only be concerned that their innovation is suitable for in-house needs. In contrast, manufacturers that wish to produce user-developed innovations commercially will be very interested in identifying those for which there is or will be a significant marketplace demand.

The fact that lead users are by definition “ahead of the market” with respect to important marketplace trends suggests that lead user innovations may in fact have general marketplace utility - despite user-innovators’ likely lack of incentive to seek this goal.

¹ For user-innovators to benefit from adoption of their innovation by others, they would have to first protect and then license their intellectual property – their innovation. As Harhoff et al. (2002) show, both of these tasks are costly and difficult to attempt, and success is very far from certain (Harhoff et al., 2002).
And indeed, empirical data available to date does suggest that innovations developed by lead users can at least sometimes have general marketplace value. Findings from 4 empirical studies illustrate this point.

- Urban and von Hippel (1988) tested the relative commercial attractiveness of product concepts developed in the field of computer-aided systems for the design of printed circuit boards—PC-CAD. One of the concepts they tested contained novel features proposed by lead users that had innovated in the PC-CAD field in order to serve in-house need. The attractiveness of the “lead user concept” was then evaluated by a sample of 173 target market users of PC-CAD systems relative to three other concept choices – one of which was a description of the best system then commercially available. Over 80% of the target market users were found to prefer the concept incorporating the features developed by innovating lead users. Their reported purchase probability for a PC-CAD system incorporating the lead user features was 51%, over twice as high as the purchase probability indicated for any other system.

- Olson and Bakke (2001) report upon two lead user studies carried out by Cinet, a leading IT systems integrator in Norway, for the firm’s two major product areas, desktop PCs, and Symfoni application GroupWare. These projects were very successful, with most of the ideas incorporated into next-generation products having been collected from lead users.

- Morrison et al. (2000) found that innovation activity by users in the field of library computer information systems was concentrated among lead users. They explored the commercial attractiveness of these user-developed product modifications by asking two library information system equipment suppliers to evaluate a brief description of the function performed by each modification. The supplier evaluations indicated that about 70% (25 out of 39) of the user modifications provided functionality improvements of at least “medium” importance from the point of view of these commercial systems vendors.

- Lillien et al. (2002) studied samples of funded new product development projects at the 3M Corporation. They compared the company’s commercial expectations for projects developed both with and without inputs from lead users. Corporate sales forecasts in year 5 for projects that had systematically incorporated ideas collected from lead users were found to be $146 million on average - more than 8 times higher than projected sales for projects not incorporating lead user inputs. These projects also had significantly higher novelty (usually being judged “new to the world”) than did those developed on the basis of information from non-lead user sources. (A unique aspect of the 3M lead user projects should be noted. 3M lead user idea generation project teams were instructed to seek out lead users both within and outside of the intended target markets. The logic was that lead users found outside of a target market often encounter even more extreme conditions on a trend relevant to that target market. They may therefore be forced to develop solutions that are novel enough to represent “breakthroughs” when applied to the target market. For example, auto manufacturers seeking to improve auto efficiency by reducing weight with lighter, stronger materials might find breakthroughs among lead users in the aerospace industry – users that face a very similar problem in an even more extreme form.)
Nature of the lead user construct

Studies of innovation by lead users have generally treated the lead user construct as a binary variable. A typical approach has been to use cluster analysis to place sample members in lead vs. non-lead clusters. Analysis of the nature of innovation-related activities, characteristics of cluster members, etc., then follows.

Morrison (1995) broke away from this pattern and focused on gaining a detailed understanding of Leading Edge Status (LES), a construct she developed that is closely related to the lead user construct. LES contains four types of measures. The first two, Benefits Recognized Early and High Benefits Expected, represent the two components of von Hippel's original lead user definition. The third represents direct inquiries regarding of the level of these two components in interviewees’ own firms, and in other firms with which the interviewees are familiar. The fourth set represents measures of innovative activities that have been hypothesized to be associated with Benefits Recognized Early and High Benefits Expected. Empirical exploration of the LES construct on a sample of 464 users of library information technology systems showed it to have both high reliability and high validity. The four component measures were found to be highly correlated, making it meaningful to view them as part of a single construct. LES was also found to be a continuous variable with a unimodal, bell-shaped distribution in the population studied (Morrison 1995; Morrison et al. 2002).

3. Research context and methods

The sample of innovations we draw upon for this study consists of user-developed modifications to security-related elements of Apache web server software. Web server software is used on computer servers connected to the Internet. A server’s function is to “service” requests from Internet browsers for particular documents or content. Initial versions of web server software were developed in the early to mid 1990’s and offered relatively simple functionality. Over time, however, Apache and other web server software programs have evolved into the complicated front end for many of the technically demanding applications that now run on the Internet. For example, web server software is now used to handle security and authentication of users, provide e-commerce shopping carts and gateways to databases. Apache software now consists of hundreds of specialized programs and program modules that collectively address the range of functions that make up a modern web server.

Apache is “open source” software that is explicitly designed to enable modification by users with appropriate programming skills. When software is “free” or “open source,” users
are allowed to download the software from the Internet and use it without charge. Users are also explicitly granted the legal right to study the software’s source code, to modify the software, and to distribute modified or unmodified versions to others.\(^2\) Apache is currently the most popular web server software on the Internet. Version 1.0 of Apache was released on December 1, 1995. In the space of five years and in the face of strong competition from commercial competitors like Microsoft and Netscape, it has been adopted by approximately 60% of the 37 million World Wide Web sites extant (Netcraft 2002). It has also received many industry awards for excellence.

In this study we focus only on security-related modifications to Apache made by users. We adopt this relatively narrow focus for three very practical reasons. First, we reduce our study space from hundreds of software functions to the more tractable number of 45 such functions. Second, the individuals or groups within server-using organizations that have direct needs for the security-related features of Apache are the “webmasters” responsible for the secure and reliable operation of corporate and organizational websites. As direct users, they are in a favorable position to evaluate the utility and novelty of the innovations that they have developed. Third, webmasters are clearly identifiable within organizations and are relatively easy for us to access via the Internet.

### 3.1 Samples of Apache webmasters and data collection methods

Our empirical study utilizes data pooled from two samples of Apache webmasters: (1) webmasters posting a question or an answer on a question at the Apache Usenet Forum (http://www.deja.com/group /comp.infosystems.www.servers.unix), and (2) webmasters subscribing to a specialized online Apache newsgroup (apache-modules.org). Both samples are likely to consist of webmasters having a higher level of technical interest and skill than the average user of Apache software. Of the two groups, subscribers to apache-modules.org, will tend to have a higher level of technical skills than will those posting on the Apache Usenet Forum.

\(^2\) A software author uses his or her own copyright to guarantee these rights to all users by affixing any of a number of standard licensing notices, such as the General Public License (GPL) to the code. Well-known examples of free or open source software are the GNU/Linux computer operating system, Perl programming language, and the Internet e-mail engine SendMail. Many thousands of free and open source software projects exist today and the number is growing rapidly. A repository of open source projects, Sourceforge.net, lists in excess of 10,000 projects and more than 100,00 registered users. Free and open source software has its roots in the “free software” movement started by Richard Stallman in the early 1980s. Stallman founded the Free Software Foundation (FSF) as a means to counter the trend towards proprietary development of software packages, and the release of software without the underlying source code. The purpose of the foundation was to encourage development of software that would come with source code and be available to users for their own modification.
We focused on samples of relatively technically interested and skilled users to ensure an adequate representation of users that had in fact modified Apache security software. Studies of Apache and other open-source software shows that much of the new functionality actually adopted into the authorized and widely-distributed versions of the code is written by a relatively few people (e.g., Mockus et al. 2002). Of course, innovations actually adopted into the authorized code are drawn from a larger pool of code developments created by users and others for their own purposes – and it is the latter that we are concerned with here.

**Sample 1: Apache Usenet Posters**

A total of 1371 postings were made to the Apache Usenet Forum between December 2000 and April 2001 by a total of 563 different individuals. We sent e-mails to them and asked them to fill out an electronic questionnaire (see Appendix for exact question wording and scales used). To raise the likelihood of a response, our cover letter included a note from Ben Hyde, Apache Software Foundation member, explaining that the results of the survey would benefit Apache. We also offered a free MIT T-shirt to all who returned a completed questionnaire.

We eventually received 75 completed questionnaires. Since 122 of our e-mails were returned by the mail server as undeliverable, our response rate was 17% for messages actually delivered to a functioning email address. The response rate for messages actually delivered into recipients hands is probably significantly higher, as it is likely that many messages were delivered to email addresses that were no longer being monitored. Many relatively sophisticated computer users change email accounts frequently to avoid ads and other undesirable email collectively known as “spam.” The 75 individuals who did respond collectively accounted for 37% of the 1371 messages posted to the Apache Usenet Forum during our sampled period. Frequent posters are over-represented in our sample of respondents, but this should not bias our findings regarding characteristics of innovating users.

**Sample 2: Apache-Modules.org Subscribers**

The apache-modules.org mailing list consists of approximately 600 users of Apache who have a general interest in the programming and application of Apache modules. We sent requests via email to all 600 to fill out electronic questionnaires. These requests contained the same inducements to respond as were described for sample 1. Forty emails bounced back as
non-deliverable and we received 63 completed questionnaires. Our response rate for messages that reached the intended address (but that may not have reached the intended addressees for reasons explained earlier) was thus 11%.

Active subscribers are over-represented in this sample but, as was noted earlier, this should not bias our findings with respect to the research questions addressed in this study. Among the active sub-population (only 95 of the 600 subscribers to the list posted a message between November 2000 and May 2001) we have a response rate of 30% while the response rate among inactive subscribers is only 7%. The number of postings i.e. the “degree of activity” does not make a difference: if we weight the answers with the number of postings we obtain almost the same response rate of 30%.

In both samples, the webmasters responding to our questionnaire displayed a good distribution across website type and size. Approximately 76% of the sites were run by for-profit organizations, and 24% by non-profit groups or individuals. The number of persons managing and maintaining each website ranged from 1 to 50 with a median of 3. The number of hits per day per site ranged from 1 to 100 million, with a median of 2,000. Respondent webmasters were also quite up-to-date in their use of Apache. Apache has been progressively improved, and new versions are periodically released incorporating the latest improvements. All of our respondents reported using the latest major release (1.3), and the great majority (83.3%) reported using a relatively recent update of that major release (version 1.3.12 or higher).

3.2 Research measures

Independent variable 1: Lead User Construct

For our lead user construct we use a continuous measure based on von Hippel’s lead user definition (1986). The additive index contains the two aspects of a lead user: (1) high benefits from an innovation, expressed in our questionnaire as “Our organization has a high need for server security” (7-point rating scale) and (2) experience of needs prior to the mass, verbalized as “We experience new server security needs earlier than most other organizations” (7-point rating scale). In order to test the reliability of the two variables we correlated them with a third variable measuring both components of the lead user construct at once, expressed in our questionnaire as “Our organization would benefit significantly from building new Apache security features (e.g. new modules)” (7-point rating scale). We find
that both variables are highly correlated with this mixed item (benefit component: \( r = .393*** \), trend component: \( r = .306*** \)), thus the measurement can be considered reliable.

We find that both components of the lead user construct are significantly correlated in our sample (\( r = .51*** \)), suggesting that in fact it is a single-faceted construct. We also find that the lead user construct follows the pattern of a normal distribution. The Kolmogorov-Smirnov test clearly rejects the null hypothesis that there are differences between the observed and a normal distribution (table 2).

| Test                                                                 | Method                        | Effect  | P       | N  |
|----------------------------------------------------------------------|-------------------------------|---------|---------|----|
| Is there a significant correlation between the two components of the lead user construct? | Bravais-Pearson Correlation   | \( r = .51 \) | .000    | 133|
| Is there a significant difference between the distribution of the lead user construct and a normal distribution? | Kolmogorov-Smirnov test       | \( z = 1.096 \) | .181    | 133|

These findings support those of Morrison et al. (2002). They also found the two components of the lead user construct to be correlated, and found that their “Leading Edge Status” construct (LES) had a bell-shaped distribution in their sample. (LES is a somewhat modified version of the lead user construct, as was explained in section 2.)

**Other independent variables**

Six resource-related independent variables were also chosen for assessment in our study. These were selected on the basis of one or both of two considerations. They were argued to be of importance in our exploratory interviews with Apache users and/or they were shown to have a significant impact on the likelihood of user innovation by Morrison et al. (2000). The variables chosen were: (1) level of in-house programming skills (developing Apache-related innovations involves programming); (2) time a user firm can devote to programming; (3) availability of external programmers; (4) funds to pay external programmers;” (5) availability of other users contacted via Usenet or other Apache user forums and (6) encouragement by the organization.

**Dependent Variable 1: Innovative activities**

The dependent variable in the analysis, innovative activities, is measured by a question asking whether users in our samples had innovated. Specifically, we asked whether or not a user performed security related modifications to his version of Apache that involved coding. In our sample, we identified 30 innovators. Innovations they developed ranged from minor
to major improvements in Apache software security functionality. Some innovators reported developing more than one innovation. When this was so, we asked them respond to our innovation-specific questions with respect to their most important innovation only. In our analyses, we treat the occurrence of innovative activities as a binary dummy variable. Here are some examples of the user-developed modifications in our sample:

- “We built our own security module, a cookie-based authentication system. The Apache plug-in would verify that the user had a properly crypto-signed HTTP cookie, extract the username from the cookie (and pop it into REMOTE_USER), verify that the user in question has access to the requested URL, and then allow the request to proceed.”

- “What we did was add safeword card authenticate into Apache. This coding change actually happened inside suexec. Suexec was modified to return an HTML form page asking for username-passwd (not via the HTTP basic auth headers) and when that was successful, to present another HTML form page providing a safeword challenge and asking for the proper safeword response. Once successful, suexec would call the cgi program like normal providing all the orginal POST or GET data to the script. Obviously, this only worked for protecting CGI programs, but it has been pretty useful for those applications that we judged required additional authentication beyond user-pass”.

- “Our organization has had for the last twelve years a Rdb database that all user accounts are registered in, and then a complex Menu and Security system, this allowed for Applications to perform data-level and task-level security checks, so we can say User X is only allowed to view student payment information for College 123. We had a number of requirements to extend that concept to the Web world (intranet) and so I wrote an Apache Module that did those checks based on URL patterns and HTTP Parameters. The Apache module has been bug-free and very robust in operation.”

**Dependent Variable 2: Likely attractiveness of most important innovation**

Innovations can differ greatly with respect to commercial attractiveness. In our questionnaire, we asked the user-innovators to evaluate the likely attractiveness of their most important innovation. Specifically, we asked them to self-assess its novelty (7-point rating scale with 1 = small improvement to an existing product; 7 = completely new product) and also the likely marketplace potential (7-point rating scale with 1 = very small, 7 = very big) of their modification. As these two scales proved to be highly correlated (r = .684***), they were combined into an index.

Self evaluations of innovations clearly can carry the risk of systematic bias (e.g., “My innovation is marvelous.”). It is especially important for us to evaluate this risk, as accurate evaluations of innovation attractiveness are an essential component of this research. Accordingly, we asked Ben Hyde, the leader of the Apache Development Foundation server
group (the official “owners” and maintainers of Apache open source software) to independently evaluate the attractiveness of the user-developed innovations in our sample.

Hyde is a very well-qualified evaluator for our purposes. He was one of the early founders of Apache, and is intimately familiar with the nature of the innovations contributed by users over time, and with both the novelty and the general utility of these. Thirteen of 30 user-innovators provided us with written descriptions of their innovations. This gave us 26 data points (13 for each of the two factors evaluated for each innovation) for the independent evaluation. A non-parametric Wilcoxon test showed the differences between the independent evaluations by Hyde and the user-innovators’ self-assessments to be non-significant for both of the two factors (and, of course, for the index variable that combined these two factors as well).

Biased self-evaluations can occur when innovators have biased information and/or have a reason to apply a bias to information they have. With respect to the first point, we have reason to believe that the innovators at least had access to unbiased information regarding their innovations. User-innovators participating in open source software projects regularly receive evaluative feedback regarding their innovations from members of their “user communities.” (In the case of open source software and similarly-functioning user innovation communities in other fields, innovators generally freely reveal their innovations to other users and get quick feedback from their peers regarding novelty and utility (Raymond 1999, Franke/Shah 2002).

With respect to the second point, suppose that users did, consciously or unconsciously, apply a bias to their self-assessment of their innovations when responding to our questionnaire. Any such bias would affect our findings in a non-conservative direction only if users that had developed more-attractive innovations had a systematic higher positive self-assessment bias than did users that developing innovations that were objectively less attractive. In fact, studies in psychology show that variation in self-assessment bias runs the opposite way. Thus Kruger and Dunning (1999) show that competent people, if biased, often slightly underestimate their performance, whereas incompetent people are much more likely to overestimate their performance. If we assume that the innovators in our sample developing the more attractive innovations were in general the more competent innovators, this finding directly supports the view that any self-assessment bias in our samples is likely to be in a conservative direction with respect to our study findings. Finally, we note that two other empirical studies of user innovations in user communities in which innovations were widely shared have also tested self-assessments of user-developed innovations with assessments by
independent third parties. No significant self-assessment bias was found in either study (Lüthje and von Hippel 2002, Morrison et al. 2000).

4.0 Findings

4.1. The nature and frequency of innovation in Apache security modules

Recall that Apache is a software product consisting of “open source” software. Such software can be modified by programmers with appropriate skills. In our questionnaire, we asked each of our respondents about the level of modification they had actually made to the Apache code used at their website.

Table 3: Security module modifications by users

| Degree of customization implemented by users | No customization: Standard version only | Security enhanced standard version of Apache installed | Integration of additional security modules | Customized version installed that involved coding by user |
|---------------------------------------------|----------------------------------------|-----------------------------------------------------|------------------------------------------|-------------------------------------------------------|
| % of sample (n = 132)                        | 42.4%                                  | 4.5%                                                | 30.3%                                    | 22.7%                                                  |

For our study of the predictive value of the lead user construct, we elected to focus only on the most significant category of user innovations in our sample: users that reported having installed versions of Apache incorporating user-developed code in their security modules. Twenty three percent of our sample - 30 respondents - were included in this category (table 3). Some of our respondents reported making multiple modifications to their Apache security modules. We asked each respondent to focus only on their “most important” modification, and to evaluate both its novelty and its general marketplace applicability. As can be seen in table 4, our sample incorporates a useful level of variability on these two matters.

Table 4: Commercial attractiveness of user innovations

|                             | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|-----------------------------|------|------|------|------|------|------|------|
| Newness a                   | 6.7% | 16.7%| 20.0%| 16.7%| 20.0%| 16.7%| 3.3% |
| Market potential b          | 0.0% | 13.3%| 16.7%| 33.3%| 20.0%| 6.7% | 10.0%|

|                             | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|-----------------------------|------|------|------|------|------|------|------|
| Newness a                   | 6.7% | 16.7%| 20.0%| 16.7%| 20.0%| 16.7%| 3.3% |
| Market potential b          | 0.0% | 13.3%| 16.7%| 33.3%| 20.0%| 6.7% | 10.0%|

|                             | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|-----------------------------|------|------|------|------|------|------|------|
| Newness a                   | 6.7% | 16.7%| 20.0%| 16.7%| 20.0%| 16.7%| 3.3% |
| Market potential b          | 0.0% | 13.3%| 16.7%| 33.3%| 20.0%| 6.7% | 10.0%|

a Rating scale (1 = small improvement; 7 = completely new) (n=30)
b Rating scale (1 = very small; 7 = very big) (n=30)

4.2 Explanatory power of the lead user construct with respect to innovative activities

To test the explanatory power of the lead user construct and its two components with regard to the occurrence of innovative activities (assuming a binary variable) we estimate four
logit models. In model 1 and 2, we look at the effects of the components when taken independently. In model 3 we estimate the explanatory power of the two components simultaneously, and in model 4 we estimate their power when combined as a single construct (as the lead user theory proposes).

Table 5: Innovative activities as a function of the lead user construct and its components

| Independent Variable                                      | Model 1 * | Model 2 * | Model 3 * | Model 4 * |
|-----------------------------------------------------------|-----------|-----------|-----------|-----------|
| Benefit from innovation (LU component 1)                  | .473*** (.155) | .384** (.169) |           |           |
| Being ahead of the trend (LU component 2)                 |           |           | .329*** (.122) | .181* (.136) |
| Lead User Index (both components combined)                |           |           |           | .269*** (.082) |

| McFadden’s R²    | 0.083 | 0.055 | 0.095 | 0.091 |
| n                | 133   | 133   | 133   | 133   |
| chi²             | 11.76 | 7.76  | 13.554 | 12.913 |
| Prob.            | 0.001 | 0.005 | 0.001 | 0.000 |
| 2 Log likelihood | - 65.38 | - 69.37 | - 63.58 | - 112.79 |
| correctly classified | 75.4% | 73.3% | 77.4% | 77.4% |

* Logit estimates (standard error)
* * * p<.10; ** p<.05, *** p<.01 (one-tailed tests)

As can be seen in table 5 both components, when taken separately as independent variables, have a strong and significant impact on innovative user activities (models 1 and 2). Model 3 reveals that both components keep their explanatory power also when simultaneously analyzed as they have an independent impact on the likelihood of innovation. All three models reveal that the impact of component 1, benefit obtained from the innovation, is stronger than the impact of the component 2, being ahead of the market. Note in this regard that model 1 has a higher R² than model 2. Also note that, when tested simultaneously in model 3, the path coefficient and probability level for component 1 are clearly better. Model 3 performs significantly better than models 1 and 2, indicating that the inclusion of both components yields in better predictions. This can be seen as a validation of the lead user construct: both components are correlated, and neither can be dropped without loss of explanatory power.

Tests on collinearity show that although the two independent variables are correlated good estimations were obtained.
In model 4 we test whether the explanatory power of the two components is shrouded when they are combined as an index. This is an important test because if the performance of model 4 is decreased as compared to model 3 (where the two components are treated separately) this would be a sharp counter-argument against the single-faceted nature of the lead user construct: although correlated, the two components would have to be treated as separate factors. The results shows, however, that the combination of the two components into one index does not affect the explanatory power of the model as compared to model 3.

4.3 Explanatory power of the lead user construct with respect to innovation attractiveness

In this section we test the explanatory power of the lead user construct with respect to innovation attractiveness. (Recall from section 2 that innovation “attractiveness” is an index variable comprised of the sum of two components: the novelty of the innovation, and the generality of marketplace demand. Recall from section 3.2 that our data on innovation attractiveness was obtained from innovator self-assessment and corroborated by an independent rater.)

We use data from the 30 innovations our sample to estimate four OLS regression models. Similar to the test in section 4, we first estimate the effects of the two components when taken separately (model 1 and 2). In model 3 we estimate their explanatory power when included simultaneously, and in model 4 we estimate their power when combined as a single construct (as the lead user theory proposes).

Table 6: Innovation attractiveness as a function of the lead user construct and its components

| Independent Variable                  | Model 1 a | Model 2 a | Model 3 a | Model 4 a |
|---------------------------------------|-----------|-----------|-----------|-----------|
| Benefit from innovation (LU component 1) | .622** (.285) | .030 (.297) |           |           |
| Being ahead of the trend (LU component 2) | 1.364*** (.308) | 1.323*** (.385) |           |           |
| Lead User Index (both components combined) |           |           | .572*** (.163) |           |

|                      | R²        | adjusted R² | n  | F   | Prob. |
|----------------------|-----------|-------------|----|-----|-------|
|                      | .145      | .114        | 30 | 4.750 | .038  |
|                      | .405      | .384        | 30 | 19.054 | .000  |
|                      | .405      | .361        | 30 | 9.196 | .001  |
|                      | .305      | .281        | 30 | 12.314 | .002  |

a OLS estimates (standard error)
b Dependent variable: index of attractiveness of innovations. (Index range: 2 = not attractive to 14 = very attractive)

* p<.10; ** p<.05, *** p<.01 (one-tailed tests)
Models 1 and 2 show that both components when taken separately are good predictors of the attractiveness of the innovations. Although the sample size is low, their impact is clearly significant. (Model 2, however, has a much higher R²). When taken simultaneously, only the second component of the lead user construct (the trend component) keeps its clear effect (model 3) and the R² of the model stagnates. This leads to the conclusion that the significant path coefficient of the benefit component reported in model 1 is only due to the high correlation of both components. In other words, only the “being ahead of the trend” component appears to selectively identify more novel and commercially attractive innovations. We will explore the reasons possibly underlying this finding in our discussion section.

As in section 5, the combination of the two components to one index (model 4) only moderately affects explanatory power of the model relative to model 3. Again, this supports the appropriateness of treating these two components as a single lead user construct.

4.4 Relative screening power of the lead user construct

The lead user construct was designed to selectively identify innovations that foreshadow general marketplace demand, and that therefore are more attractive from the viewpoint of the general marketplace and the manufacturers that supply it. We illustrate this capability by comparing the predictive power of the lead user construct relative to that of users’ possession of or access to 6 types of innovation-related resources considered significant by Apache webmaster interviewees. As can be seen (table 7) users in the top 20% with respect to the lead user construct are more likely to innovate and likely to develop innovations having high attractiveness than are those in the top 20% with respect to the other variables tested.
Table 7: Seven variables’ performance in identifying attractive user innovation

| Predictive Variables                                                                 | Percentage Innovators | Mean Attractiveness of the Innovation\(^a\) |
|-------------------------------------------------------------------------------------|------------------------|--------------------------------------------|
| Top 20% on Lead User Index                                                           | 48.1%                  | 9.54 (3.42)                                |
| Top 20% on “Programming skills in our webmaster group”                               | 36.2%                  | 8.11 (2.95)                                |
| Top 20% on “Encouragement by organization to modify Apache”                          | 33.3%                  | 8.53 (3.22)                                |
| Top 20% on “Time available to modify Apache”                                         | 36.7%                  | 8.63 (3.12)                                |
| Top 20% on “Funds available to modify Apache”                                        | 42.5%                  | 8.23 (3.13)                                |
| Top 20% on “Other users available to help modify Apache”                             | 24.0%                  | 8.06 (3.15)                                |
| Top 20% on “External programmers available to help modify Apache”                    | 11.4%                  | 7.01 (4.25)                                |

\(^a\) Index range from 2 = very low to 14 = very high

5. Discussion

In this study we have explored the performance of the lead user construct in selectively identifying commercially promising user-developed innovations – operationalized as innovation that were both very new and of utility to many others in the target marketplace. We first found that the two components of the lead user definition (potential benefit a user obtains from an innovation, and users’ position at the leading edge of important marketplace trends) each has an independent impact on the likelihood of innovation by users. We also found that combining the two components into a single index does not decrease explanatory power. This finding clearly confirms the appropriateness of a single lead user construct incorporating these two components. (The high correlation of \(r = .51 (p = .000)\) between the two components shows that it is likely that a user simultaneously has the characteristic of high need for an innovation and a position ahead of the trend.)

Next, we found that applying the lead user construct as an independent variable to a sample of innovations did yield the effect predicted for it: It selectively predicted commercially attractive user innovations. Further analysis traced this selection effect to one of the two components of the lead user construct: a user’s position relative to important marketplace trends.
A discussion of the likely mode by which each of the components of the lead user construct impacts the likelihood of innovation by users can enhance our understanding of this central finding. The potential benefit component of the lead user index represents the “demand side” of users’ innovation calculations. Studies of industrial product and process innovations (e.g., Mansfield, 1968) have shown that the greater the benefit a firm expects to obtain from a novel product or process, the greater will be the investment devoted to obtaining a solution.

The “ahead of marketplace trends” component of the lead user index makes an independent contribution to predicting the likelihood of user innovation because it addresses the “supply side” of the innovations desired by lead users. Lead users experience needs for products ahead of others in the marketplace. The “leading edge” of markets are by definition small and in addition may be uncertain. As a consequence manufacturers are unlikely to have a product on offer when lead users encounter a need for it – and those that do want the product early are likely to have to innovate rather than buy. The further ahead of a trend a user is, the lower the likelihood of an existing solution and so the greater the likelihood this “supply side” motivator will contribute to inducing innovation.

Finally, the filtering effect of the “ahead of the trend” component – resulting in selective identification of innovations that are more generally promising – can also be understood in a straight-forward manner. Innovations that are “at the leading edge of the general market” in the view of innovating users will tend to be of general value and interest when the bulk of the market does encounter the same needs as are now being encountered by lead users.

Beyond an improvement to our understanding of the lead user construct, our central finding has an important practical application for innovation manufacturers and others who may have a reason to selectively identify “attractive” user-developed innovations. Recall from table 1 that a significant fraction of the users in a population may innovate. When the total number of user innovations is relatively small, as in our sample, the cost required to individually evaluate each might not be excessively burdensome to a manufacturer. However, when the population of users judged likely to innovate rises into the millions – as it may, for example, in the case of sports equipment and electronic games – the cost of evaluating each user innovation for commercial promise would clearly be very high. Under such conditions, the selective effect of the lead user construct becomes very valuable.

In the small sample studied here, we showed the utility of focusing on users scoring among the top 20% with respect to the lead user construct. Presumably, in larger samples,
individual evaluations of innovations by users could profitably be restricted to innovators receiving only the very highest scores on this measure. It is important to point out, however, that simple mass screening of target market users in search of those high on the lead user construct is unlikely to be efficient. There are two reasons for this. First, as was done in this study, it is often relatively easy to reduce the target market group most likely to develop valuable innovations from millions to a few thousands or hundreds by applying a few common-sense screening criteria. (In the case of the study we report upon here, for example, we screened only 137 “high likelihood” Apache webmasters in a total population numbering over one million.) Second, as was shown in the Lillien et al. (2002) study of 3M lead user study practice and performance, the most promising lead user innovations are often found among users outside of the target market (see “suggestions for further research”).

Suggestions for further research

The data in this study were acquired from users innovating with respect to an aspect of an open source software product, Apache webserver software security modules. The open source software context differs from that of most product types in that users are explicitly encouraged to modify the product – indeed, the entire product is the net result of many innovations freely contributed by users and others. We see no reason why this unusual aspect of our study context will affect the generalizability of our results. However, only similar studies carried out in other product and service arenas can determine this with certainty.

In this study we explored how one might selectively identify the most promising innovations among lead users in a target market. However, recall from Lillien et al. (2002) that innovations by users offering “breakthrough” potential for a target market may often be developed by lead users that are entirely outside of a target market population. (This is reasonable when such outside users face needs that are more intense than and/or ahead of all members of the target market. The illustration we cited earlier: Auto manufacturers seeking to improve auto efficiency by reducing weight with lighter, stronger materials might find breakthroughs in the aerospace industry, which faces a very similar problem in an even more extreme form.) Those seeking “breakthroughs” developed by lead users will therefore find it very important to explore how to incorporate promising groups of “outside” lead users into populations to be filtered for attractive innovations with the aid of the lead user construct.

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### Appendix: Variables

#### Measurement

| Motivational Variables | Lead User Status |
|------------------------|------------------|
|                        | “We experience new server security needs earlier than most other organizations” (7-point rating scale) |
|                        | “Our organization has a high need for server security” (7-point rating scale) |
|                        | “Our organization has benefited significantly by the early adoption and use of Apache security features (e.g. new modules)” (7-point rating scale) |
|                        | “Our organization would benefit significantly from building new Apache security features (e.g. new modules)” (7-point rating scale) |

| Resources | Programming skills |
|-----------|--------------------|
|           | “Some people in our server maintenance group have the programming skills to download and integrate an Apache module in our web server software” (7-point rating scale) |
|           | “Some people in our server maintenance group are able to do some modifications of Apache that involve coding” (7-point rating scale) |

| Encouragement by organization | “Our organizational policy encourages “home-made” changes to Apache” (7-point rating scale) |
| Time | “Our group has the time to work on possible improvements to Apache” (7-point rating scale) |

| Funds | “Our group has the funds to pay external programmers to help us improving our version of Apache” (7-point rating scale) |

| Other users available | “Other users (contacted via Usenet or other Apache user forums) can help us improving our version of Apache” (7-point rating scale) |

| External programmers available | “It is easy to find appropriate external programmers to us improving our version of Apache” (7-point rating scale) |

| Innovative activities | Likelihood of innovating |
|-----------------------|--------------------------|
|                       | “Are you currently using additional security related modules of Apache in your organization?” |
|                       | Answer scale: (1) no, standard version only (downloaded from e.g. Apache or purchased from Red Hat) (2) no, security enhanced standard version only (purchased from e.g. Covalent or Stronghold) (3) Yes, we added security related modules (downloaded from e.g. www.modules.apache.org) (4) yes, we used a customized version (security related modifications that involved coding) |
|                       | Only respondents who checked (4) were treated as innovators |
|                       | Additionally, we cross-checked the validity of this classification by the characteristics of their most important innovation. We detected no overt inconsistence. |

| “Attractiveness” of the most important innovation your webmaster group has developed | “Please rate the most important product idea/improvement on the following dimensions” |
|--------------------------------------------------------------------------------------|---------------------------------------------------------------------|
|                                                                                      | newness (7-point rating scale: 1 = small improvement to an existing product, 7 = completely new product) |
|                                                                                      | market potential (number of potential users) (7-point rating scale: 1 = very small, 7 = very big) |