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Abstract

Our goal in this study is to provide insight into the motivational profiles of open source contributors. Adopting a functionalist view of motivation, we identify five functional dimensions from the literature on volunteerism that are relevant to the open source context and three functional dimensions from the literature on open source development. To assess the salience and relative strength of each functional explanation for open source participation, we conducted secure Web-based surveys of developers who participated in three large Apache open source projects. Applying exploratory factor analytic techniques to analyze the survey data collected from 122 Apache participants, we found 5 distinct factors underlying the motivation to participate in open source projects. We then used conjoint analysis to assess the relative importance of these underlying motivations. Results from the conjoint analysis indicate that while several dimensions are significant in explaining the motivation to participate in open source projects, the dominant motivations include increasing the contributor's use value of the software (27 percent) followed by the recreational value of the task (19 percent) and the potential career impacts from participation (12 percent). This study contributes to the growing literature on open source software development by providing insight into the underlying motivational profiles of open source participation and by identifying the relative importance of different motivations within those profiles.

Keywords: Open source software development, motivation, conjoint analysis

Introduction

Open source software (OSS) development, i.e., public software development projects where participants can read, modify, and redistribute the software source code (O'Reilly 2000; OSI 2001), is arguably one of the most exciting phenomena in the software industry today. One widely debated question is why open source programmers voluntarily contribute significant amounts of time and effort to these projects, thereby foregoing any direct remuneration that they might accrue by spending that same time working on a commercial software project. Often quoted individual level motivations for participating in open source development projects cover a broad spectrum including scratching a "personal itch" with respect to software functionality, enjoyment, and a desire to be "part of a team" (Ghosh 1998; O'Reilly 2000; Raymond 1999). Others liken the open source community to a gift culture where the status of a participant depends on "what he gives away" (Raymond 1999). Alternatively, Lerner and Tirole (2002) suggest that open source participation may in part be explained by existing theories of labor economics.

In this study we examine two unanswered but important questions regarding open source participation. What motivates developers to participate in open source projects? And, which motivations are most salient in explaining open source participation? With some exceptions, theorizing about the motives for open source participation has largely been left to the advocates inside the open source community. Although there has been significant discussion concerning which explanations are best suited to describe open source participation, there are few rigorous empirical studies of open source participation. Given the increasing importance of open source methods to software producers and open source products to software consumers, it is vital to seek a more formal approach of theory formulation and empirical validation to explain differences in open source participation. For producers of software, this means understanding how to get things done in open source projects. For consumers of open source software, this means understanding how things get done, thereby reducing some of the uncertainty associated with open source adoption. As is the case for software development in general, the viability of OSS projects ultimately depends on the individuals who staff the projects. As observed by Strasser (2001, p. 44), "the viability of open source software as a serious alternative to proprietary software hinges upon the resolution of the incentive issue."

Our study contributes to the growing body of research on OSS in several important ways. First, our work contributes to the research on OSS participation by drawing upon well-established theories of individual motivation to derive the motivational profiles of OSS participants. Applying factor analytic techniques to analyze survey data collected from open source participants, we find empirical support for five distinct factors underlying individual motivations to participate in open source projects. Our findings lend support to a functional explanation of open source participation. An additional and significant contribution of our work is establishing the relative importance of underlying motivations through the novel application of conjoint analysis in the OSS domain. The relative strength of motivations has significant practical implications for software producers contemplating the use of open source methods and software consumers seeking informative measures on which to evaluate OSS project viability. Thus, our research provides the first clear picture of the underlying motivational structure of open source participation and the relative importance of those motivations within that structure.

In the following sections, we adopt a functionalist view of motivation and identify five functional dimensions from the literature on volunteerism that are relevant to the open source context. We then consider the literature on open source software development and derive three additional functional explanations for OSS participation.

A Functional Explanation for Open Source Participation

The motivation for open source participation can be investigated from a variety of theoretical perspectives including social psychological, cultural, and economic. Eric Raymond, an evangelist of the open source movement, popularized social psychological and cultural explanations of open source participation. In the cultural view, open source functions as a gift culture, where the reputation of a programmer is primarily determined by his or her free contributions (Raymond 1999). As a second explanation, Raymond offers a craftsmanship model, where the artisan aspects of programming motivate developers to create works to be admired not only by themselves but also by others. In both cases, developers are motivated through the recognition of their contributions by their peers. Such explanations find theoretical support in social psychology (Clary et al. 1998; Mauss 1967).

Social psychology is a branch of psychology that studies individuals in their social context. It is the study of how and why people think, feel, and do the things they do depending upon their situation. There are numerous theoretical bases of motivation and performance in social psychology including social exchange theory (Blau 1964), psychological contracts theory (Rousseau 1995), helping behavior and volunteerism (Benson et al. 1980; Clary and Orenstein 1991), work design (Hackman and Oldham 1980), and others. Both social exchange theory and psychological contracts theory are premised on the notions of an exchange relationship between two actors (typically an employee and an organization) where the relationship is based upon norms of reciprocity or rules governing the social exchange (Settoon et al. 1996) or upon promises made or implicit in the actors' interactions (Rousseau 1995). As Rousseau notes, in remote or distributed environments where the actors do not meet face-to-face (such as in open source software development), the formation of exchange relationships could be difficult and thus relatively unlikely. Indeed, recent empirical studies of field support for open source software projects have not found evidence of the operation of reciprocity in open source environments (Lakhami and von Hippel 2000). Thus, in this study, our focus is on the social psychological theories that closely relate to the motives most likely to operate in an open source context. Specifically, these include theories of helping behavior and volunteerism.

Helping behavior has enjoyed significant and long-lived attention as a field of psychological inquiry (Staub 1978). Research in this area distinguishes between spontaneous and planned helping behavior (Benson et al. 1980). Volunteerism is often cited as an exemplar of planned helping (Clary and Snyder 1991), which "often calls for considerably more planning, sorting out of priorities, and matching of personal capabilities and interests with the type of intervention" (Benson et al. 1980, p. 89). As observed by Clary et al. (1998), volunteerism, as planned behavior, requires actively seeking volunteer opportunities, as well as deliberations about whether to volunteer and to what extent. A commitment to volunteer may require considerable personal costs such as time, effort, and opportunity. That open source developers are, for the most part, volunteers is axiomatic. The question of interest is why do developers volunteer and what sustains this behavior? It is the voluntary, sustained, and ongoing nature of participation in open source projects that suggests such participation has motivational underpinnings. Theories of motivation seek to explain the processes that give behavior its energy and direction (Litwin and Stringer 1968). These concerns accurately reflect the nature of our inquiries regarding open source participation—that is, what motivates developers to participate?

Contributing to open source software involves voluntarily spending one's time in the coding of software. A functional approach to understanding motivation toward volunteer activities, one that emphasizes the social-psychological purposes served by participation, is well established in the literature (Clary et al. 1998; Clary and Snyder 1991). One consistent theme of any functional approach is that people engage in the same activity in the service of different social psychological functions (Smith et al. 1956; Snyder and DeBono 1989). In the context of open source projects, developer contributions, while seemingly similar, may reflect distinctly different underlying motivational processes. As a consequence, the functions served by participation can significantly influence the outcome or products of participation. Theorized social-psychological functions served by volunteerism that are relevant to OSS participation include the following:

- ***Normative***. Motivation to volunteer is considered to serve a normative function when participation is initiated to better align oneself with the expectations or actions of peers or significant others. In the context of open source development, OSS participation may be esteemed within one's peer group such as on a college campus or within an online community. Thus, an individual motivated by a normative function will contribute to OSS projects to gain the respect of significant others.

- ***Values***. Motivation to volunteer is considered to serve a values function when participation is undertaken out of solidarity with the core beliefs or values of the organization. One example of this type of motivation in open source would be a common dislike for all things Microsoft that is prevalent in several OSS communities and projects (Stallman 2001). An individual motivated by such a values function would contribute to OSS projects because he or she shares the core value that software should be "free."

- ***Understanding***. Motivation to volunteer is considered to serve an understanding function when participation is initiated to facilitate general learning or the exercise of knowledge, skills, and abilities. In the context of open source, an individual motivated by an understanding function may undertake OSS participation to become more familiar with the Web in general or to become familiar with a technology out of intellectual curiosity.

- ***Career Concerns***. Motivation to volunteer is considered to serve a career-related function when participation is undertaken for the purpose of acquiring marketable career-related skills or for the maintenance of existing skills. A career-based explanation of OSS participation is one of job training: that participation serves as on-the-job-training. For example, an individual motivated by career concerns could participate in OSS projects in order to gain or update programming skills.

- ***Ego Enhancement***. Unrelated to egotism, motivation to volunteer is considered to serve an ego enhancement function when participation involves a motivational process that centers on the ego's growth and development including self-esteem, self-improvement, or personal growth. Similar to understanding, an ego enhancement explanation of OSS participation would involve the desire to feel better about oneself or one's abilities through accomplishment in an OSS project. Contributing to an open source project's code base and being acknowledged as a contributor could serve as a powerful motivation for an individual seeking to fulfill an ego enhancement function.

Other Functional Motivations for Open Source Participation

In addition to the various motivations to volunteer, there are several other functional motivations for open source participation in the OSS literature. In a recent article, Hars and Ou (2001) explore various theoretical bases for OSS participation and report the results of an exploratory survey. Two broad categories of motivation are identified: internal motivations and external rewards. Some argue that in work activities, an ideal internal motivator derives from the work content which should be satisfactory and fulfilling for workers (Hackman and Oldham 1980; Osterloh and Frey 2000). According to the job characteristics model, five core task dimensions (variety, identity, significance, autonomy, and feedback) influence perceptions of the motivating potential of tasks as well as work performance. In open source development, both variety and autonomy are likely to be high as participants can select the different features they want to add or repair. Identity is also likely to be high as contributions are self-contained pieces of work. Task significance and feedback could be high, depending on the kind of code contributed and the reactions of others in the community to the contribution. Thus, contributing to OSS projects is likely to be internally motivating, i.e., developers may contribute because they enjoy it. This suggests that open source tasks, and hence participation, may serve a ***recreation*** function for OSS participants.

A source of motivation related to ego enhancement is reputation. Participating in open source projects may serve to build up one's reputation or status within the community. For example, Moon and Sproull (2002) cite a motivating "credit" policy as an important component of any successful open source project. A credit-where-credit-is-due philosophy may be critical in building and maintaining reputation within an open source community. Similarly, Bezroukov (1999) compares OSS projects to academic and scientific communities driven by competition for status and reputation. Thus, motivation to participate may serve a ***reputation*** enhancement function for OSS participants.

Finally, we consider the prospect that the need for specific functionality from the open source software itself may play a role in motivating OSS participation (Hars and Ou 2000). The need for specific functionality is often cited by OSS developers as the reason they initially became involved in their projects (Bollinger 1999; DiBona et al. 1999). A study by Hertel et al. (2003) of Linux participation reveals pragmatic motives to improve the usefulness of the software as an important motivation for contributing. Indeed, increasing the use value of the software has been cited as the primary motivation to initiate many of the projects that ultimately have become some of the most successful of open source projects to date. Lerner and Tirole (2002) report the results from three case studies into the origins of three popular open source projects: Apache, Perl, and SendMail. In all three cases, use value of the software was cited as the primary motivation for the initial creation of the software. Thus, motivation to participate may derive the need to increase the ***use value*** of the software for OSS participants.

In summary, drawing upon the literature surrounding volunteerism and job design we have adopted a functionalist view of motivation to identify eight functionally based motives to participate in open source projects. These hypothesized functional motivations include normative pressures, shared values, understanding, career concerns, ego enhancement, recreation, reputation, and use value.

Research Methods and Results

To identify and analyze the motivational profiles of open source contributors, we used a mixed methods approach (Tashakkori and Teddlie 1998) involving a survey and a conjoint analysis exercise. We surveyed the developers of three open source projects under the control of the Apache Software Foundation (ASF). The Apache HTTP (Web) server and associated projects are some of the most successful open source products to date. The Apache server, the original ASF project, and its derivatives, have a dominant 63 percent share of the Web server market (Netcraft 2003). Since its inception, the Apache Web server has had over 7,000 source code contributions from more than 400 different open source developers (Mockus et al. 2000). Although any of the Apache projects could provide an interesting vehicle to explore our research question, we have chosen to concentrate our data collection efforts on the HTTP, Jakarta, and XML projects.[1] The Apache HTTP server project is a freely available source code implementation of an HTTP (Web) server and is the project around which the Apache Group initially formed. The Jakarta project consists of all Apache-related server side Java projects and includes more than 18 Java-related subprojects. The Apache XML project is home for Apache XML related activities and has more than nine XML related subprojects.

The data for this study comes from a targeted, secure, Web-based survey of Apache developers. The survey consists of two instruments designed to elicit the motivational profiles of the developers (instrument one) and to reveal the relative importance of each motivation in influencing their participation (instrument two). Using archival data on the Apache projects, we identified 237 Apache contributors.[2] The survey was introduced via e-mail, and data were collected in 2003. Eleven e-mail invitations were

[1]We limit our attention to these three projects for practical reasons. First, these projects are by far the largest, both in terms of the number of developers and the number of contributions. Second, access to archival data for these projects has proven less problematic than for some of the smaller projects.

[2]Contributors' contact information (e-mail) was extracted from publicly available Apache project archives using a series of tools developed for that purpose. Specifically, metadata from the source control software used by the Apache projects was mined to associate Apache developers with their specific contributions.

undeliverable. Of the remaining 226 contributors, 122 completed the first instrument yielding a response rate of 54 percent, and 86 completed the second instrument yielding a response rate of 38 percent. A detailed description of the methods, analysis and results for the survey and the conjoint analysis follows.

Identifying the Motivational Profiles of OSS Developers: Survey and Factor Analysis

To assess the social psychological functions served by volunteerism in an open source context, we adopted the volunteer functions inventory assessment (VFI) instrument (Clary et al. 1998). Because the instrument was originally conceived to measure the motivations of volunteers in non-profit organizations, we adapted the VFI questions to the OSS environment. In addition, we added measures for the three functional OSS motivations identified earlier: recreation, reputation, and use value.[3]

We used exploratory factor analysis to identify the latent variables that account for the correlations among responses regarding our hypothesized functional dimensions of OSS participation (Cattell 1988). Although the VFI instrument has been validated in numerous settings, we adapted the instrument to the OSS setting and also added questions to the instrument to assess three other constructs. Thus, given our modification and enhancement of the VFI instrument, exploratory (not confirmatory) factor analysis is most appropriate. Several considerations are important to justify the use of factor analytic techniques. First is sample size. Cattell offers a heuristic of a 2:1 ratio of observations to items while Gorsuch (1983) argues for an "ideal" ratio closer to 5:1. A total of 122 responses were available for this analysis resulting in an acceptable ratio of 5.1:1 of observations to items. Another issue deals with identifying the underlying factors or latent constructs. There are two considerations here: significance of factor loadings and simplicity of factor structure. While there is no precise lower bound where one should recognize factor loadings as significant, we used a cut-off of .45 to determine significant factor loadings. This lower bound is well above the published criteria of .30 deemed acceptable in exploratory studies such as ours (Sethi and King 1991).

Our common factor analysis procedure specified a principal axis initial extraction method using communality estimates set to the squared multiple correlations between the items. Preliminary factor analytic results of the scale items were obtained and analyzed from an unconstrained factor solution using orthogonal (varimax) rotation. Nine items failed to meet our minimum factor loading threshold of .45 and were dropped from analysis. One additional item cross-loaded on two or more factors at a level of .35 or greater and was also dropped from analysis. Thus, 14 items were retained for final analysis. The final analysis employed an oblique (promax, power 3) rotation as we did not want to presume orthogonality of the factors. Again we used a combination of several criteria to determine the appropriate number of factors to be retained (Loehlin 2004). First, given an average initial communality estimate of .54, an adjusted eigenvalue criterion would recommend a four-factor solution. Examination of the scree plot, however, recommends a five- or six-factor solution. Examining the proportion of the common variance accounted for by the factors in this case also recommends a five-factor solution as the first five factors account for nearly 100 percent of the initial common variance estimate. We interpret the above results to indicate a five-factor solution. As an additional check of the five-factor solution, the analysis was repeated while constraining the results to a five-factor solution. We then examined the resulting off-diagonal elements of the residual correlation matrix. In nearly all cases the residual values are less than .05 (all values below .07) with a root mean square off-diagonal residual of .032, indicating that the original correlations can be accurately reproduced from the five-factor solution.

Cronbach's alphas were calculated to assess the internal reliability of each factor with all values exceeding the recommended cutoff of .70 (Nunnally and Bernstein 1978). Interpretation and discussion of the five factors that emerged from the exploratory factor analysis follow.

Use-value motivations stem from a need for OSS product functionality that is currently not implemented or missing due to defects. Factor 1 consists of three items originally intended to capture motivations consistent with a use value interpretation. This latent variable (factor) is labeled ***Use-Value***. The ***Use-Value*** factor accounts for 46.8 percent of the common variation of responses in our analysis. Reputation motivations are the result of needs to garner stature within the OSS community. Factor 2 consists of three items originally intended to capture motivations consistent with a reputation interpretation. This latent variable is labeled ***Reputation***. The ***Reputation*** factor accounts for 24.0 percent of the common variation of responses in our analysis. Career related motivations are driven by concerns about one's career—that OSS participation may serve as some form of job-training. Factor 3 consists of three items originally intended to capture motivations consistent with a career-concerns interpretation. This latent variable is labeled ***Career Concerns***. The ***Career Concerns*** factor accounts for 13.3 percent of the common variation of responses

[3]A complete listing of the survey instrument is available from the authors upon request.

in our analysis. Normative motivations for OSS participation stem a normative reaction to peers or significant others with whom respondents share similar interests. Factor 4 consists of two items originally intended to capture motivations consistent with the normative interpretation. This latent variable is labeled ***Normative***. The ***Normative*** factor accounts for 5.5 percent of the common variation of responses in our analysis. Recreation motivations are the result the motivational nature of the task (primarily programming) and that the task is internally motivating and thus serves as form of entertainment. Factor 5 consists of three items originally intended to capture motivations consistent with a recreation interpretation. This latent variable is labeled ***Recreation***. The ***Recreation*** factor accounts for 10.5 percent of the common variation of responses in our analysis.

Identifying the Relative Importance of Motivations: Conjoint Analysis

To assess the relative importance of the different motivational factors, we implemented a conjoint exercise. Conjoint analysis was first used by researchers in marketing and product development (Green and Rao 1971; Green and Wind 1975), but is now used in various disciplines ranging from agriculture to capital budgeting and healthcare (Detsky et al. 1997; Wigton et al. 1986). In applying this method, respondents make trade-offs of perceived benefits against perceived costs. The data from this exercise allow us to estimate a respondent's utility for various dimensions of hypothesized benefits and costs.

To keep the conjoint tasks to a manageable size, Green and Srinivasan (1990) recommend that the number of attributes be limited to six or fewer where possible. Based on our exploratory factor analysis, we selected the five unique motivational dimensions: Career Concerns, Use-Value, Reputation, Recreation, and Normative. Each of these five dimensions was operationalized with three levels in the conjoint analysis (i.e., with low, medium, and high values to be used by individuals for making trade-off decisions). The Career Concerns dimension is predicated on the belief that participation in OSS projects is sometimes rewarded by current and future employers. Thus, this dimension is operationalized as the anticipated annual dollar impact of OSS participation and has the following levels: $0 (no impact), $740, and $2,100.[4] The Use-Value dimension is operationalized as the time participants might expect to save as a result of their contribution. Such time savings might take the form of increased efficiency in the performance of their jobs or less downtime as a result of their contributions. The anticipated time savings resulting from increased Use-Value is operationalized as 17, 34, or 51 hours per year. To operationalize the Reputation dimension, we take advantage of the Apache career structure.[5] Specifically, as a result of their contributions, participants may anticipate achieving either the rank of developer, committer, or ASF member. The Recreation and Normative dimensions are operationalized as simple ordinal scales of very high, moderate, and very low.

In addition to the five factors discussed above, we add two control dimensions that are relevant for making trade-off evaluations: the amount of effort required by participation and contribution type. The objective of the effort dimension is to impose a cost of participation. Many OSS participants devote significant amounts of time to their projects (Torvalds and Diamond 2001). If OSS participation were costless, higher levels of the five previously mentioned factors would always dominate lower levels. Thus, the Effort dimension is operationalized as the time a participant might expect devote to their OSS contributions and has values of 15, 35, and 100 hours per year.

Not all programming tasks have the same level of desirability (Weinberg 1998). While OSS participants are free to self-select the projects and tasks on which they would like to work, all options may not be open to them. For example, it is now well established that within the Linux community only a select few "lieutenants" regularly make contributions included in the Linux kernel (Browne 1998; Moon and Sproull 2002). The objective of the contribution type dimension is to capture the scarce nature of the most desirable work on many popular OSS projects. By motivating this notion of scarcity, we capture an essential trade-off of OSS participation. As a result, this dimension is designed to capture a realistic set of tasks common to all OSS projects. Thus, this dimension is operationalized as "Adding New Functionality," "Enhancing Existing Functionality," and "Fixing Software Bugs" (defects).

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[4]Values for the Career Concern dimension derive from correlational results reported in Hann et al. (2002) and from the *Computerworld* 2002 Salary/Skills Survey. Values for the Use-Value dimension derive from Kemerer and Slaughter (1999), Slaughter et al. (1998), and Banker et al. (1998). Values for the Effort dimension are from Hann et al. (2002).

[5]There are five observable levels of recognition or rank within the ASF. In order of increasing status, these are developer, committer, ASF member, project management committee member, and ASF board member. In all cases advancement in rank is in recognition of an individual's commitment and contributions to an Apache project. Thus, rank symbolizes both status (reputation) and the degree of accomplishment within ASF projects.

Taken together, our conjoint analysis assessed trade-offs along the seven dimensions set out above. Based on these seven dimensions and their treatment levels, there were a maximum of $3^7 = 2187$ possible conjoint stimuli. To avoid asking subjects to rank too many alternatives and following advanced techniques in conjoint analysis, we apply individualized hybrid models, which combine compositional, decompositional, and hybrid preference models (Green 1984; Green and Krieger 1996).

Hybrid conjoint models combine a two-stage compositional procedure and a decompositional conjoint exercise. Specifically, the contributor's preference for various dimensions is measured in three separate steps. Steps 1 and 2 comprise the compositional aspects of the model (referred to as the self-explicated stage) while step 3 comprises the decompositional. In step 1, the respondent is asked to assign a weight to the various cost and benefit dimensions. In step 2, the respondent rates the desirability of the levels of each dimension. And in step 3, the respondent rank orders a set of hypothetical open source participation scenarios (called full profiles or stimuli) and assigns a probability of participation. This allows us to estimate the contributor's utility function, which assigns a part-worth to each benefit and cost dimension. Essentially, the part-worth is the marginal utility of the dimension in the contributor's ranking of the conjoint scenarios. Establishing a part-worth facilitates comparison of economic benefits such as salary increases with non-economic benefits such as a raise in status or reputation. Hence, one can assess the weight that open source contributors give to various factors underlying their participation decisions.

The hybrid approach has emerged as the method of choice in situations involving complex trade-offs or a large number of dimensions or attributes. There are several models used to analyze the results of hybrid conjoint data. We have chosen a model that has shown superior empirical performance in a recent review of competing hybrid models— the modified importances/ desirabilities model (Green 1984). The following equation defines this model:

$$y_{ml} = u_{ml} A + \varepsilon; \; m = 1..M; \; l = 1..L_m$$

$$Where: \; y_{ml} = w_m d_{ml} \text{ and } (s_r - \upsilon) / \tau = \sum_{m=1}^{M} \sum_{l=1}^{L_m} u_{ml} I_{rml+\delta_r}$$

The implementation of this equation requires that we estimate the final part-worth (or utility) of attribute ***m*** at level ***l*** to an individual in two stages. In the first stage, we estimate a multiple regression with 21 observations of self explicated likelihood-of-participation scores derived using data collected during the self-explicated stage of the conjoint exercise. In addition to derived likelihood scores, we add 8 likelihood-of-participation scores resulting from the decompositional stage of the conjoint exercise for a total of 29 observations per respondent. In the second stage, we perform a simple regression of the full profile scores ($\boldsymbol{s_r}$) on the current predicted score for profile r based on the current estimates of the part-worths ($\boldsymbol{u_{ml}}$). The intercept and slope from this simple regression become the updated location parameters ($\boldsymbol{\upsilon}$ and $\boldsymbol{\tau}$) for the next iteration of the multiple regression. This procedure continues until the sum of the squared errors from the multiple regression decreases by no more than some user-supplied amount, epsilon.

The key outcome of conjoint analysis is the part-worths (marginal utilities) of the various dimensions that comprise the conjoint stimuli. To estimate the part-worths, we used the modified importances/desirabilities model outlined above. Recall that the dependent variable in our model is a vector of likelihood-of-participation scores from two sources: the full profile scoring and those derived from the self-explicated data collected during the compositional phase. The independent variables in this model are indicators of the various levels of the five hypothesized dimensions of OSS motivation and the two control dimensions. The coefficient of each independent variable, then, would be the part-worth corresponding to that level of the dimension. Further, we calculated the relative importance of each dimension. We express the relative importance as a percentage by dividing the part-worth corresponding to the maximum level of that dimension divided by the sum of the part-worths corresponding to the maximum levels of all other dimensions.

First, we examine whether the respondents' preferences over the stimuli (OSS participation dimensions) show significant variation with a dimension. If the part-worth for a particular level of a dimension differs significantly from zero, then the evidence suggests that respondents are willing to make trade-offs between that level and the other levels within that dimension holding the other levels of the remaining dimensions constant. In our sample, respondents are willing to make trade-offs among all levels for all dimensions of OSS participation motivations. For example, the part-worth for a ***Use-Value*** of 51 hours is .2094 and is statistically significant. This means that, on average, participants would be willing to increase their likelihood-of-participation estimate by 3.31 percent as compared to an identical experience having the base ***Use-Value*** level 17 hours (.2094 – .1763 out of 100 percent). A similar calculus can be performed for all levels within each dimension.

Of particular interest, however, is the ***Career Concern*** dimension. Our results can be used to calculate the marginal utility for each $100 of ***Career Concern***. The part-worth for a ***Career Concern*** of $0 (no impact) is .0475 and is statistically significant. Following the procedure above, participants would be willing to increase their likelihood-of-participation estimate by only .21 percent, or 3.0E-4 per $100 of impact. Alternatively, between the $700 and $2,100 levels of ***Career Concern***, the $1,400 increase raises the likelihood-of participation estimate by 4.29 percent, or .003 per $100 of impact. These two estimates provide a range of 3.0E-4 to .003 per $100 of impact.

Using the ***Career Concern*** marginal utilities and the part-worths for any of the other dimensions, we can estimate the dollar value of that dimension level on a per-respondent basis. As an example, consider the ***Use-Value*** dimension. The part-worth for 51 hours of ***Use-Value*** is .2094. Using the upper-bound for the ***Career Concern*** marginal utility (.003 per $100), the value is $1,030. Using the ***Career Concern*** marginal utility between $0 and $2,100 (2.14E-5 per $100), the value is $1,545.

As a check on the external validity of our results, notice that the per hour dollar value from the ***Use-Value*** calculation above is close to the hourly market value of quality software developers. Using the average senior systems analyst salary reported in the 2002 *Computerworld* survey (*Computerworld* 2002) the market value of one hour is $38.15 ($76,300/2000 hours). Accordingly, a ***Use-Value*** of 51 hours would have a market value of $1,945—very near the $1,545 value estimated in the preceding paragraph using the ***Career Concern*** marginal utilities. We can use the same method to derive estimated dollar values for the remaining dimension levels.

Discussion and Conclusions

In this work we empirically investigated the motivations of open source contributors for three Apache projects. Based on theories of volunteerism and job-design, we identified functionally based motivations to participate in open source projects. A survey instrument and a subsequent factor analysis were used to explore the appropriateness of our hypothesized motivations. Of the motivations, five (normative, career impact, recreation, reputation, and use value) were related to latent variables or factors that held significant explanatory power for the observed correlations among the observed variables. A hybrid conjoint exercise was introduced to investigate the relative importance of the motivations to contribute to open source projects. Of the five relevant factors, use value and recreational value were found to be of highest relative importance, followed by career concern and reputation. Normative was found to be the least important motivation.

Gaining an understanding of the motivational structure of contributors is a critical first step in evaluating open source as a viable development model for commercial software engineering endeavors (Strasser 2001). Corporations such as IBM, SUN, and AOL Time Warner have embraced open source development as a new paradigm for software engineering. One of the main concerns has always been how to align the unstructured and often uncertain initiatives of the open source community with the zeal for milestones and project accountability in commercial software development.

This study provides important insights for the management of commercial initiatives based on open source. Our results indicate that contributors are primarily motivated to contribute by higher use value for their own purpose, by the recreational value of coding, and by considerations for future career concerns. Recognizing this, it is unlikely that voluntary contributors can be convinced to adhere to timetables per se. Our results imply that attempts to impose deadlines or similar management control practices are not likely to be successful in the open source context, because open source contributors are motivated more by internal factors. For firms hoping to leverage open source methods, this implies that substantial complementary investments have to be made before the potential of high-quality open source software can be realized. These investments encompass all areas, which are not attractive to voluntary contributors, such as interoperability with proprietary platforms, documentation, and maintenance.

Our results also have interesting implications that are open for future research. First, our results would benefit from further validation in other open source contexts and methodologies. Our research approach is characterized by a deep sampling of the three major Apache projects. The results that we obtained are, therefore, strongest in internal and external validity with respect to the Apache projects sampled. While we have not encountered any systemic differences across the three projects that we have covered and have no indication why this should be the case with the other subprojects, only a similar analysis in other open source projects can provide assurance. In addition, a validation through other methods would strengthen our results. For this work, we have relied on a survey instrument to provide us with data. Although the same individuals provided responses via the survey, we see no reasonable alternative than to obtain the data from the same source. Motivation is a subjective construct. Only the individual involved can report on his or her own motivations (motivations can neither be observed nor inferred). Similarly, only the individual can tell us what is the personal utility of a particular motivation for contributing. However, future studies could relate self-reported motivations to objectively observed behaviors (such as documented source code contributions) to mitigate same-source bias. Another question is the viability of open source communities with voluntary contributors when firms with commercial interests are contributing significantly to the project and hence yield greater influence. One implication of our research is that such "paid" contribution may reduce the motivation based on recreational value (fun factor), but increase the motivation based on career concern. In addition, from a motivation point of view, it may be best if the firm's commercial efforts are concentrated on complementary areas. IBM's focus on making their hardware and software suites Linux compatible is one example of a viable partnership. Similarly, Red Hat (for Linux) and Sun (for OpenOffice) primarily offer services in the areas of distribution, service and support, and consulting.

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