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RESEARCH ARTICLE

DEVELOPER CENTRALITY AND THE IMPACT OF VALUE CONGRUENCE AND INCONGRUENCE ON COMMITMENT AND CODE CONTRIBUTION ACTIVITY IN OPEN SOURCE SOFTWARE COMMUNITIES[1]

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Appendix A

Summary of Empirical Research on Impact of OSS Values on Developers

A growing body of empirical research has examined the role of OSS values in affecting developers (Benbya and Belbaly 2010; Chou and He 2011; Stewart and Gosain 2006). With few exceptions, the research to date has typically focused on either the community (or OSS team) OSS values or the developer OSS values. In their seminal study, Stewart and Gosain (2006) find that when OSS teams embrace OSS values, there is a positive influence on communication quality and affective trust in OSS teams. Surprisingly, they also find that embracing OSS values negatively influences task completion. They explain their findings by suggesting that teams who embrace OSS values that are geared toward collaboration tend to prioritize consensus over completing tasks. Chou and He (2011) find that a team embracing OSS values positively impacts its collaborative elaboration, and communication decoding and encoding competence. Taken together, this research suggests that the community (or team) OSS values can influence team attitudes and activity level. A looming open issue in this research is that researchers do not consider the role of the individual developer OSS values. As such, it is possible that a developer may not necessarily support the OSS values in the same way as the community.

Other researchers focus on the individual developer OSS values as a determinant. For instance, researchers find that a developer who embraces such values is likely to expend a greater amount of time and effort contributing to OSS initiatives (Benbya and Belbaly 2010) and is likely to report being more involved in OSS communities (Xu et al. 2009). In contrast to these findings, Henkel (2008) finds that OSS values play no role in affecting developers' contribution to OSS communities. In sum, this stream of research suggests that the developer OSS values can influence developer contribution to OSS communities. However, this research overlooks the role of the OSS community's values in affecting developer attitudes and contribution behavior. As such, it provides an incomplete picture of the role of OSS values in shaping developers' attitudes and behavior in OSS communities.

Table A1. Summary of Empirical Research Findings on OSS Values

Article \ Referent	Focus of OSS Values		Key Finding
	Developer	OSS Community	
Xu et al. 2009	√		+ impact on developer involvement
Henkel 2008	√		n.s. developer contribution
Benbya and Belbaly 2010	√		+ impact on developer participation type + impact on developer effort
Ke and Zhang 2009	√	√	– developer goal commitment n.s. developer effort intensity
Ke and Zhang 2010	√	√	– developer task effort
Chow and He 2011		√	+ collaborative elaboration + communication decoding competence + communication encoding competence
Stewart and Gosain 2006		√	+ impact on communication quality + impact on affective trust – task completion

+ denotes values antecedent has positive impact on listed outcome, – denotes values antecedent has negative impact on listed outcome, n.s. denotes values antecedent has nonsignificant impact on listed outcome.

Appendix B

Results of Confirmatory Factor Analysis

	Factors		
Items	1	2	3
As a software developer…			
Developer values1: I value sharing knowledge.	***.32***	.01	.24
Developer values2: I believe in helping others.	**.76**	.17	.06
Developer values3: I place great value on technical knowledge.	**.70**	.23	.13
Developer values4: I am driven by a desire to learn new things.	**.70**	.03	.05
Developer values5: I think cooperation is important.	**.75**	.08	.11
Developer values6: I value the reputation I gain by participating in open source. projects.	**.67**	.17	.09
In my view, members of this OSS community…			
Perception of OSS values1: value sharing knowledge.	.13	***.24***	.28
Perception of OSS values2: believe in helping others.	.20	**.82**	.22
Perception of OSS values3: place great value on technical knowledge.	.13	**.83**	.17
Perception of OSS values4: are driven by a desire to learn new things.	.17	**.69**	.22
Perception of OSS values5: think cooperation is important.	.18	**.73**	.18
Perception of OSS values6: value the reputation gained by participating in open source projects.	.08	**.78**	.23
Commitment1: I am willing to put in effort beyond the norm for the success of GNOME.	.15	.18	**.79**
Commitment2: For me, this is the best of all possible OSS projects for which to work.	.10	.21	**.85**
Commitment3: I am extremely glad to have chosen GNOME to work for over other projects.	.11	.23	**.86**
Commitment4: GNOME inspires me to be my best technical work.	.09	.30	**.79**
Commitment5: I show by my actions that I really care about the fate of GNOME.	.10	.30	**.77**

Note: Items with italicized loadings were dropped.

Appendix C

Coefficients for Response Surface Analysis Predicting OSS Commitment at Low Versus High Developer Centrality

Variable	Coefficient	Low Developer Centrality	High Developer Centrality
(Intercept)	b_0	4.98***	5.06***
Developer values	b_1	.13	.17*
OSS values	b_2	.60***	.52***
Developer values-squared	b_3	.13	.13
Developer values × OSS values	b_4	-.11*	-.07
OSS values-squared	b_5	.17	.25**

Notes: Significance levels are based on bias-corrected confidence intervals generated from bootstrap estimates. Analysis includes project fixed effects.
*p< .05, **p < .01, ***p < .001.

Appendix D

Results of Moderation–Mediation Analysis

		Developer Contribution Activity		
	OSS Commitment	Number of Commits	Lines of Code Added/deleted	Number of Files Changed
(Intercept)	5.42***	-4.99***	-4.28***	-4.35***
Age	-.01	-.02	-.03	-.02
Gender	.35	2.42*	3.76*	2.33*
Education	-.14*	-.24	-.57	-.36
Volunteer status	-.08	-1.04*	-1.42*	-.94*
OSS Value (in)congruence	.69***	.41	.67	.41
Developer centrality	.46*			
OSS commitment		.71***	.90**	.58**
Value congruence × developer centrality	-.52*			
Project fixed effects	Yes	Yes	Yes	Yes
R^2	.46***	.30***	.29***	.28***

Notes: n = 410
1. Value congruence is computed from block variable using the predicted value from the polynomial regression equations.
2. Pattern of results is similar when using different measures of developer centrality.
*p < .05, **p < .01, ***p < .001.

Appendix E

Robustness Analysis Regarding Degree Centrality in Communication Network

In order to ensure that our results were not an artifact of the timeframe upon which our degree centrality measure was based, we conducted the moderated polynomial regression analysis using degree centrality based on the past 24 months of email communication. The pattern of results was consistent across this alternative operationalization as shown in Table E1. Further, in order to ensure that the results were not an artifact of the use of email communication as the basis for computing degree centrality, we computed degree centrality based on developers' collaboration on the same projects. We examined degree centrality based on collaboration on the same projects in the past 12 months and the past 24 months. As the results show, the pattern of results was similar to that of the analysis using degree centrality based on email communication.

Table E1. Results of Polynomial Regression Analysis Using Alternative Measures of Developer Centrality

Variable	Coefficient	1	2 Centrality: 12-month email	3 Centrality: 24-month email	4 Centrality: 12-month project	5 Centrality: 24-month project
Age		-.04	-.04	-.03	-.02	.00
Gender		.03	.03	.04	.03	.02
Education		-.10*	-.10*	-.10*	-.10*	-.10*
Volunteer status		-.05	-.05	-.06	-.03	-.06
Developer values	b_1	.16*	.15*	.18*	.19**	.20**
OSS values	b_2	.50***	.56***	.53***	.41***	.43***
Developer values-squared	b_3	.13*	.13*	.14*	.15*	.15*
Developer values × OSS values	b_4	-.14*	-.09†	-.10*	-.14*	-.15*
OSS values-squared	b_5	.15*	.21**	.11*	.10*	.13*
Developer centrality	b_6		.15**	.18*	.30***	.31***
Developer values × developer centrality	b_7		.07	.08	.06	.07
OSS values × developer centrality	b_8		-.16**	-.21**	-.12*	-.19*
Developer values-squared × developer centrality	b_9		.00	.03	.06	.03
Developer values × OSS values × developer centrality	b_{10}		.07	.13	.01	-.01
OSS values-squared × developer centrality	b_{11}		.16**	.14*	.10*	.16*
Project fixed effects		Yes	Yes	Yes	Yes	Yes
Adjusted R^2		.30***	.33***	.33***	.34***	.36***
ΔR^2			.03**	.03**	.04***	.06***

Notes: n = 410.

1. Developer centrality in model 2 is measured on email communication activity over prior 12 months, developer centrality in model 3 is measured on email communication activity over prior 24 months, developer centrality in model 4 is measured on project collaboration activity over prior 12 months, developer centrality in model 5 is measured on project collaboration activity over prior 24 months.
1. ΔR^2 for models 2 through 5 represent change in variance explained over and above model 1 (i.e., the polynomial regression model without moderation).

†p < .10, *p < .05, **p < .01, ***p < .001.

Appendix F

Robustness Tests for Endogeneity

An argument could be made that developers who have greater commitment to the OSS community are more likely to be highly central in the communication network.[1] Empirically, our study design does not lend itself to testing the influence of commitment on centrality since our data were time lagged. That is, the developer centrality variable is based on email communication *before* commitment was measured. However, we acknowledge that this does not preclude the possibility of there being endogeneity between the two variables. Consequently, we estimated the polynomial regression models using an instrumental variables two-stage least squares (2SLS) analysis. We identified an instrumental variable that was correlated with commitment but uncorrelated with the error term. As shown in Table F1, the pattern of results from the 2SLS are similar to those of our main analysis. This provides additional confidence in the robustness of the model specification and results.

Table F1. Results of Instrumental Variables Two-Stage Least Squares Analysis with Robust Standard Errors

		OSS Commitment		
Variable		**1**	**2**	**3**
Age		.00 (.00)	.00 (.01)	.00 (.00)
Gender		.06 (.18)	.03 (.17)	.12 (.19)
Education		-.10* (.05)	-.10† (.06)	-.14* (.06)
Volunteer status		.09 (.12)	.07 (.12)	.07 (.13)
Developer values	b_1	1.71* (.73)	2.15* (1.00)	2.40* (1.05)
OSS community values	b_2	2.36*** (.25)	2.62*** (.45)	2.06*** (.51)
Developer values-squared	b_3		8.91** (2.66)	5.94* (2.93)
Developer values × OSS community values	b_4		-9.09* (3.83)	-7.60† (4.02)
OSS community values-squared	b_5		.86** (.28)	1.21* (.60)
Developer centrality	b_6			2.59** (.91)
Developer values × developer centrality	b_7			.06 (.08)
OSS community values × developer centrality	b_8			-1.41** (.52)
Developer values-squared × developer centrality	b_9			.00 (.05)
Developer values × OSS community values × developer centrality	b_{10}			4.49 (3.66)
OSS community values-squared × developer centrality	b_{11}			2.49** (1.05)
Wald χ^2		150.20***	212.67***	220.292***
Adjusted R^2		.28	.30	.32

Notes: n = 410; standard errors are in parentheses; country, number of commits made (pre-survey), total number of messages posted to listserv (pre-survey), total number of projects (pre-survey), and number of replies posted to listserv (pre-survey) were used as instruments.
$^{\dagger}p < .10$, *p < .05, **p < .01, ***p < .001.

[1]We thank an anonymous reviewer for drawing our attention to this possibility.

Appendix G

Robustness Analysis Regarding Operationalization of Dependent Variable

We wanted to ensure that the results of the mediation analysis were not an artifact of the specific operationalization of developer contribution activity as number of commits. Therefore, we repeated the analysis using two alternative operationalizations: number of lines of code added/deleted and number of files changed. As the results in Table G1 show, the mediating role of commitment is stronger among less central developers than among highly central developers in predicting number of lines of code added and deleted (test of differences: .75 – .50 = .25, $p < .05$) and number of files changed (test of differences: .48 – .32 = .16, $p < .05$). Specifically, we find that the mediating effect of commitment is nonsignificant among highly central developers and is significant among less central developers, providing support for H4. Number of commits may be a less granular measure of the volume of work compared to the actual lines of code and files changed.

Table G1. Results of Mediation (H3) and Moderated-Mediation (H4) Tests on Number of Lines of Code Added and Deleted and Number of Files Changed

Level of Developer Centrality	Direct Effect	Indirect Effect	95% Bias-Corrected CI		R^2	Dependent Variable
			Lower Bound	Upper Bound		
	.68 (.46)	.39 (.20)	.04	.86	.23***	Number of lines of code added/deleted
High	.68 (.49)	.50 (.31)	-.01	.97	.29***	
Low		.75 (.27)	.29	.99		
	.46 (.30)	.33 (.14)	.07	.64	.19***	Number of files changed
High	.41 (.32)	.32 (.20)	-.01	.62	.28***	
Low		.48 (.18)	.18	.89		

Notes:
1. Value congruence and incongruence block variable is the independent variable, developer commitment is the mediator, developer centrality is the moderator; control variables were included as covariates in the analysis.
2. Standard errors are in parentheses.
3. Dependent variables were log-transformed prior to analysis.
4. The pattern of results is the same when using degree centrality based on email communication in past 24 months, collaboration activity on projects in past 12 months and past 24 months.

***$p < .001$.

Appendix H

Results of Model Estimation Using Heckman Two-Step Selection Procedure

Variable		Commitment
Age		.00 (.01)
Gender		.16 (.26)
Education		-.14* (.06)
Volunteer status		.02 (.10)
Developer values	b_1	2.29* (1.01)
OSS community values	b_2	2.60*** (.40)
Developer values-squared	b_3	6.99* (3.41)
Developer values × OSS community values	b_4	-7.45† (3.93)
OSS community values-squared	b_5	1.62* (.60)
Developer centrality	b_6	.28*** (.06)
Developer values × developer centrality	b_7	.93 (.66)
OSS community values × developer centrality	b_8	-.99** (.45)
Developer values-squared × developer centrality	b_9	.01 (.05)
Developer values × OSS community values × developer centrality	b_{10}	3.97 (3.61)
OSS community values-squared × developer centrality	b_{11}	.78* (.35)
Inverse Mills ratio		.10 (.52)
Wald χ^2		234.98***

Notes: n = 410; standard errors are in parentheses; developer degree centrality in the communication network (pre-survey), number of commits (pre-survey), number of different projects (pre-survey), and number of messages and replies posted to the listserv (pre-survey) were used as determinants in the estimation of the first stage probit model.
$^{\dagger}p < .10$, *p < .05, **p < .01, ***p < .001

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