

ONLINE APPENDIX

Understanding the Motivations, Participation and Performance of Open Source Software Developers: A Longitudinal Study of the Apache Projects

Jeffrey Roberts • Il-Horn Hann • Sandra Slaughter

Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA
Marshall School of Business, University of Southern California, Los Angeles, CA
Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA
jroberts@andrew.cmu.edu • hann@marshall.usc.edu • sandras@andrew.cmu.edu

I. RESEARCH SITE

The projects of the Apache Software Foundation (ASF) enjoy wide acceptance both in the marketplace and in the OSS development community. According to a recent web server survey by Netcraft (2005), the Apache web-server and its derivatives have attained a dominant 70% share of the web-server market, and the Apache web-server software is installed at more than 44 million sites worldwide. Similarly, the ASF projects consistently attract and retain the large number of participants vital for OSS project success (Von Krogh et al. 2003). The three ASF projects in this study accepted 100,000 changes from over 1,300 different open source developers from 1999-2002. Membership in the ASF is by invitation only and is based on a strict meritocracy.

A characteristic of many OSS projects is the presence of a strong project leader (Raymond 1999). However, as we have noted, the Apache projects operate under a model of shared leadership and responsibility. This model of shared responsibility is reflected in the principles of the meritocracy that define advancement within the ASF (Fielding 1999).

II. DATA COLLECTION

A. Archival Data

One of the basic tenets of OSS is that the development process and resulting products are “open” and freely available. In keeping with free and open access, all OSS work products are placed in the public domain under various “free software” licensing arrangements.

To assess a contributor’s performance ranking requires the construction of an Apache career path for each contributor. We capture the upward progression as a series of discrete transitions from one level to another in the ASF meritocracy. In our study, a participant’s first source code contribution is considered a consummation of the joining decision, signaling entry into the meritocracy and the beginning of one’s Apache career. To determine each individual’s Apache career progression we used archival data from three sources: the Apache developer web site, contribution meta-data from the Concurrent Versioning System (CVS) revision control software, and minutes

from the Apache Board of Directors meetings. Each Apache subproject maintains a separate developer website that includes a list of contributors and project management committee members. By observing changes to these files over time we are able to construct a timeline for the promotion of individuals within each project.

To extract information about individual contributions from the data, we developed tools to mine contribution information at the level of the individual developer. A submission to an OSS project is known as a “patch.” Patches are analogous to modification requests in traditional software development environments. Unlike modification requests in traditional environments, however, patches result from the nearly random arrival of developer submissions and have no formal designation or means of tracking. Our research follows the method used by Mockus et al. (2000) to reconstruct patches from source code archives. For each patch we extracted and retained common software metrics including lines of code added and deleted, the date of submission, the names and number of source code files affected by the change, change log entries, and the list of patch authors. We constructed a data set of participant contributions by year.

B. Sample Bias Tests of Survey Data

One important aspect of any survey is determining whether respondents differ from non-respondents. A comparison of these groups can reveal how representative is the sample of the population along relevant dimensions. Participant contribution levels and rank within the ASF play a critical role in the analysis and interpretation of the results that follow. To discern whether the distribution of these two variables in the sample is comparable to that of the population, we performed a series of non-parametric tests of location and empirical distribution. Similar to prior OSS research (Mockus et al. 2000), we find measures of rank and contribution are asymmetrically distributed and thus must rely on distribution free (non-parametric) statistics to compare our sample and population. The tests evaluate the hypothesis that respondents and non-respondents are drawn from the same underlying population for the variables of interest. For respondent rank, the p-value for the Kolmogorov-Smirnov (KS) statistic of 0.56 for the two-sample test was 0.91, supporting the null hypothesis that the empirical distribution of rank is identical for our sample and the Apache population. The Mann-Whitney U test for location also supports the null hypothesis of no difference ($Z=1.49$, $p=0.14$). Likewise for contributions, both tests support the null hypothesis of no difference between our sample and the population ($KS=0.86$, $p=0.45$; $Z=-0.18$, $p=0.86$). These results suggest that our respondents and non-respondents are drawn from the same underlying population.

A particular strength of our research design is our collection of data from different sources and using different methods. In doing so, we have limited our exposure to common method and common data source biases (Straub et al. 1995). Even so, to assess the degree to which common method bias might present a problem for our subjectively measured motivation constructs; we subjected the motivation scale items to a principal components analysis using a varimax rotation (Harman 1967). Results indicated that the items loaded cleanly on the factors representing the expected constructs. Thus, we found no general factor that would have emerged due to common

method variance; this suggests that common method bias is not an issue for the motivation constructs used in this study.

III. PSYCHOMETRIC PROPERTIES OF SCALES FOR MEASURES OF MOTIVATION

Following Anderson & Gerbing (1988) we assessed the motivation measurement scales used in this study for content, convergent, and discriminant validity as well as for reliability. The motivation constructs are subjected to an evaluation of measurement properties because, in contrast to participation and performance (which are measured objectively) the motivation constructs are subjectively measured using multiple indicator items. *Content validity* was established via an iterative process of expert-influenced questionnaire development. A Web-based pilot questionnaire was created and tested using five OSS developers who were either students or employees of the university where the research was conducted. In addition, a founding member of Apache Software Foundation, Dr. Roy Fielding, reviewed and commented on the instrument under development. All respondents were debriefed to assess the clarity of the questions and the adequacy of the candidate scale items in capturing their motivations for participation. All comments were incorporated, and the resulting instrument was reviewed a final time by Dr. Fielding. The remaining properties of the motivation measurement scales were assessed using confirmatory factor analysis (CFA) techniques and measures. *Scale reliability* was assessed using composite reliability and coefficient alpha scores. Similar to alpha scores, composite reliabilities reflect the internal consistency of the scale items measuring a given factor (Nunnally & Bernstein 1978; Fornell & Larcker 1981). Both composite reliability and coefficient alpha scores exceeded the recommended cutoff value of .70. *Convergent validity* was demonstrated when all scale items loaded significantly on their hypothesized latent constructs (Anderson & Gerbing 1988). Lastly, discriminant validity was assessed by computing a series of χ^2 difference tests between the standard confirmatory factor analysis (CFA) model where all factors co-vary and a constrained model where inter-factor correlations are fixed at 1. All χ^2 difference statistics were significant, demonstrating discriminant validity (Bagozzi & Phillips 1982). Overall, these tests provide strong support for the reliability and validity of the motivation measures used in this study.

IV. SCALE ITEMS, FACTOR LOADINGS, AND RELIABILITIES FOR MEASURES OF MOTIVATION

Extrinsic motivations are assessed in terms of the extent to which the respondent is paid to contribute to the Apache projects. We used the following two questions. “At any time during this year, were you paid to participate in Apache projects?” and “If ‘YES’, approximately how many hours a week were you paid for participating in Apache projects?” Hence, we operationalize extrinsic motivation (EXTRINSIC_{t_2}) as the average number of hours per week for which respondents received monetary compensation for their Apache development efforts.

Five-point Likert scales were used to measure the remaining three dimensions of motivation – intrinsic, status and use value. Respondents were given the following introduction to the motivation scale items. “People volunteer, or otherwise do unpaid work, for many different reasons. They also derive different kinds of

satisfaction from such work. Following are some reasons other developers have given us regarding their participation in OSS projects. Thinking of your own participation, please indicate how important each reason is to you personally.” Response choices ranged from 1 (little importance) to 5 (great importance). Both pre-existing and new scale items were used. The scale items, reliabilities, and factor loadings are given in Table 1 below.

Table 1 - Motivation Scale Items

Question No.	Question Text	Standardized Loadings
<i>Intrinsic Scale Items (Coefficient Alpha = .82; Composite Reliability=.82)</i> ^{a,d}		
Q1	It is the satisfaction of seeing the results.	.78
Q2	It gives me the chance to do things I am good at.	.74
Q3	I really enjoy it. It is fun.	.67
Q4	It gives me a sense of personal achievement.	.71
<i>Status Scale Items (Coefficient Alpha=.73; Composite Reliability=.79)</i> ^{b,c}		
Q5	It gives me the chance to attain a recognized qualification or skill.	.65
Q6	It gives me status at work.	.70
Q7	It increases my opportunities for a better job.	.74
Q8	It gives me status in the Apache community.	.68
<i>Use Value Scale Items (Coefficient Alpha=.71; Composite Reliability=.77)</i> ^{e,f}		
Q9	I fixed a bug or problem that was causing me trouble.	1.00
Q10	I added a feature I wanted or needed to use.	.55

Notes:

- a. Items adapted from subscales of the *Multi-Item Measures of Values* instrument (Herche 1994). Subscales: Being Well-Respected, Fun and Enjoyment, Sense of Accomplishment.
- b. Items adapted from the Career sub-scale of the *Volunteer Functions Inventory* (Clary et al. 1998).
- c. Items adapted from concepts regarding the effects of recognition on volunteerism (Fisher and Ackerman 1998).
- d. Items adapted from subscales of the *Job Diagnostic Survey* (Hackman and Oldham 1974). Subscales: Task Identity, Task Significance, and Autonomy.
- e. Synthesized from qualitative discussions and theory regarding open source participation (Raymond 1999; Dempsey et al. 1999).
- f. The factor loadings for the Use Value construct reflect the almost unanimous responses to both Use Value scale items. Thus, the measurement error for this construct is very small, and the error variance is constrained to zero. We re-formulated our models using each scale item individually as a single item measure of Use Value. Treating Use Value as a manifest variable using either item individually generates results consistent with the original model where Use Value is treated as latent.

V. MEANS, STANDARD DEVIATIONS, CORRELATIONS, AND COVARIANCES

Panel a – Primary Model (N=288)

	Mean ^d	SD	CONTRIB ^{b e}	EXPER	EDU ^f	EXTRINSIC ^e	PERF ^b
Q1	4.26	0.85	0.14**	-0.09*	-0.09*	0.01	0.08*
Q2	3.88	1.10	0.05	-0.07	-0.07	0.06	0.06
Q3	4.04	0.97	0.08	-0.13**	-0.10*	0.08	0.04
Q4	4.02	1.05	0.07	0.01	-0.15***	-0.03	0.10*
Q5	2.95	1.30	0.20***	-0.12**	-0.07	0.14**	0.05
Q6	2.37	1.21	0.18***	-0.08	-0.10	0.19***	0.12**
Q7	2.58	1.25	0.23***	-0.09	-0.17***	0.07	0.16***
Q8	2.21	1.18	0.33***	-0.07	-0.18***	0.05	0.09**
Q9	4.35	1.05	-0.28***	0.05	0.11	-0.12**	-0.06
Q10	4.26	1.11	-0.19***	0.02	-0.01	-0.12**	-0.04
CONTRIBUTION ^{a b}	402.10	2796.50	12.77	-0.11*	-0.01	0.22***	0.19**
EXPERIENCE ^c	5.58	4.13	-1.68	17.04	0.16***	0.03	0.01
EDUCATION ^c	16.56	2.09	-1.18	39.66	3576.30	-0.01	0.05
EXTRINSIC	3.29	9.94	0.82	0.13	-0.20	1.10	0.08
PEFORMANCE ^b	0.03	0.21	0.14	0.01	0.64	0.02	0.04

Panel a – Continued

	Q1	Q2	Q3	Q4	Q5
Intrinsic Construct Indicators					
Q1	0.70	0.57***	0.50***	0.54***	0.29***
Q2	0.53	1.22	0.52***	0.49***	0.33***
Q3	0.40	0.55	0.92	0.44***	0.29***
Q4	0.47	0.56	0.44	1.08	0.31***
Status Construct Indicators					
Q5	0.32	0.47	0.36	0.41	1.70
Q6	0.24	0.31	0.19	0.32	0.70
Q7	0.21	0.33	0.19	0.49	0.78
Q8	0.08	0.12	0.07	0.15	0.19
Use Value Construct Indicators					
Q9	-0.02	-0.06	-0.05	-0.03	-0.34
Q10	0.04	0.06	0.06	0.10	-0.09
Manifest Variables					
CONTRIBUTION ^a	0.41	0.21	0.28	0.26	0.93
EXPERIENCE ^c	-0.32	-0.33	-0.51	0.06	-0.67
EDUCATION ^c	-4.27	-4.81	-5.51	-9.53	-5.38
EXTRINSIC	0.01	0.07	0.08	-0.03	0.20
PEFORMANCE ^b	0.01	0.01	0.01	0.02	0.01

Panel a – Continued

	Q6	Q7	Q8	Q9	Q10
Intrinsic Construct Indicators					
Q1	0.24***	0.20***	0.23***	-0.02	0.04
Q2	0.23***	0.25***	0.27***	-0.05	0.05
Q3	0.16***	0.16***	0.18***	-0.05	0.06
Q4	0.26***	0.38***	0.37***	-0.03	0.08*
Status Construct Indicators					
Q5	0.44***	0.49***	0.38***	-0.24***	-0.06
Q6	1.46	0.53***	0.49***	-0.13**	0.01
Q7	0.78	1.51	0.53***	-0.15**	0.01
Q8	0.23	0.25	0.15	-0.17***	-0.05
Use Value Construct Indicators					
Q9	-0.18	-0.21	-0.07	1.21	0.51***
Q10	0.02	0.01	-0.02	0.63	1.28
Manifest Variables					
CONTRIBUTION ^a	0.79	1.01	0.46	-1.10	-0.76
EXPERIENCE ^c	-0.39	-0.46	-0.12	0.21	0.07
EDUCATION ^c	-7.14	-12.29	-4.28	7.29	-0.52
EXTRINSIC	0.24	0.09	0.02	-0.13	-0.14
PEFORMANCE ^b	0.03	0.04	0.01	-0.01	-0.01

Panel b – Enhanced Model (N=180)

	Mean ^d	SD	CONTRIB ^{be}	EXPER	EDUC ^f	EXTRINSIC ^e	PERF ^b
Intrinsic Construct Indicators							
Q1	4.24	0.83	0.14**	-0.09*	-0.09*	0.01	0.08*
Q2	3.88	1.10	0.05	-0.07	-0.07	0.06	0.06
Q3	4.03	0.96	0.08	-0.13**	-0.10*	0.08	0.04
Q4	4.02	1.04	0.07	0.01	-0.15***	-0.03	0.10*
Status Construct Indicators							
Q5	2.96	1.30	0.20***	-0.12**	-0.07	0.14**	0.05
Q6	2.39	1.21	0.18***	-0.08	-0.10	0.19***	0.12**
Q7	2.59	1.23	0.23***	-0.09	-0.17***	0.07	0.16***
Q8	2.21	1.18	0.33***	-0.07	-0.18***	0.05	0.10**
Use Value Construct Indicators							
Q9	4.31	1.10	-0.28***	0.05	0.11	-0.12**	-0.06
Q10	4.24	1.13	-0.19***	0.02	-0.01	-0.12**	-0.04
Manifest Variables							
CONTRIBUTION ^{ab}	402.10	2796.50	12.77	-0.11*	-0.01	0.22***	0.19**
EXPERIENCE ^c	5.58	4.13	-1.68	17.04	0.16***	0.03	0.01
EDUCATION ^c	16.56	2.09	-1.18	39.66	3576.30	-0.01	0.05
EXTRINSIC	3.29	9.94	0.82	0.13	-0.20	1.10	0.08
PEFORMANCE ^b	0.03	0.21	0.14	0.01	0.64	0.02	0.04
PAST PERFORM ^b	0.47	0.73	0.50	-0.26	-1.25	0.03	0.01

Panel b – Continued

	PAST PERF ^b	Q1	Q2	Q3	Q4	Q5
Intrinsic Construct Indicators						
Q1	0.01	0.70	0.57***	0.50***	0.54***	0.29***
Q2	0.06	0.53	1.22	0.52***	0.49***	0.33***
Q3	0.08	0.40	0.55	0.92	0.44***	0.29***
Q4	-0.03	0.47	0.56	0.44	1.08	0.31***
Status Construct Indicators						
Q5	0.14**	0.32	0.47	0.36	0.41	1.70
Q6	0.19***	0.24	0.31	0.19	0.32	0.70
Q7	0.07	0.21	0.33	0.19	0.49	0.78
Q8	0.05	0.08	0.12	0.07	0.15	0.19
Use Value Construct Indicators						
Q9	-0.12**	-0.02	-0.06	-0.05	-0.03	-0.34
Q10	-0.12**	0.04	0.06	0.06	0.10	-0.09
Manifest Variables						
CONTRIBUTION ^a	0.22***	0.41	0.21	0.28	0.26	0.93
EXPERIENCE ^c	0.03	-0.32	-0.33	-0.51	0.06	-0.67
EDUCATION ^c	-0.01	-4.27	-4.81	-5.51	-9.53	-5.38
EXTRINSIC	1.10	0.01	0.07	0.08	-0.03	0.20
PEFORMANCE ^b	0.02	0.01	0.01	0.01	0.02	0.01
PAST PERFORM ^b	0.03	0.03	0.10	0.09	0.07	0.10

Panel b – Continued

	Q6	Q7	Q8	Q9	Q10
Intrinsic Construct Indicators					
Q1	0.24***	0.20***	0.23***	-0.02	0.04
Q2	0.23***	0.25***	0.27***	-0.05	0.05
Q3	0.16***	0.16***	0.18***	-0.05	0.06
Q4	0.26***	0.38***	0.37***	-0.03	0.08*
Status Construct Indicators					
Q5	0.44***	0.49***	0.38***	-0.24***	-0.06
Q6	1.46	0.53***	0.49***	-0.13**	0.01
Q7	0.78	1.51	0.53***	-0.15**	0.01
Q8	0.23	0.25	0.15	-0.17***	-0.05
Use Value Construct Indicators					
Q9	-0.18	-0.21	-0.07	1.21	0.51***
Q10	0.02	0.01	-0.02	0.63	1.28
Manifest Variables					
CONTRIBUTION ^a	0.79	1.01	0.46	-1.10	-0.76
EXPERIENCE ^c	-0.39	-0.46	-0.12	0.21	0.07
EDUCATION ^c	-7.14	-12.28	-4.28	7.29	-0.52
EXTRINSIC	0.24	0.09	0.02	-0.13	-0.14
PEFORMANCE ^b	0.03	0.04	0.01	-0.01	-0.01
PAST PERFORM ^b	0.02	0.07	0.05	-0.02	0.05

Notes:

*** p =.01, ** p=.05, * p=.10. Covariances (Correlations) in lower left (upper right) triangular matrix. Variances along the diagonal.

a. Function points added.

b. Measured as deviation from subproject mean.

c. Measured in years.

d. Means and standard deviations for nominal variable values.

e. Natural log of variable used in model.

f. Square of variable used in model

VI. MODEL FIT EVALUATION STATISTICS

Panel a – Primary Model (N=288)

	<i>Chi-Square</i>	<i>Df</i>	<i>CFI</i>	<i>SRMR</i>	<i>RMSEA</i>	<i>NNFI</i>	<i>GFI</i>
Independence Model	1230.85	105.00	0.00	0.22	0.19	0.00	0.57
Uncorrelated Factors Model	222.06	95.00	0.89	0.14	0.07	0.88	0.88
Saturated Model	86.75	67.00	0.98	0.05	0.03	0.97	0.95
Theoretical Model	101.45	79.00	0.98	0.06	0.03	0.97	0.94

Panel b – Enhanced Model (N=180)

	<i>Chi-Square</i>	<i>Df</i>	<i>CFI</i>	<i>SRMR</i>	<i>RMSEA</i>	<i>NNFI</i>	<i>GFI</i>
Independence Model	1153.37	120	0.00	0.20	0.18	0.00	0.59
Uncorrelated Factors Model	225.69	113	0.89	0.18	0.06	0.88	0.86
Saturated Model	101.65	77	0.98	0.15	0.03	0.96	0.93
Theoretical Model	106.99	88	0.98	0.06	0.03	0.98	0.94

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