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Abstract

This paper seeks to close an empirical gap regarding the motivations, personal attributes and behavioral patterns among free/libre and open source (FLOSS) developers, especially those involved in community-based production, and considers the bearing of its findings on the existing literature and the future directions for research. Respondents to an extensive web-survey's (FLOSS-US 2003) questions about their reasons for beginning to work FLOSS are classified according to their distinct "motivational profiles" by hierarchical cluster analysis. Over half of them also are matched to projects of known membership sizes, revealing that although some members from each of the clusters are present in the small, medium and large ranges of the distribution of project sizes, the mixing fractions for the large and the very small project ranges are statistically different. Among developers who changed projects, there is a discernable flow from the bottom toward the very small towards to large projects, some of which is motivated by individuals seeking to improve their programming skills. It is found that the profile of early motivation, along with other individual attributes, significantly affects individual developers' selections of projects from different regions of the size range.

Keywords: Open source software, FLOSS projects, community-based peer production, population heterogeneity, micro-motives, motivational profiles, web-cast surveys, hierarchical cluster analysis

JEL Code Nos.: J22, L17, L23, L25, L39, P13

1. Introduction: Closing a Surprising Gap in Empirical Research on Open Source

There is surprising gap in the present state of empirical knowledge regarding the motivations, personal attributes and behavioral patterns of those who are engaged in producing free/libre and open source software (FLOSS). There has been no lack of theoretical conjectures, anecdotal insights from participant observers and systematic collection and analysis of survey questionnaire data, all directed toward answering the question "Who are the open source software developers, and why do they do it?" Much has been learned, yet the resulting collective picture has remained rather blurry, if not inchoate, especially at the focal point where interest in the question has been strongest and one might therefore have expected that the resolution would be sharpest. Unarguably, the focal point of the recent wave of academic research and business interest in "open source" as a movement and a mode of producing computer programs has centered on the large collaborative development "communities" that are associated with emblematically successful FLOSS products such as the Linux kernel, Mozilla (and lately Firefox), KDE, Gnome, FreeBSD, and Python. That interest certainly is warranted, and yet has not been well served. It remains difficult to extract from the existing research literature an empirically grounded picture of any sizable portion of the global population that is participating in one or another of the large, community-based collaborations developing open source software systems. That is the bothersome 'gap', and the surprise is that it has persisted this long and, unlike other obtrusive gaps, has remained largely unremarked upon.[1]

1.1 "Minding the gap": What we don't know, but need to learn about the participants in the "commons-based peer production" paradigm

The particular lacuna in the literature that concerns us has formed because obtaining suitably large and appropriately constituted samples of observations on the population of large project participants turns out to be not such a simple a matter as one might casually assume. The difficulty, in a nutshell, is that the kind of data which is most straightforward for quantitative researchers to obtain is not what one really wants if the aim is to understand processes such as skills mobilization, the coordination of effort, and organizational governance in the context of large community-based development projects. On the one hand, web-cast surveys have been collecting extensive bodies of data from self-identified open source developers at large, although it is becoming increasing clear that many (if not most) of those who regard themselves as open source software developers are not participants in big collaborative projects, but, instead, are individuals who work independently or in

[1] Calling attention to hazardous 'gaps' remains a regular public practice – as may be noted at some stops on the London Underground, where passengers boarding the train are cautioned by the loudspeaker system to "Please mind the gap!" between the platform and the cars.

very small groups to compose and release programs under one or another "open source" license.[2] On the other hand, numerous small-scale surveys and case studies have successfully examined specific research issues, such as the strength of ideological vis-à-vis utilitarian or purely pecuniary motives, the emergence of internal specialization and division of labor, movements of individuals from contributing to project forum discussions to core development tasks such as algorithm design or the responsibility of being a maintainer with authority to commit new material or patches to the codebase of particular modules or "code packages." These obviously are topics that hold considerable interest, and so have been studied within the context of particular community-based FLOSS projects. Yet, the individuals whose behaviors are observed (and whose attitudes and concerns are expressed) in those contexts may well be self-selected into the specific project on the basis of characteristics, attitudes or propensities that render them (and their project) idiosyncratic, rather than "typical" or "representative" of the population that distributes itself among the totality of community-based development efforts; and *a fortiori* unrepresentative of developers who choose to work independently, or on very small projects. It would be necessary to accumulate an appropriately stratified comparative set of such project studies on the basis of which a meta-analysis of findings might be performed, but, inasmuch as the need for that has not been perceived, the substantial effort that this would entail has not been undertaken.

The empirical strategy pursued here addresses these problems by classifying the respondents to an extensive web-survey (FLOSS-US 2003) according to the approximate membership sizes of the principal projects on which these individuals were working, thereby permitting separation and analysis of sub-populations associated with different portions of the distribution of project sizes. Our analysis introduces a further methodological innovation, designed to capture significant heterogeneities in motives of the general population of FLOSS developers: hierarchical cluster analysis is use to extract a set of distinctive "motivational profiles" from the entire web-sample's responses to a battery of questions concerning their reasons (Likert-scaled on "importance") for beginning to develop FLOSS. This procedure assigns each individual to one or another among the set of the identified "profiles," which are interpreted with the aid of normalized motivational intensity maps. In this way we are able to reveal the existence of some significant differences in the mixtures of motivational profiles, as well as in the distributions of other individual characteristics among the participants in community-based projects participants, as contrasted with the mass of developers that are essentially working independently or in very small projects.

[2] Dalle and David (2005, 2006), and Dalle et al. (2005) draw attention to the importance of differentiating between developers in community-based ("*C-mode*") production of FLOSS and those working in *"I-mode"* projects. For evidence of the latter's numerical importance, see below (Section 4.1).

1.2 Why go to the trouble of trying to closing this gap?

The fascination of contemporary social thinkers and social scientists with “open source software” is quite understandable when one considers the several distinct novelties that were presented by the growth of the free/libre and open source software movement, and the emergence of large communities of volunteers engaged in developing computer programs that were made freely available for downloading. Early contributions to the academic literature on “the open-source phenomenon” were directed primarily to identifying the motivations underlying the sustained and in many instances intensive involvement of many people in this non-contractual and unremunerated productive activity. That issue has been particularly prominent in economists’ and management and organization scientists’ contributions to the literature. This reflects the view prominent within those branches of social science that widespread voluntary participation in the creation of commercially valuable goods which are to be distributed without charge constitutes a quite significant behavioral anomaly. Others, particularly legal scholars, have been more intrigued with the implications of using novel contractual terms for licensing intellectual property use for purposes quite different than garnering revenue, namely assuring open access to future versions of the code built upon current contributions (Benkler 2002, McGowan 2005). Still others, observing these developments from the vantage points of organizational and political science have focused on the implications of the potentials for wider implementation of a new organizational paradigm -- initially described by Weber (2004) and forcefully advocated by Benkler (2006) under the label “commons-based peer production.”

In good measure it is the impressive technical achievements and the communitarian ethos associated with the mode of software production carried on by the members of large, geographically distributed projects, and their dependence upon and expression through a particular class of (copyleft) software licensing terms, that has generated the great interest that the open source movement had commanded in both popular and scholarly circles. But the picture one draws from the research literature of the population of FLOSS developers remains disappointingly “blurry”, if not somewhat inchoate.

One is presented with a widely varying assortment of human motivations for participating in open source development, ranging from “fun” to “necessity of modifying programs” or “liberating code” from proprietary vendor’s packages, to improving one’s software skills, or furthering one’s professional career in the software industry.[3] Considerable disagreement persists as to whether FLOSS code, particularly that produced by the larger, well-known projects is mainly contributed by volunteers or is being paid for by corporate sponsors, and, correspondingly, whether those projects are attracting skilled professional programmers, young students who join communities as social contexts in which to learn about computer software development, or other individuals who are seeking to

[3] See, e.g., von Krogh et al. (2003) and the literature discussed below (Section 2).

familiarize themselves with specific programs that they wish to customize for their own immediate needs.[4] It is possible, indeed plausible that all of the foregoing statements are descriptively valid about some developers that are participating in some projects. But without being able to assign quantitative weight to the variety of motivations among developers, or to say something about the nature of the projects in which they participate, the richness of the detail has the effect of defeating efforts to discern the main outlines or think about their implications for the sustainability of community-based production of open source software.[5] How faithful a likeness the collective portraits drawn from the foregoing research efforts are to the participants in the larger open source software development projects should be a matter for concern, because the picture's accuracy is relevant for an understanding of the incentives to which members of those project are likely to respond, the capabilities of those communities as social entities, and the mechanisms of coordination and resource allocation that are at work where open source software is being produced in "community mode." The scale of these projects poses problems of coordination and governance that render them very different, and more interesting than the "independent mode" of creating open source software, which can be as simple as deciding to release pre-existing (copyrighted) code, or new code under open source license.[6]

Precisely for those reasons there is a need to improve our descriptive knowledge about the population of FLOSS developers that are at work in these larger, community-based projects, for such information would be likely to have a quite direct bearing on a number of critical practical issues. These include the distribution of expertise in algorithm design and programming among the community of developers that the large projects can expect to attract, the strength (and durations) of their attachments to particular projects, and the strategies of governance and management of human resources in the absence of contractual relationships and the so-called "high-power incentives" of direct pecuniary payments that are under the control of project leaders. Recruitment and retention of volunteers is a much more significant issue in the life of large FLOSS projects than it is for those that originate when one or a few developers re-release a mature code base under an open source license, without aspiring to expand it by attracting a large and active community. Coordination of numerous volunteers (see Dalle and David 2008), and management of projects in which there are both paid and unpaid contributors that are likely to have different motives and responsiveness to a variety of incentives (see Michlmayr, 2004; Michlmayr and Hill, 2003) pose many issues that simply don't arise

[4] For example, compare, respectively, Lerner, Pathak and Tirole (2006), Maurer and Scotchmer (2006), with Ghosh and Glott (2005), and with Lakhani and von Hippel (2002).

[5] On issues of sustainability, see, e.g., Fitzgerald (2005); also David (2006) and references therein.

[6] Even the role of the choice of licensing can be thought to be implicated in the decision to undertake a project that will require mobilizing volunteers from the open source software community at large, for the characteristic "copy-left" feature of open source licenses is a commitment mechanism that affords contributors future access to the program that will evolve from their (and others') contributions – if the undertaking is successful.

with the same force when a very small number of individuals are involved -- especially as it is more likely in the latter cases that the participants can be co-located.

It therefore is surprising that greater concern has not been expressed in the literature about the potentially serious gap in our knowledge about the developers that are attracted to participate in community-based projects. Observers of the open source movement (since Krishnamurthy 2002) have been aware that a large proportion of those identifying themselves as contributing to FLOSS are engaged on very small projects (scattered in separate "caves") rather than belonging to the large collaborative project "communities." Whereas Krishnamurthy (2002) arrived at this on the basis of studying a small sample of project groups hosted by Source Forge (the widely known open source collaboration environment), a complete enumeration of the over 54 thousand project-groups on SourceForge.Net at the close of 2003 discloses that 67 percent of them had only a single participant-member.[7] The supposition that a random sample of survey respondents to web-cast surveys would include a substantial segment of *I-mode* developers may be inferred from the fact that among the 1473 FLOSS-US (2003) Survey respondents who list a current project, 64.8 percent described it as “unknown” or “slightly known,” and as many as 33.0 percent said they launched the project alone, while another 46.8 percent reported having launched it with others.[8]

But it is more than the sheer wealth of quantitatively un-weighted detail that frustrates clarity of description and interpretation in this area. The collective portrait of FLOSS developers has remained “blurred” because the constituent subjects are varied, and they are in motion. Firstly, much of the literature, whether theoretically or empirically informed has tended to approach the descriptive task as though the desired goal was to arrive at “representative agent” characterization of the developers that were participating in the FLOSS movement. In what regard such a construct would be useful remains unclear. But, in the event, the literature has seen a growing assortment of candidates entered into contention for that mantle, as successive research contributions have added still another motivation to the lengthening list – each accompanied by some supporting anecdotal evidence. Consequently, the picture conjured up when one tries to distill the various contending assertions as to who are “the open source developers and why they are doing it”, unfortunately, is one of a representative “agent” whose is suffering a nearly pathological multiple personality disorder -- being animated by a mélange of very different sources of gratification and accordingly diverse behavioral orientations. A more plausible conceptualization of a heterogeneous population in which there are

[7] Healy and Schussman’s (2003) study of the August 2002 Source Forge archive had put the median project size at 1 developer. We are indebted to Francesco Rullani, who supplied the estimates based on projects with non-zero membership in the January 2003 SourceForge.Net data archive, further details about which are available in Guiri et al. (2004), and David and Rullani (2008). Whether the bulk of these small projects are truly solo development efforts conducted on Source Forge is not certain, as some may have originated in code previously written for commercial purposes and subsequently released under open source license by the copyright holders.

[8] Another consistent indirect indicator of the numerical importance of very small open source projects may be cited: of 1055 FLOSS-US survey respondents reporting the proportion of code they had contributed to their current project, 31 percent put that figure at or above 95 percent. See David (2006) for further discussion.

recognizably distinct demographic and personality or motivational "types" would direct empirical research differently, and more intelligibly, toward identifying a set of dominant "types" and establish their respective numerical weights in the population of FLOSS developers.

Secondly, when one considers human motivations as well as individual capabilities, and roles and position in the community, it must be admitted that these are mutable qualities rather than characteristics that remain fixed. Becoming a competent programmer, a participant in community, and a project member are not processes bounded by crisply defined and standardized "states". Although it would be convenient to suppose the micro-level dynamics could be revealed by "snapshot" showing the whole ensemble of actors in cross-section, that would be informative only of a community that was in steady-state equilibrium – and we have no warrant to assume such a condition obtains. This applies even more strongly to the "communities" associated with specific FLOSS projects, because the latter are likely to have life-cycles whose durations are considerably shorter than that of the collectivity of such projects. Consequently the degree of structure, of institutionalization of governance arrangements, rate of membership turnover and intensity of commitment are not static properties of the projects that have been studied, and variations in findings from one study to the next could well reflect differences among their respective "life cycle stages." In the absence of careful "controls" for the latter, efforts to compare and synthesize findings, and casual aggregation of impressions from a variety of case studies are likely to be a source of confusion rather than deeper insights.[9]

Similarly, tastes and priorities that affect micro-level behavior may change with social experience and material circumstances, and the expressed reasons for having acted in one way and not another are likely to be affected by individuals' changing need for self-identification in reference to their current social contexts.[10] Social scientists' hopes of identifying stable universal motivational drives and correspondingly predictable patterns of behavior in response to some set of situational stimuli would seem to rest on relinquishing the conceit that simple and persuasive general psychological explanations can be found for actions that are aspects of very general classes of human behavior. Volunteering something of personal value (one's time or money) to a cause that benefits

[9] von Krogh et al. (2008) propose a framework for the comparative, longitudinal study of open source software projects that recognizes the reciprocal interactions between individual intrinsic sources of motivation, socially shaped norms of practice and formal institutional structures. Although possibly implied, the life-cycle dynamics of community and project do not figure explicitly in their interesting proposal for the future direction of research. See also Krishnamurthy (2005) on the role of social "incentives" in shaping developers' motives and behaviors.

[10] The endogenous elements in individual motivation (defined as the reason for "doing something"), and the feedback not only from private experience but more strongly from social norms that legitimate and assign moral value to particular courses of action within specific social contexts, has been explored by MacIntyre (1984). This richer psycho-social perspective recently has been embraced by von Krogh et al. (2008) as a promising framework for studying open source software projects. See Rullani (2007) for an effort to econometrically estimate the effects of antecedent community social interaction experience on project-founding behaviors of developers on Source Forge.

others, such as contributing to the production of open source software, is not likely to have a unique explanation that is accessible to theorists of *homo economicus*. For economists, it has proved more useful to proceed by seeking to isolate motivating considerations and constraints that impinge upon, and shape the extent of human behaviors "at the margin": better to ask the reasons for choosing to joining a large open source projects rather than smaller ones, or a community project with one purpose rather than another, or, indeed preferring a particular "copyleft" license (such as the GNU GPL) under which to release the code that one has written, than to expect to find "*the* reason why" people put themselves into situations where they will face choices of those kinds.[11]

Still another dimension of "motion" on the part of the micro-level agents in the world of open source projects is that relating to the circulation of developers among projects. There is considerable potential for ambiguity in this, for when one asks "who are the participants in community-based FLOSS development?" the answer should properly distinguish between those who ever have been mainly involved in such activities, and those who are thus engaged at some particular moment in time. Obviously, if developers form a principal attachment to a project and never leave it, there would be no point at all to this distinction; and, once again, in a steady-state world, where both the numbers of active projects and their membership sizes were stationary, there would be at best limited scope for temporal change in the distribution of developers observed at the upper (or lower) extremes of the project size distribution. On the other hand, were there an appreciable rate of turnover in the membership of large projects, the characteristics, acquired attributes and attitudes typical of the population of participants in such projects could be hard to extrapolate reasonably from samples of existing project members – unless the circulation of personnel tended to be stratified by project size. To put this differently, if there was substantial local attraction to projects of more or less the sizes of those from which the "movers" had originated, one would not need to worry about the representativeness of sub-sample of developers found in a small and non-randomly selected set of projects, or whether the population of large project members today would be replaced tomorrow by one that didn't resemble it closely. Where open source developers first acquire practical experience, and where they subsequently come to apply it and share it with others, is obviously dependent not only on the sites where skills and opportunities for employment are to be found.[12] What is most striking about this is the paucity of empirical guidance for thinking about these questions, because, important though it may be, the circulation of developers among projects has not been systematically examined from this angle.

[11] The positive case for focusing attention on "motivations-at-the-margin" in understanding resource allocation behaviour in the context of open source software projects has been more fully elaborated and applied in Dalle and David (2005), and Dalle et al. (2005).

[12] On the potential for software skills development provided by experience in FLOSS communities associated with large projects, see the findings of the EC funded survey research studies directed by Rishab A. Ghosh (UNU-MERIT, Maastricht), including: FLOSSPOLS (2005), FLOSSImpact (2006) and FLOSSWorld (2007); also David and Shapiro (2007).

Yet, far more straightforward than the foregoing noteworthy complications, there is another, quite fundamental source of the “blurry vision” projected by the literature concerned with open source developers. Curiously, given the researchers’ primary fixation on issues relating to the phenomenon of community-based software production, they have not paid adequate attention to examining the right data. As has already been suggested, many of the generalizations currently in circulation about the characteristics, motives and behaviors of contributors to FLOSS, to the extent that they have a substantially empirical basis, rest insecurely upon two bodies of observational evidence that are not exactly “fit for purpose.” On the one hand there are several extensive web-cast surveys that have drawn self-selected responses from the population of developers at large, among which, as has been pointed out, a sizeable proportion are not engaged in community-based projects. [13] On the other hand, an important component of the research literature has been based on the findings of targeted small-sample email surveys, and still more intensive interview-based case studies. Among these is the handful that has focused upon specific FLOSS development communities associated with big projects (the Linux kernel, and GNOME being popular objects of repeated study).[14] The individuals whose behaviors are observed (and whose attitudes and concerns are expressed) in such case studies may be self-selected into projects on the basis of characteristics, attitudes or propensities that render them (and their project) idiosyncratic rather than “typical” or “representative” of the population that distributes itself among the totality of community-based development efforts. Thus, the research relying on large web-cast survey populations may claim to be in some sense representative of FLOSS developers at large, but by that token not necessarily of those who are engaged in community-based software production; whereas the participants in the small collection of large projects selected for study has not been shown to be representative of the membership of the broader class of such projects.

Thus, to recapitulate, our principal goal here must be simply to improve the resolution of the group portrait of sub-population of developers who have chosen to develop FLOSS by working in one or another of the larger “community” (that is in C-mode) mode, and to determine whether and in what respects they differ from those who have chosen to work essentially independently (in *I-mode*). Quite

[13] See, primarily, the 2002 FLOSS-EU survey (Ghosh et al., 2002); the 2003 FLOSS-US survey (David, Waterman and Arora, 2003. Included with these might be the 2003 Boston Consulting Group Survey) the largest of the targeted email surveys, gathering 684 responses from individuals listed as project group members on Source Forge. For analyses of this dataset, see Lakhani et al., 2002, and Lakhani and Wolf, 2005. Table 1 (below, in Section 2.1) provides further details of these data sources on developers characteristics and motivations.

[14] See Table 1, in Section 2.1 (below); also, Bitzer et al (2004), Bonaccorsi and Rossi (2004), Iannici (2005), Lee et al. (2003), Rossi and Bonaccorsi (2005), Ye and Kishida (2003) and the more extensive review of empirical papers in von Krogh et al 2008. There have been still other highly informative empirical studies of developers associated with Linux and others among the large project (e.g., Hertel, Nieder, and Herrmann 2003), including those that have been concerned with analyses of the pattern of communications among all the participants (see Crowston and Howison, 2005, 2006; Howison, Inoue and Crowston, 2006), the nature of attachments and the changing roles of participants in these projects (Elliott and Scacchi, 2006). But these have not focused on questions relating to the motives for participation, developers capabilities and experience, or the persistence of project attachments.

apart from the fact that this task is "doable" and yet has been left not done, there are compelling reasons for returning to these often discussed topics in the micro-economics and micro-sociology of FLOSS communities in order to arrive at a more discriminating descriptive study of the human resources that are engaged in the "open source way of working." These follow from an acknowledgement of the potentially important longer-term implications of community-based open source software development as a "paradigm-shifting" phenomenon, a movement whose consequences may well beyond those affecting the organizational evolution of the software industry.

1.3. Organization of the paper: a 'roadmap' of our procedures and main results

Section 2 describes the main data source upon which the present analysis rests, the 2003 FLOSS-US Survey whose design and descriptive findings were reported by David, Waterman and Arora (2003). We situate this source (in Section 2.1) among the set of nine surveys carried out before 2005, all but one of which had focused on discovering the characteristics and avowed motives of contributors to the development of FLOSS, and indicate the particular features of this survey that rendered it especially suitable for the present purposes. We follow the previous research contributions in giving special attention to the question of motivation in Section 2.2 discusses the strengths and limitations of the available information from the FLOSS-US respondents about their reasons for beginning to develop open source software, and for their choices of the first project and the main project in which they currently were participating.

Section 3 occupies a major portion of the paper, in which we present a multi-step reanalysis of the motivations data for the subset of 1459 individuals who supplied complete answers to the battery of FLOSS-US questions that asked them to assign relative importance of each of 11 suggested reasons for beginning to contribute to FLOSS development. Contrasts been the character of those Likert-scaled responses, and the salient reasons for project choice are reviewed in Section 3.1. Although the attention focused on delineating FLOSS developers' motivations has encouraged the projection of a static picture, Section 3.2 takes notice of evidence extracted from surveys that points to the mutability of motives – in regard to both the reasons for current involvement with FLOSS and the choices among projects. Not only do motives evolve, but there is reason to view those changes as interdependent with changes in individual material circumstances and social contexts. This points to the usefulness for purposes of statistical analysis of explicitly recognizing developer's stated reasons for having first become involved with FLOSS development as a lagged endogenous state-variable that may be treated as a pre-determined "fixed" effect; the advantages of this for econometric studies of the putative role of motivation in accounting for subsequent behavioral patterns are considerable. In Section 3.3 we are able to show that the population of self-identified developers at large is heterogeneous in the "fixed" patterns of its members' initial motivations for involving themselves in FLOSS activities. This is done first by adopting a "bootstrap" estimation approach to calculating the variance of individual responses to each of the specific items in the battery of questions about motivation, re-sampling from the universe of all 1459 responses to show the variations that would appears in projects of 30, and 100 (randomly drawn) members. Second, factor analysis is applied to the complete set of Likert-scaled responses, and the resulting factor-loadings are used to generate a distribution of motivational factor scores, the properties of which can be examined and interpreted. Having established an empirical basis for treating individual "motivation" as a multi-dimensional profile, and shown the population of developers at large to be heterogeneous in those "profiles," we proceed (in Section 3.4) to group them into distinct "types", or "motivational profile clusters". Rather than trying to chop up the continuous distribution for motivational factor scores, hierarchical clustering analysis has been applied to the full set of Likert-scaled responses regarding developers' reasons for beginning to work on FLOSS development. The results, which enable us to assign one of five mutually exclusive motivational profiles to each of the survey respondents is a significant advance beyond the present state of the literature, in that it yields quantitative estimates of the numerical weights of distinct motivational (cluster) types in the population of developers at large.

To aid in the interpretation of the resulting five clusters, we introduce (in Section 3.5) the device of "normalized motivational intensity maps", using the distribution of Likert scores to show the relative intensity of importance assigned to each of the questionnaire's 11 specific suggested reasons for becoming involved in FLOSS development. This approach is applied both for the entire set of survey respondents and for the sub-populations comprising the component clusters, and presented graphically in intensity maps for each. Rather strikingly, these reveal the main features in which the motivational profiles represented in those clusters are systematically different from one another. Lastly, to round out our portraits of those several motivational types, we examine the available information provided by the written "other reasons" that the survey respondents could supply as supplements to the way they answered questions which suggested reasons for initially contributing to FLOSS development and choosing specific projects. The "other reasons" lend themselves to classification within an extended version of Deci and Ryan's (1985) "intrinsic-extrinsic" taxonomic scheme for human motivations, and the distributions of the "other reasons" to which developers attached importance among those categories for each of the clusters' members. This contributes to providing a richer, more nuanced interpretation of the 'caricatures' we present of these distinctive motivational profiles. The portraits of each clusters' membership then are rounded out with descriptive statistics of demographic and occupational variables elicited by the FLOSS-US survey, which reveal that some significant variations exist among them also in those objective dimensions.

Section 4 connects the micro-level data pertaining to individual developers with information about the projects with which they cay be associated. The discussion starts with a brief description of the methods used in locating the FLOSS-US survey respondents in projects whose position in the contemporaneous distribution of project sizes can be obtained, thereby assigning some 847 of the 1459 FLOSS-US survey respondents to three domains within the project size distribution: those at the extreme lower end, having 1 or 2 members (which we associate with *I-mode* production), those at the opposite extreme having 30 members or more (which we take to represent "large" project engaged in *C-mode* production of FLOSS), and the those in the intervening "middle" range from 3 to 29 members. Consistent with the known skew of the SourceForge project size distribution, fully half of this linked sample of survey respondents are found to have been engaged at the low end of the project size distribution, whereas approximately 20 percent were associated with projects at the upper end of the distribution.

With the project-linked survey respondents partitioned among these three size ranges, Section 4.1 examines the association between project size and patterns of motivation in these sub-populations, using the information from the distribution of motivational factor scores, and the device of motivation-intensity maps to identify differences in this respect between FLOSS developers who were working in *I-mode* and those in *C-mode* projects. The question of the extent and directionality of the circulation of developers among projects, and specifically the degree which such movements occur across the boundaries that we defined (rather than being largely confined with the respective strata of small, medium and large projects) is examined in Section 4.2. This analysis makes use of the data from the FLOSS-US survey's questions about the respondents' initial and current projects in those cases where the two were different.

Section 5 brings together the preceding findings about the characteristics of the FLOSS developers in the different motivational clusters, on the one hand, and the distribution of those motivational types across the small, medium and large projects, on the other hand. This integration proceeds in two main steps. We look first (in Section 5.1) at the issue of whether the mixture of motivational factors of the developer populations is much the same or exhibits distinct differences as one moves across the range of their project sizes. Then the descriptive statistics of developers at the upper and lower extrema of the project size distribution are compared to identify whether there are significant statistical differences between those contributing to FLOSS production in *C-mode* and those who are working in *I-mode*. This analysis examines demographic, occupational and experience characteristics, as well as the variation of expected proportions of motivational types and motivational intensities across the range from the large to the very small projects.

A further (second) step in the analysis (in Section 5.2) asks whether the initial motivations of developers and their objective characteristics have significant predictive power on the choices made by FLOSS developers regarding the sizes of the main projects to which they contribute. For this purpose we estimate an ordered probit regression model, whose independent variables include experience in FLOSS, age upon first developing FLOSS, occupational status, earnings from FLOSS, expected future job roles, country of residence, and educational attainment.

The paper concludes (in Section 6) by recapitulating the main empirical findings and considers briefly some of their implications for future research on the interplay between individual motivations, organizational practices and institutional structures in the mobilization and coordination of resources, and the governance of community-based production of open source software.

2. Data from other studies and from the present paper

The basic dataset on which our analysis in this paper rests is drawn from the responses to the 2003 FLOSS-US web-cast survey (conducted between January and June 2003) that elicited a total of 1,587 valid responses from open source software developers.[15] The online survey asked 46 questions about developers' demographic characteristics, education, occupational status, software experience, reasons for participating in FLOSS development, open source project roles and contributions, remuneration, and other topics. Respondents learned about the survey from advertisements posted on 50 websites and mailing lists in many countries. Hence these data do not represent a probabilistic sample of all FLOSS developers. Other data on FLOSS developers use a similar voluntary sample, whether gathered from web posting of a questionnaire (e.g., Ghosh et al. 2002), or from responses to targeted e-mailing of a questionnaire in the case of the Boston Consulting Group's "Hacker Survey" (Lakhani et al., 2002; Lakhani and Wolf, 2005).

Several advantages of working with the FLOSS-US data in the present connection may be noted briefly at the outset. First, although the number of observations is smaller than those available from the FLOSS-EU, it is still quite ample and the geographical balance between Europe and North American respondents is more representative of the global population.[16] Secondly, while responses to the same array of suggested reasons for beginning to contribute to open source software development are available from both surveys (by design), those from the FLOSS-US survey are Likert-scaled. Thirdly, the self-selected sample elicited by the web-cast survey method is likely to yield a more representative sample of the global population, particular in the relative balance between participants to very small and large projects, in comparison with the BCG approach, which targeted individuals in the e-mail lists of established projects. Lastly, the timing of the FLOSS-US survey in 2003 coincides with the coverage of a documented database of all the projects in the SourceForge archive, from which it was convenient to obtain project size information that could be linked to the files for more

[15] David, Waterman, and Arora (2003) provide a detailed description of the survey methods (including the web-postings and non-English translations of the request for cooperation) and the basic statistical findings. The present study is a reanalysis of the FLOSS-US dataset, which has selected the subset of respondents who provided complete answers to questions regarding their motivations for beginning to contribute to open source software development.

[16] SourceForge.Net contains perhaps the web's largest repository of open source projects, and comparing the geographical location of FLOSS-US respondents against the more than a million registrants on SourceForge in 2006 (as estimated by Robles and Gonzalas-Barahona [this Issue]) provides some idea of the extent to which the FLOSS-US represents the larger universe of developers (see also Robles et al., 2006). The comparison we have made of the regions of residence of the two populations shows a reassuringly close correspondence, although because the SF.Net population is very large, the proportions are precisely estimated and the differences between the two are statistically significant. These statistics are not shown here due to space constraints, but may be obtained privately from the authors.

than half of the individual survey respondents – particularly those who reported themselves engaged principally in projects that were discovered to fall into the very small and medium size-ranges.

Since the true universe of FLOSS developers has dynamic size and lacks clear definition, it is not possible to strictly examine the representative-ness of any sample, even one that is quite large; an on-line survey such as FLOSS-US cannot even report a defined response rate.[17] Nevertheless, it is important to set this data source in the context of other studies conducted in roughly the same time period, namely the opening quinquenium of the present century, and to establish that if we cannot say whether or not it is representative of the global FLOSS developer population, it is reassuring that the FLOSS-US respondents collectively resemble those described by other survey-based studies of that population in respect to a number of their basic characteristics.

2.1 The FLOSS-US Survey in Context

At least eight other empirical analyses have surveyed FLOSS developers during the period up to 2005, almost all of which had among their goals a clearer understanding these developers' motives. One may group these surveys into the three categories summarized in Table 1: four of the studies prepared an online survey to which developers were invited to respond (Robles et al. 2001; Ghosh et al. 2002; David, Waterman, and Arora 2003; Mitsubishi 2004)[18]; three surveys involved contacting developers whose emails were obtained from online code repositories, achieving response rates from 8 to 34 percent, and gaining between 79 and 684 respondents (Lakhani et al., 2002; Lakhani and Wolf 2005; Hars and Ou, 2002 and Haruvy, Wu, and Chakravarty 2003); and two surveys, each of which obtained a few hundred responses, were conducted by emailing questionnaires to participants in a single large project (Lakhani and von Hippel 2002 on Apache, and Hertel, Nieder, and Herrman 2003 on the Linux kernel).

Table 1 about here

The heterogeneous methods, unequal sample universes, different survey dates, diverse phrasing of questions and answer choices, and varied selection biases due to low response rates across these studies, all allow one to reasonably question their comparability. Nonetheless, comparing the demographics of their respondents gives some idea of their consistency. Several studies' lack of reporting of standard deviations makes it difficult to know the statistical significance of differences

[17] Although one might infer that FLOSS-US developers had a greater proclivity to participate in a survey than was the case among the developers that are not represented among the responses, this is not edifying, and even that conclusion must be qualified by the observation that not all those who might have wished to respond actually became aware of the survey before it was closed.

[18] The 2003 FLOSS-US survey, as a described by David, Waterman and Arora (2003), repeated an number of basic questions in the same form in which they appeared in the 2002 FLOSS-EU survey of developers designed by Ghosh et al. (2002) The survey conducted by Mitsubishi (2004) followed suit, especially repeating the motivational questions of the two previous surveys.

between surveys, but for some of the demographic variables the mean values across these surveys are very similar. The mean ages of the developers in these samples are quite tightly clustered between 27 and 30 years; between 95 and 99 percent of respondents are male, and the respondent sub-populations have mean durations of FLOSS experience in the range from 4.1 to 5.3 years.[19]

Other demographics vary widely among these surveys. The portion of survey respondents from North America ranges from 1 percent in Mitsubishi (2004), a study focusing on Asian developers, to 48 percent in Hertel, Nieder, and Herrman (2003), a study focusing on Linux. Between 14 and 32 percent of respondents are students, and between 4 and 11 percent are not employed. In Robles et al. (2001), the survey yielding the largest sample, 15 percent of the respondents had a graduate degree,[20] whereas the corresponding figure is 43 percent for the respondents to the FLOSS-US (as reported by David, Waterman, and Arora, 2003).

As has been noted (in the discussion of Section 1.1) these empirical studies collectively emphasize an assortment of motives for FLOSS contributors. Almost all included questions seeking to elicit information on the relevance of a variety of suggested reasons for participating in FLOSS, Robles et al. (2001), which focused on software engineering questions, being the exception in that regard. The FLOSS-EU survey allowed developers to choose up to 4 from 14 listed reasons for joining a FLOSS community, and to choose another four reasons for staying in the FLOSS community, and Ghosh et al. (2002) report that the two dominant motivations were focused on human capital formation: “sharing knowledge and skills” and “learning and developing new skills” were mentioned twice as frequently as any of the other listed reasons. The least frequently cited motives were making money, gaining reputation, and distributing non-marketable software. Similar results arose from a question on the expectations held by respondent regarding the motivations of others in the FLOSS movement. The FLOSS-US survey instrument included one battery of questions (in Q 4) about the respondent’s reasons for first developing FLOSS, and a second question (Q12) asks for the respondent’s reasons for selection to work on a particular FLOSS project. Many respondents wrote in other reasons, but the reasons indicated as having been important in motivating initial involvement in FLOSS development are reported (by David, Waterman, and Arora, 2003) to be rather differently focused than those found from the FLOSS-EU data: the preponderant responses were strongly normative, emphasizing the ideology of “libre” software and a communitarian ethos (“we should be free to modify software we use,” and wanting “to give something back to the community”). This presented a contrast with the tenor of the reasons stated for having selected one’s main project, which

[19] It may be noted that all these surveys also concur in not having obtained any responses from FLOSS developers located on the continent of Africa -- probably as much a reflection of the surveyors’ limited access to websites and email lists there than of anything else, although even in 2006, as Gonzales-Barahona et al report [this Issue), the Africa’s proportion of the global FLOSS developer population remains quite small.

[20] Robles et al. (2001) was a short survey aimed at programmers and software engineers, and which did not explore motivations but asked only technical questions. The difference in focus between this and other surveys may partly explain the higher educational attainment in FLOSS-US and others vis-à-vis Robles et al. (2001).

were more instrumental and ego-oriented ("it was technically interesting" and the "software . . . would be useful to me").

Among the surveys with defined sample universes, the Boston Consulting Group study (Lakhani et al.,2002) similarly permitted respondents to indicate their agreement with various proposed motives for developing FLOSS. The dominant reasons included intellectual stimulation and improvement of skills, whereas the least common motivations were the requirement of a license, and the goal of "beating" proprietary software. Hars and Ou (2002) found that 70 percent of respondents identified improvement of programming skills as a dominant motivation, 52 percent stressed the value of a peer network, and 39 percent cited their need to use or modify the software in question. Haruvy, Wu, and Chakravarty (2003) had developers choose items from a 7-point Likert scale, and report that "[q]uite a few respondents sent emails expressing indignation at survey items which suggested [that] monetary items could possibly motivate their contributions to open source projects" (p. 21). They convert these responses into scalar intensity values for selfish and non-selfish motives, and find a modal unselfish-to-selfish ratio of 1.25.

The two surveys in Table 1 that studied the developers participating in a large project identify additional motives. Lakhani and von Hippel (2002) explain that Apache developers devote time to the mundane task of reading and answering user queries because such activities help the developers improve their own code and websites, and they suggest that such direct rewards may supersede altruism or direct enjoyment of work as motivations for FLOSS development.[21] Hertel, Nieder, and Herrmann (2003) derive seven factors from principal component analysis on motivational questions, which they interpret as follows (i) identification as a Linux user, (ii) identification as a Linux developer, (iii) desire to improve a developer's own software and career prospects, (iv) positive expected reactions of friends and family, (v) ideological motives regarding FLOSS, (vi) enjoyment of programming, and, as a counter-motive (vii) expenditure of time on FLOSS programming. While this study identifies multiple motives for developers, like many others, it does not emphasize heterogeneity of motivation within the population of developers. Thus, the survey respondents might reflect the existence of several groups each distinguished by a unique motivation, or a homogeneous population of developers, each of whom has multiple motivations. To fully understand the motivations of FLOSS developers, however, requires an effort to distinguish empirically between those two interpretive possibilities – which is the main task that will occupy us in the next section.

2.2 Problems of bias and noise in data about individual motivations

We proceed with the caveat that our data, being generated in response to a web-cast survey,

[21] This interpretation represents an extension of von Hippel's user-innovator model which figures as the guiding framework for empirical research in other studies, including, more recently, those focused upon open source software production. See von Hippel (1988, 2002); Morrison, Roberts, and von Hippel (2000); and Henkel and von Hippel (2004).

pertains to a self-selected population's reported characteristics, perceptions and expressed reasons for (some of) their actions. Further, our use of the information supplied by developers in response to questions posed by the FLOSS-US survey about their reasons for beginning to participate in open source development, and their choice of particular projects on which to focus their contributions adds some special sources for concern. But it seems quite unavoidable in the circumstances, even though economists typically are inclined not to accord much weight to the personal testimony that economic actors might offer regarding the subjective beliefs or reasons for their behaviors.[22]

No incentive in the structure or implementation of the FLOSS-US survey would have encouraged developers to misrepresent their motives in replying to the anonymous on-line questionnaire, and developers' stated reasons for their participation should not be dismissed in favor of essentially a aprioristic speculations guided by psychology, or sociology or economics. But a measure of skepticism and considerable caution nevertheless is warranted in working with these micro-data on expressed motivations. Developers may generate beliefs and statements about their "values" to satisfy their suppositions about what survey-takers will regard to be appropriate; or, for reasons of cognitive dissonance, they may offer statements about their perceptions or goals that have the effect of rendering the their own behaviors more readily rationalized and consistent. [23] Errors in measurement in stated reasons may therefore be correlated with other, objective observations on behavior, and so may give rise to biased regression estimates when the forms of data are used in conjunctions with one another.

In view of the interest of this study in learning whether the attributes of the developers who contribute to community production in large projects are different from those who are drawn to projects in the lower range of the size distribution, it is natural to worry that the reporting of motivations might be distorted in some way that was related to choices of project size. If such relationships do exist, not all of them seem as transparent and straightforward as the connection between being motivated to learn to be a better programmer by observing and interacting with others, and choosing not to develop software independently; or to reverse the causation, finding opportunities for skills development in the FLOSS large project that one had joined out of curiosity to be a important "reason" for participating in the open source movement. To illustrate the point that the motivation-size connections are multi-valent, consider one of the most widely discussed of the early "economic" explanations offered for the puzzle of the "open source software movement" by Lerner and Tirole (2002), who suggested that software developers might volunteer their efforts without requiring immediate compensation because the open setting of FLOSS projects permitted career-seeking algorithm designers and programmers to openly exhibit their technical expertise; by sharing

[22] Rather than asking individuals about the motives and intentions that led them to make one choice rather than another, the modern theory of demand instructs us that it is better to proceed by observing how behaviors change when constraints are altered, and interpreting the outcomes as reflecting "revealed preferences."

[23] Bertrand and Mullainathan (2001), who review literature on the usefulness of subjectively reported beliefs.

the fruits of their knowledge, they might more readily build a reputation that would widely "signal" their expert capabilities to potential employers.[24] A different argument that similarly involved an instrumental or extrinsic purpose, has come from the management and innovation studies side[25]: developing and freely sharing open source software could be a form of innovative investment that allowed those undertaking it to better satisfy their own particular human wants, by developing a new artifact that would meet its creator's need more satisfactorily than any of those that were already available. The latter explanation therefore "naturalized" open-source software developers as simply one among a larger class of "user-innovators" who looked forward to benefitting directly from the "own use-value" of the customized programs they were creating or modifying so as to better meet their personal use requirements.

Neither of the foregoing depictions of what is motivating FLOSS developers would seem to carry any clear and compelling implications regarding the size of the projects that people thus motivated would chose to join. Fleshing out the specifics of these "reasons" a bit further, however, points to different considerations that could favor either large project or small project participation. Opportunities to generate direct financial benefits are likely to be more certain in the case of programmers who were owners or partners in a software services enterprise, and thus could work essentially independently, or on small projects to adapt or modify existing open source programs, or develop new ones for clients with idiosyncratic needs. The prospects of commercial success in each of such endeavors are likely to be closely circumscribed by the market competition of others with similar skills, whereas both the expectation and the up-side variance in the "payoffs" from successfully initiating and leading a large project would tend to be considerable bigger by comparison. On that argument, the motivation of "signaling" one's software expertise, suggested by Lerner and Tirole (2002) would seem more immediately pertinent in the case of developers who choose to contribute to large open source software projects, especially as displaying extraordinary technical abilities in that arena would make them more widely visible and elicit expressions of peer-esteem that attracted the attention of potential employers. But, except for the exceptional few, the expected pecuniary rewards of winning that sort of reputational tournament may well be dominated

[24] See Lerner and Tirole (2002), whose influential paper asked (p.98): "Why would thousands of top-notch programmers contribute freely to the provision of a public good?" Their suggestion that there was a reputation-building advantage to making prominent contributions to a large and successful open source project echoed the point made by Dasgupta and David (1994), concerning the "signaling value" for young researchers of initially accepting academic "open science" appointments, even though they contemplate eventual employments in corporate proprietary R&D labs.

[25] See, e.g., von Hippel (2002) for the initial reflexive extension of his previous research on user-innovators (von Hippel 1988) to both "explain" open-source software development, and broaden the significance of user-driven innovation. Hars and Ou (2002) added empirical support to this line of explanation, emphasizing the value placed by survey respondents on "own use" of their contributions to open source code, and reported finding positive correlation between high values accorded to this reason for participating in FLOSS development and greater reported weekly hours of work. Lakhani and von Hippel (2002) suggested "own-use" motives might be especially important for developers carrying out ordinary, unchallenging programming tasks.

by the opportunities to create a small software service business. Materialistic and rational "explanations" in that case might actually be masking "reasons" that involve ego-gratification and the quest for peer esteem as an end in itself.

3. Analysis of Survey Data on Motives for Engaging in FLOSS Development

The FLOSS-US survey included two sets of questions about the motives of developers. The first of these (Q4) asks the importance of several motivations in the respondent's decision to first develop FLOSS. Respondents choose from a four-option Likert scale (very important, important, a bit important, or not important) for each of 11 listed motivations. (These are displayed in Fig.1a, below.) While FLOSS-US presented sub-parts of Q4 in alphabetical order, denoting the questionnaire items by letters a through k, the chart in Fig. 1a re-orders these questions and the distribution of Likert-scaled response to each in a sequence starting with intense expressions of ideological that can be read as serving to identify (or self-identify) the respondent with the ethos and values of the "open source movement," or with a particular community of FLOSS developers. The ordering of responses proceeds downwards toward responses that place greater and greater emphasis on pragmatic and technical reasons.

Figure 1a about here

Some measure of instability or endogenous formation of motivations is afforded by the second survey question (Q12), which asks why developers chose to participate in a particular project, and allow for the possibility of reasons that would different in case of the respondents' current project from those that governed this choice in the case of the first project. The suggested options for answers to Q12 are shown in Figure 1b, but (unlike Q4) this question did not ask for Likert-scaled responses.) While Q4 invites articulation of general expressions of interest and values, Q12 captures decisions at the margin—given a developer's reason for developing FLOSS: What pushed the individual to select that particular project over alternatives? Again the chart presents sub-parts of Q12 in descending order, from social and community-oriented to technical. FLOSS-US obtained Q12 responses separately for a respondent's current or most recent project (for exposition, we subsequently call this the "current" project) and for a respondent's first project.[26]

Figure 1b about here

Overall, pecuniary and direct career motives have comparative small importance among the reasons listed in Q4 for beginning their participation, and direct business sponsorship is infrequent: only 7 percent say that their employers' having directed them to collaborate in open source

[26] Our analysis generally makes use of Q12 results for both the first and the principle recent or current projects, as will be seen, but in a few cases only the current project data are used.

development work was very important or important in their initial involvements.[27] Commitment to the FLOSS ethos, by contrast, has notable prominence: 68 to 79 percent list positive ideological reasons (Q4a,b,e) as being either very important or important, whereas only 52 percent assigned that measure of importance to the negative element of the FLOSS movement's anti-proprietary software stance (Q4f). Whereas the proportion declaring freedom "to modify software we use" (Q4b) to be unimportant just approaches 7 percent, the proportions that felt the same way regarding their actual "need" to modify existing software, or to fix bugs in existing software was almost three time larger (20 and 22 percent, respectively). The motivation to become a better programmer (Q4h) was assigned the top two degrees of importance by just over 68 percent of the respondents, and matched the joining FLOSS activities because they constituted "the best way for software to be developed" (Q4a) in assigned importance. Pragmatic interests in learning how particular programs worked, and interacting with like-minded programmers held somewhat less power as a motivation for initial involvement in FLOSS, with 55-59 percent scoring those reasons as important or very important. It may be remarked that the FLOSS-EU and the FLOSS-US data both show that ideological and pragmatic reasons each have important roles in inducing programmers' to embark upon open source software development, whereas only for very small minorities do direct career considerations and employer sponsorship appear to figure importantly in that regard. The FLOSS-US survey sample, which drew about half its members from Western Europe -- compared with the 70 percent share that the latter region held in the FLOSS-EU sample population -- shows greater importance being assigned to ideological motivations, whereas it is the pragmatic aspects of open source code development that are cited with greater relative frequently as important reasons. [28]

While respondents often emphasize ideological motives for first developing FLOSS, they give greater emphasis to practical reasons for choosing a particular project. From Figure 1b it is seen that fewer than half of developers listed a project's importance and visibility as reasons for joining it, while about two-thirds mentioned their chosen project's technical appeal, and nearly 80 percent expected that the software would be personally useful. There were only small differences between respondents' motives for choosing their current and first projects. For example, 61 percent of

[27] It will be seen by inspection of Figure 1a that the sum "very important" and "important" responses varies directly with the former of the two components, so giving the sum in the text is not misleading in indicating differences in relative importance attached to the prompted reasons.

[28] Since the FLOSS-US 2003 Surveys included questions on motivation that were very similar (by design) to those posed in the FLOSS-EU 2002, a merged FLOSS-EU and FLOSS-US dataset could be created by R. Glott and A. Waterman, using responses from 4,402 respondents to very similarly worded questions regarding their reasons for participating in FLOSS development. This yielded counts of positive responses to the six principal motivations noted in the text. Over half of respondents emphasized their desires to improve programming skills, while only 43 percent emphasized the value of "sharing knowledge and contributing to community." Still fewer – only 30 percent – emphasized the value of providing alternatives to proprietary software, and only a fourth valued the experience of participating in community. The percentages cited refer to the proportion of all respondents who had either listed the motivation in question on their answers to the FLOSS-EU questionnaire, or marked the Likert-scale to indicate that reason as "very important" when answering the FLOSS-US questionnaire. Further analysis of this dataset is the subject of a future paper.

respondents chose their first project out of technical interest, while 69 percent of respondents chose their current project for its technical interest. The stability of the distribution of answers relating the respondent's first project and current project is attributable in good part, although not wholly, to the fact that for more than a third of the sample their current project is also their first project.[29] Moreover, the distributions of the aggregated responses to the suggested reasons for project selection (in Q12) can mask shifts in such considerations that occur with the passage of time and accumulation of experience in the case of those developers whose main current project differed from their first project. To see this mutability of "motivations-at-the-margin" it is necessary to shift our analysis of the data to the micro-level, where the heterogeneity of the pattern of individual motives also will come into view.

3.2 Mutable motives and "fixed effects"

In the analysis of the evidence on individual level patterns of motivation that will be described later in this section we proceed by treating the reported reasons for beginning to contribute to open source (from Q4) as a comparable "fixed effect", inasmuch as it reports the state of all the respondents at a comparable point in their experience with the activity. Motives (being reasons given to having done something) may be shaped by experience, and hence re-shaped by learning and reflection; expressed reasons may well be colored by social contexts and situational norms, which are subject to change. Further, inasmuch as the FLOSS-US survey sought retrospective reports on developers' motives for first involving themselves in FLOSS production activities, it is legitimate to treat our observations on this multi-dimensional lagged variable as an exogenous "fixed effect" – even if it is acknowledged that current motivations may be endogenous and co-evolving with other variates describing the developer's employment status and roles, capabilities, perceptions, goals.[30]

There is some evidence to support taking developers' reasons for their initial FLOSS engagement to be lagged endogenous variables (and hence predetermined for purposes of further analyzing the currently observed behaviors of those actors). The data comes from comparing results

[29] Within the subset of FLOSS-US respondents for whom the membership sizes of their project(s) could be established, it is seen from Table 9 (in Section 4.2) that the proportion having identical first and current projects was higher than this, at 0.36. But this reflects the greater ease of identifying and establishing the project sizes if both the first and the current projects when the individual list the same project under each heading.

[30] It may be important to emphasize that the conceptual of a motivational factor-score, as it is used here, applies to a past state of the individual; that Figure 2 therefore depicts the distribution of past motivational states (all relating to a comparable event, their initiation into the world of open source). The same point applies to the related concept of individual "motivational profiles" that will be introduced operationally by employing cluster analysis methods in Section 3.4, below. Whether one's recollected frame of mind at a past point in time, and in one's personal history, exerts any causal influence on one's current beliefs and actions is an empirical question. It could be reframed as an hypothesis, but to test it one would need first to be able to distinguish been the effect of a past mental state that was no longer operative, and the actual recurrence of the same mental state. The retrospective character of the underlying data adds another issue, namely whether errors in the recollection of a person's past motivating concerns are independently distributed, or induced by changing circumstances that would render them correlated with individual current characteristics and external situation. This is territory into which we have no intention of venturing econometrically on this occasion.

obtained from the within-survey repetition of two sorts of motivational questions. Because the design of the 2002 FLOSS-EU survey used the same set of suggested answers about their reasons for starting and for continuing to contribute to FLOSS, Ghosh and Glott (2005) report that comparison of the two patterns of motivations that they obtain by application of cluster analysis to this data exhibits a very substantial transformation: the distribution obtained for the initial event (from retrospection observations) found almost half of the of the 2784 respondents grouped in a single large cluster whose reasons were so diffuse that they defied characterization, leaving the remainder more-or-less evenly distributed among 5 clusters (the 4 larger ones being labeled "ideologists", "materialists", "recognition seekers," "software improvers").[31] The prominent reasons for "continuing" to contribute, which presumably refer to the respondents' current states at the time of the survey, an average of 4.1 years later, were reduced to a list of 4 clusters from which the "materialist" label disappeared (along with a small group previously caricatured as "enthusiasts"). The relative numbers of those clustered under the heading "ideologists" was almost doubled, and "skill improvers" not only emerged but became the dominant cluster.[32]

These findings suggest the reasons that are expressed for *continuing to contribute* not only are mutable, but should be viewed as being endogenously formed by the experience of participation itself.[33] Taken in conjunction with the Rullani's (2007) work on the influence of social communications with other developers in conditioning developers' behaviors with regard to project-founding on Source Forge, such evidence should at very least raise doubts about econometric studies that include currently expressed motivation among the (presumed exogenous) regressors in models purporting to explain variations in micro-level measures of the nature and extent work effort contributed by FLOSS developers (see, e.g., Lakhani and Wolf, 2005, and other small sample studies discussed by von Krogh et al. 2008).

Further support of the apparent mutability of the reasons people offer for their involvement involved in FLOSS activities is provided by the FLOSS-US data on developers' reasons for the choice

[31] The clustering algorithm used by Ghosh and Glott (2005) assigned 50.0 percent of the sample to these the four roughly equal motivational clusters for "starting" that are named in the text, and the remaining 46.3 percent in the "diffuse" motives group. The clusters for "continuing" were reduced to 4 from 6, and by the elimination of the "diffuse" and "materialist" categories, along with the small cluster of "enthusiasts", and the inflow of individuals into the clusters now labeled "skills improvers" (which emerged as the latest cluster), "ideologists" (next largest in relative size) and "software improvers." These three clusters then accounted for 88 percent of the sample.

[32] Table 1 give this as the mean duration of FLOSS experience from the FLOSS-EU survey respondents, "experience" being calculated as the difference between the date of the survey and that of started to work on FLOSS. .

[33] Rullani's (2007) econometric analysis of micro-level data from SourceForge finds that there are significant positive effects upon project-launching probabilities of the extent of the developer's social communications interaction experience with others who are active in that open source collaboration environment. Although von Krogh et al. (2008), p. 20 interpret these findings as supporting the general notion that "learning" in peripheral activities promoted increasing levels of participation, Rullani's discussion is cast more in terms of positive socialization experiences acting to reinforce the individual's commitment to the common purpose of creating open source software.

of a specific project Q4. As has already been noted, the character of the reasons supplied by FLOSS-US respondents to the latter questions (in question-set Q12) is quite different, and generally more immediately practical in nature than those indicated as motivating their participation in unspecified open source activities. But the point of interest here is that the considerations affecting marginal, or differential choices – "motivations for actions at the margin", as they are described by Dalle and David (2005) – show significant inter-temporal consistency and do not appear to evolve as the individual acquires experience in the pursuit.

It is possible to use the responses to a different motivational question in the FLOSS-US survey to examine whether and how individual developers' motives change over time, in regard to the choice of their main open source project. The respondents provided two sets of reasons for choosing specific FLOSS projects – one set for their choice of a beginning (first) project and the other set for their subsequent choice of their principal current project, so that the comparison of these reasons in Table 2 provides some indication of the inter-temporal stability of developers' expressed motives.[34] As is seen from Panel A, the distribution of responses to the prompted set of reasons show substantial differences between the first and the current project. Even though there is a weak degree of persistence, which is visible when one reads down the columns, a Pearson chi-squared test cannot reject the hypothesis that the two sets of responses are statistically independent.

Table 2 about here

The lower panel (B) of Table 2 examines the "other reasons" (an optional and non-exclusive supplement to the respondents' answers to Q12's prompted reasons) that were supplied, but in this case only one "other reason" is recorded for the individual that took up this option.[35] Across motivations, developers listing practical motivations showed slightly more stability than developers listing instrumental or social motivations. For example, 73 percent of developers who chose their current project because its "software would be useful" listed the same motivation for choice of first project, and 59 percent of developers who chose their current project because it was "technically interesting" listed the same motivation for choice of first project. By contrast, less than half of developers who listed instrumental ("important and visible project") or social motivations ("knew people working on it") for their current project listed the same reason for choosing their first project.

[34] A respondent was able to indicate multiple reasons for choosing the first project and, similarly, multiple reasons for choosing the current project; so, in Panel A of Table 2 the frequencies of responses in the columns and rows reflect the multiple reasons provided by individual respondents.

[35] In Panel B of Table 2, as the Notes explain, only one 'other reason" is recorded for each of the respondents that exercised the "write-in option" on Q12. With the exception of those supplying instrumental reasons of a "practical" or utilitarian kind (see the elaborated classification Table 6a and 6b), those supplying an other reason for choosing their first project represented the majority of those who also supplied another reason for their current project choice. The elaboration of various "practical reasons" prompted by Q12 may account for the exception to this general pattern.

This emerges from Table 2 when one compares the frequency distribution of responses to the promoted "reasons" (in Q12) for selecting the developer's first FLOSS project with those supplied when asked the same questions in regard to their primary current project. Reading down the columns in the upper panel (A) of the table, it is seen that the proportions entered in the cells along the principal diagonal of the matrix (boldfaced) are in every instance essentially as large as, or greater than those appearing in the column's other cells, but the positive association is not statistically significant. The lower panel (B) repeats the analysis for the "other reasons" offered to this pair of questions, with a stronger, significant result: the "motives at the margin" for the selection of a first project tend to recur in regard to the individual's choice of a subsequent project.

3.3. The heterogeneity of developer' motivations

Descriptive statistics of the kind presented by Figures 1a and 1b show that multiple motivations characterize the whole population of FLOSS developers, but they do not disclose whether the array of motives are widely shared, and whether, if that is not the case, there are different groups within the whole that are characterized by distinctive motivational patterns. When one looks at survey data about the distribution of motives that developers offer for participating in FLOSS activities, or for selecting a particular project in which to work, it is temping to form a picture of a representative individual who harbors these varied reasons for their actions. In doing so, one is implicitly weighing the several dimensions of motivation according to the relative frequency with which they occur among the reasons expressed by members of survey populations. That is a facile conceptual simplification which is usually recognized to be without empirical warrant. It is nonetheless appealing because some further analysis at the micro-level would be required to discern and measure just how different the individual members of the population are from one another in their motivations, and in their behaviors. Consequently an effort to establish that such heterogeneity is present and to quantify its extent may yield an important step toward more appropriate analytical modeling. as well as in providing the means to better understand the diversity of individual actors' goals, capabilities, norms and strategies whose interplay produces the social and institutional structures that emerge in FLOSS communities and affect the performance of specific projects.

3.2.1. Quantifying the heterogeneity of micro-motives: bootstrapping

We employ two approaches to delineating the heterogeneity of developers' motivations at the micro-level. The first mimics what would be found among the members of a project who had been randomly recruited, a counterfactual presupposition that is useful in exhibiting the variability of the distribution of motives. A Monte Carlo approach can be employed to obtain estimated sample means and standard deviations for a simple measure of the importance of each of the specified motivations suggested by Q4 and Q12 of the FLOSS-US survey. This entails re-sampling from the entire survey population that provided complete responses to those question, first drawing replicated samples of 30 developers, and then of 100 developers by random sampling with replacement.[36] Coding each individual response that scored the suggested reason to be “very important” as 1, as 0 otherwise, the sample mean motivation variable for each questions is a proportion. Consequently, the standard error of the proportion found from the re-sampling of developers who listed that particular reason as being very important is a deterministic function of the overall portion of developers who gave that (certain) answer. The bootstrapped standard errors nevertheless provide us with some estimate of the heterogeneity in the population from which the random samples were drawn.

To interpret these estimates, one may imagine that the set of estimates mimics the variability in the motives of participants that were mobilized to work on a FLOSS project by a process of random attachment. The variances around the means of the proportions of members who regarded the suggested motives in this array to be very important are decreasing functions of the size of the project created by random draws from the population. Therefore it is pertinent to note that the generated sample sizes (ranging from 30 to 100) span the part of the project group membership size distribution that contained almost all of the large and well-established projects that Source Forge hosted during the years 2001-2003. The standard error across these samples is small but nonzero, as may be seen from Table 3.

Table 3 about here

But these bootstrapped estimates reveal substantial heterogeneity: a 95 percent confidence interval, for example, suggests that if a project has 30 developers, anywhere between 16 and 48 percent of those developers will claim that a very important reason for their developing FLOSS is that FLOSS is that it is the “best way for software to be developed.” Similarly, a project leader can know with 95 percent confidence that between 25 and 61 percent of developers in a project of 30 people – a fairly wide range – will hold their desire to “give back to the community” to be “very important” in motivating their contributions to developing FLOSS. It remains the case that only a small proportion of such “random recruits” would have been asked to cooperate with the project by an employer: the 95 percent confidence interval around the mean proportion for whom this reason is very important in motivating their participation would range from nil to 9 percent.

3.2.2. Quantifying the heterogeneity of micro-motives: factor scores

The second approach to describing heterogeneity of motives uses factor analysis to derive a single motivational factor for every respondent, and then constructs the distribution of this factor-score over the whole survey population. Although motivations at the individual level are certainly multi-dimensional (or vector-valued), it is convenient to try to form a scalar measure of the individual’s expressed motivations, simply in order to reduce the problem of quantifying its

[36] The computations were performed with Stata’s Bootstrap: see http://www.stata.com/help.cgi?bootstrap. Setting the replication level at 200 is generally found to be fully adequate for estimates comparable with the distributions of normal variate.

variability among the individuals in the population. We can do this by first applying factor analysis to the 1459 individual survey responses to Q4's that underlie the distributions (seen in Table 1a) of the reasons FLOSS-US developers offered for beginning to contribute to open source software. For the purposes of this analysis we consider all the Likert-scale answers to the battery of 11 suggested reasons, and extract the first factor's loadings on those questionnaire items. These may be inspected in Table A1 of the Appendix, where it is seen (at the top of the table) that assigning greatest importance to the more ideologically and normatively colored reasons (i.e., wanting to "become a better programmer", to "interact with like-minded programmers", to "be free to modify software we use", etc.) receive high positive factor loadings. The more technical reasons that are held to be very important by respondents appear with lower but still positive loadings toward the bottom of the list.

These statistical results in a broad way recapitulate the informal and subjective arrangement of the data on the aggregate distributions of responses to the survey questions (Q4) on the reasons for beginning to develop FLOSS, which appear in Figure 1a. Their advantage is purely descriptive, for factor analysis cannot be used to discriminate between alternative interpretations or theories; as employed here it is essentially a means of data-reduction that permits the computation of a scalar variable from all the information in each respondent's answers to that battery of questions. This scalar is the individual's "motivational factor-score," which is found by applying the factor loadings from Table A1 to his (or her) answers to Q4 {q(a)…q(k)}.

Doing this for each respondent in the FLOSS-US dataset who supplied complete answers to all the items in the Survey's Q4 the items in the survey yields the frequency density displayed by Figure 2. Here we have a continuous representation of the heterogeneity of self-reported motives in the population of FLOSS developers.

Figure 2 about here

If all developers had the same motivations, then the factor score would have constant value and variance of zero. The probability density function (Figure 2) shows that reported motivations differ substantially between developers. The factor score evidently has a non-symmetric distribution, and the hypothesis that the factor is normally distributed is decisively rejected by a Shapiro-Wilk test.

3.3. Cluster analysis: grouping heterogeneous respondents by motivational profile

Having established that the "representative FLOSS developer" is an inappropriate construct, because the population we are examining exhibits significant heterogeneity in the members motivational profiles, we now turn to more carefully describe the main profiles suggested by combinations of important reasons for FLOSS participation, and examine their distribution in the population of survey respondents. For this purpose we proceed by use cluster analysis, and then characterize the "normalized motivations" associated with each of the identified clusters. The objective being to be able to assess the quantitative importance of various complexes of motivation that have figured in previous theoretical and empirical discussions of this question, grouping developers into clusters is a natural way to approach that question. [37]

The principal tool employed in this analysis is hierarchical complete linkage cluster analysis, based on the full set of responses to Q4. Although the number of methods for cluster analysis exceeds the number of studies using cluster analysis, and statistical theory gives limited guidance as to the appropriate choice of cluster method (Everitt 1993), several reasons can nevertheless be offered in support of the choice of hierarchical complete linkage analysis. Hierarchical agglomerative cluster analysis forms a taxonomy of characteristics that allows quantitative comparison of different numbers of clusters via stopping rules and graphical comparison via dendrograms. Partitioning methods – principally k-means and k-medians analysis – allow stopping rules but no easy graphical comparison and require an *a priori* specification of the number of clusters to be formed. Hierarchical analysis also has the advantage of permitting a choice of what method to use in comparing cluster characteristics, whereas partitioning methods generally use the mean or median value. Among various methods for hierarchical analysis that were tried, it was found that complete linkage analysis with the FLOSS-US data consistently forms medium-sized clusters, allowing for sufficient observations in each cluster to compare developer motivations.[38]

Figure 3 about here

The hierarchical analysis uses the 1,459 developers who answer every sub-part of Q4 to form five clusters. This analysis produces one dominant cluster containing 696 developers (nearly half the sample), another cluster with 325 observations, and others with 59, 145, and 234 developers. The population of developers breaks into two distinct branches—the first two clusters come from division of the first branch, and the last three clusters come from division of the second branch. The dendrogram in Figure 3 suggests that clusters 1 and 2 will have similar characteristics, that clusters 3

[37] A plausible alternative to cluster analysis for examining heterogeneity in a population of developers would be to solely use factor analysis to construct several “motivation” factors, then to discuss the distribution and meaning of these factors (see Hertel, Nieder, and Herrmann 2003). We prefer to focus on the results of cluster analysis, however, since discussion of survey responses among different clusters allows more direct examination of motives than discussion of a combined product of many survey responses, which is what factor analysis would allow. Since responses to Q4 and Q12 pertain to quite different questions, and since the binary answers for the five listed motivations in Q12 provided limited additional information for constructing clusters, we use only Q4 in constructing clusters, though we report the answers of these clusters on Q12.

[38] Any cluster method can form unstable results from a given distribution of data, as the agglomeration of observations into clusters when multiple observations have equal distinctness requires arbitrary decisions. Since the assignment of all developers to clusters depends on assignment of the first few developers to clusters, breaking of such ties can cause results to vary each time that analysis forms clusters. For simplicity, we assign each developer a randomly generated number and use this random assignment to choose among different developers when more than one developer has similar characteristics. Nonetheless, exact results from cluster analyses can vary based on small differences in the underlying data or the chosen distance measure and methods of generating clusters, leading some researchers to emphasize that cluster analysis serves a more useful role in generating hypotheses than in testing them (see Everitt 1993).

and 4 will have similar characteristics, and that cluster 5 will have the most similarity to clusters 3 and 4.

3.4. Methods for characterizing and distinguishing the motivational clusters

To simplify analysis of the four-option Likert scaled responses to Q4, we calculate "normalized intensity" measures for populations of developers. “Population” here refers to any subset—all developers, a cluster of developers, or another grouping. We define a population’s response *intensity* as the number of developers in the population who list a motivation as “very important” or “important,” divided by the number of developers who list a motivation as “not important.” Intensity summarizes responses to the Likert scale in scalar form. The first and within-question normalization divides, for each sub-part of Q4, each population’s intensity for the question by the mean intensity for the question among all developers, producing a *normalized intensity* for that population. The second and within-population normalization divides population’s normalized intensity measure for each question by the mean normalized intensity across questions. This second step gives the *twice-normalized intensities* that appear in Tables 4 and 5. This approach ensures that all motivations have a within-population mean of one, facilitating comparison of the listed value of motivations across questions within each population but not across populations.

3.4.1. Defining measures of “motivational intensity”

To explain this approach formally, let *i* index developers, *P* denote the number of developers in population *p*, *N* denote the total number of developers, and *q* index a sub-part of question four, so $q \in \{a, b, . . . , k\}$. The intensity A_p for population *p* on question *q* is

$$A_{pq} = \frac{\sum_{i=1}^{i=P} (vimp_{ipq} + imp_{ipq})}{\sum_{i=1}^{i=P} nimp_{ipq}}$$

where *vimp*, *imp*, and *nimp* represent indicators that take the value one if a developer gives response “very important,” “important,” or “not important,” respectively, and zero otherwise. The intensity for all developers on question *q*, *B*, is

$$B_q = \frac{\sum_{i=1}^{i=N} (vimp_{iq} + imp_{iq})}{\sum_{i=1}^{i=N} nimp_{iq}}$$

The first normalization *F*, for question *q* equals the ratio of a population’s intensity to the mean intensity for all developers:

$$F_{pq} = \frac{A_{pq}}{B_q} \qquad (1)$$

The twice-normalized intensity *T* for population *p* divides the normalized intensity for question *q* by the mean normalized intensity for all 11 sub-parts of Q4:

$$T_{pq} = \frac{11F_{pq}}{\sum_{q=1}^{q=11} F_{pq}} \qquad (2)$$

For Q12, we use a similar approach but define intensity as the portion of developers listing a particular motivation, since Q12 does not use a Likert scale. By definition, each cluster has mean twice-normalized intensity of one on Q4 and the same mean on Q12.

3.4.2.Reading the motivational intensity maps

The normalization methods outlined above (in section 3.5) applies readily to sub-populations of all developers, but also can apply to one population that includes all developers. To derive such normalization, we calculate intensities for all developers on each part of Q4, and then omit the first normalization in equation (1) since we only have one population. We proceed to directly calculate the second normalization in equation (2). We use a similar approach for Q12, but define intensity as the portion of respondents who agreed with a motivation listed in sub-part of Q12.

Table 4 about here

Table 4 presents these normalized results, and they imply similar conclusions to Figures 1a and 1b, albeit with more simple scalar comparison. Desires "to give back to the community", and belief in the importance being "free to modify the software we use" constitute the two dominant motivations for becoming engaged in developing FLOSS. An employer's request that one collaborate in a FLOSS project, and the enjoyment of fixing bugs, on the other hand, have comparatively slight quantitative importance. For Q12 the potential usefulness of a project's software represented the leading reason for choosing that particular project, and knowing participants in the project was the least important motivation for choosing to contribute to it. In the responses to Q12, the normalized intensities are seen to vary little between current project and first project (Table 4).

Table 5 about here

Table 5 presents twice-normalized intensities for each cluster (see section 2.2 for explanation of the method), and further explanation of the table's structure may increase its comprehensibility. Each of the first five columns shows values for a particular cluster, while the last two columns test equivalence of mean demographic characteristics across clusters. For Q4, dark grey cells show the three top twice-normalized values for each cluster while white cells indicate the three least common responses for each cluster, though the cluster 4 has a tie between q4j and q4i for low motivation. For Q12, dark and light grey appear for only the top and bottom single responses, though cluster 1 has two questions with equally low twice-normalized intensity (q12c and 12d). As was explained previously, earlier, sub-parts of Q4 and Q12 appear in intuitive rather than alphabetical order. One could read the ordering as proceeding from identification with the public ethos of the FLOSS community, toward commitment to programming expertise, and in the limit to non-ideological professionalism.

It is striking that, as the shadings indicate, clusters have pronounced differences in the gradient of intensity. One indication that these clusters identify ideological or non-ideological groups appears in the concentration of common and uncommon responses. In clusters 1, 2, and 5, the most common answers appear in adjacent rows. Cluster 5, for example, emphasizes ideological reasons for developing FLOSS and rarely lists pragmatic reasons. Clusters 2 and 4, by contrast, more often list pragmatic reasons and less often list ideological reasons.

These motivations cohere with the dendrogram (Figure 3) in suggesting the similarity of clusters. Clusters 1, 2 and 4 emphasize responses in the lower part of Table 5, indicated by having two or three dark grey (most intense) responses below Q4h and two or more of the white (least intense) responses at or above item Q4h. Clusters 1 and 2 have greatest similarity, with one apparent difference being that only the few developers who fall in Cluster 1 emphasize the specific reason fpr their initial participation: an employer's request that they collaborate in developing open source software.

Table 6 about here

Table 6 offers some thumbnail characterizations, or caricatures of the motivational profiles represented in these clusters. Clusters 1 and 2 eschew ideological reasons and emphasize technical motivations. Learning and social interactions rarely motivate the anti-ideological hackers of Clusters 1 and 2, and so they resemble the motivation profile that Lerner and Tirole (2005) suggest—an individualist, materially motivated programmer who develops FLOSS in the interest of a future career, and, in cluster one, for current employment. The differentiating label of "professionals" given to Cluster 1 is meant to reflect the exceptionally high intensity score associated with being initially having been asked by an employer to work on open source (as seen from Table 5:Panel A), as well as the relative concentration within this group of individuals whose project choice was bound up with having launched the project as one that was technically interesting (Table 5: Panel B). By contrast, the "aspiring hackers" of Cluster 2 share the motive of needing to patch bugs in existing software, but differ in being strongly motivated to start contribution to FLOSS projects by the the challenge of fixing bugs and their desire to learn how particular programs work.

Cluster 3 appears more individualist and instrumental about improving software programming skills—including learning how particular programs work. Developers in this cluster do not attach great importance to "giving back to the community" as their motive for stating to develop FLOSS, although, if they have little experience, they may be conscious of being unable to contribute expertise to the FLOSS community and having joined a project in order to develop programming and other software skills. Members of Cluster 3 evince a distinct social orientation – those who want to work with like-minded others and regard open source as the best mode for software development are relatively prominent, while wanting to become better programmers. This complex of expressed motives would appear to reflect a particularly strong attraction to membership in a community that includes other neophytes who, similarly, are seeking mutual instruction or reassurance. Clearly, patching code does not motivate those in the Cluster 3 profile: they are not code producers, so much as "social learners" – the label affixed to them in Table 6.

Developers in cluster 4 heavily emphasize the need to modify code and identify with the free software movement's ethos: this cluster resembles Raymond's (2001) hackers in expertise. They rarely emphasize interaction with others, improvement of programming skills, or the desire to learn about particular programs. This cluster rarely mentions the "challenge of fixing bugs in existing software" but often emphasizes needing to "fix bugs in existing software." Perhaps the first phrasing of challenge does not appeal to these developers, but the second of practical need more reflects their motivations. This cluster has the greatest intensity of the need to modify existing software—its users have some clearly practical motivation.

Cluster 5 more than any other voices ideological positions often associated with the FLOSS movement, while attaching least importance to the instrumental technical reasons or to professional reasons for engaging in FLOSS projects. Developers in this cluster somewhat resemble Cluster 3 in attaching moderate importance to improving software skills with like-minded others. They also appear to continue learning, though with more confidence than developers Cluster 3. This may explain the response of wanting to "give back to the community"—if they had watched and communicated with others before beginning to work on a project. But that statement may be read as referring to the FLOSS community at large rather than to a project-based community, particularly since Cluster 5 developers often launched the project on which they work, which for many was their first project.

Further light is shed on Cluster 5 types by the observation that three-fourths of them are members of the very small project sub-sample (Table 10). Also, Cluster 5 assignees disproportionately reported that the reason for their current project choice was that "I launched the project" (Table 3 Panel B). In the context of the latter statements, the relative importance that Cluster 5 assigns to "giving back to the community" might be interpreted as referring to the contribution of the project's code, rather than a contribution to larger projects that were community-based. This reading reinforces the suggestion that "community" refers to the open source community at large rather than a particular project community. For cluster 5, lack of identification with the FLOSS movement perhaps compensates for lack of involvement in a FLOSS community project.

Perhaps the characterization of the profile of Cluster 5 as that of "user-innovators" (by Table 6) may be viewed as less than entirely appropriate, inasmuch as its application by von Hippel (2002, 2005) to explain the behavior of open source developers has associated its use in this context with special connotations that derive in large measure from von Hippel's (1988) influential earlier studies of the sources of innovation in certain fields of business. There the image of the proto-typical user-innovator is that of the *individual* hobbyist, or professional, who shuns large organizations and designs and proves the usefulness of novel artifacts which satisfy his or her needs that have remained unmet by existing, mass-produced goods. Although such people might write a particular driver for the Linux kernel, it seems more likely that individuals having the user-innovator's salient motivation would have focused upon software needs that they believed themselves to be capable of meeting by working independently or in a small project collaboration.[39] One therefore should recall (from Table 5:Panel) that among developers' motives in chosing to work on specific projects, the reason to which the highest normalized intensity score attached attaches in the Cluster 5 group is that they launched the project themselves. This congruence reinforces the case for application of the "user-innovator" labeling, while leaving open the empirical question of whether it will be found that Cluster 5 developers predominate in the very small projects.

The collective portraits of the motivational cluster sub-populations can be rounded out by looking at their respective demographics, educational attainments, employment status and career expectations (Table 7). The two rightmost columns present tests of the hypothesis that the clusters have equal mean values, and show that this hypothesis is rejected in regard to for the means of age, experience, portion with children over age six, the portion of respondents with high school and graduate education, and the expected future role in FLOSS-based commercial enterprise as a company owner, officer, director, or some other professional capacity.[40] . The other categories have some differences across the clusters, though ANOVA cannot reject the hypothesis that the clusters have equal means.

Cluster 1 (*professionals*) has the demographics that one might expect given their motivational responses. They have above-average experience and relatively fewer students (19 percent of Cluster 1) than any other cluster. Cluster 1 has the greatest portion of people with undergraduate education (42 percent). Although this cluster has relatively fewer graduates of professional school (4 percent) than any other cluster, the small number of professional graduates overall and similarity across clusters gives the difference limited importance. Consistent with our characterizations based on the motivations data, Cluster 1 and 2 members are exclusively male, included substantially larger cohorts who had embarked on FLOSS development prior to the year 2000, and averaged more years of experience without having started their involvement with FLOSS at ages as young as those of the members of Clusters 3 and 5. Compared to developers in other clusters, the members of Cluster 2

[39] For such such people, the attractions of starting to develop FLOSS in *I-mode* would be far stronger than those of becoming part of a large, on-going community based project that was already at work building a complex software system, and this might be expected to lead Cluster 5 developers being disproportionately represented among the members of very small projects.

[40] The variable for which inter-cluster differences in means are significant are denoted by boldface, a convention that is followed in subsequent tables.

(*aspiring hackers*) have more experience, a greater probability of working in a firm, and lower probability of having children. Cluster 3 (*social learners*) ties for the youngest developers overall. These developers expend the greatest work effort on FLOSS but have the lowest probability of working in a firm. Cluster 4 (social programmers) has the oldest developers on average, the highest proportion of female developers is found in Cluster (albeit only 3 percent), as is the highest level average educational attainment level. Cluster 5 (*user-innovators*) has the lowest mean experience of any cluster and ties with cluster 3 for lowest mean age. Developers in this cluster have lower average education, with relatively few developers completing graduate school and more than any other cluster completing high school.

3.5. More clues for cluster interpretation: "written-in reasons" for developing FLOSS

The FLOSS-US survey also allowed developers to write-in a motivation for first developing FLOSS. Nearly a third of respondents wrote in an additional motivation for first developing FLOSS or for choosing a specific project,[41] and these write-ins give further insight into the heterogeneity of developer motives. Write-in motivations had varied length and substance: some resembled a listed option; others did not. These written motivations spanned many topics – enjoyment of programming as a hobby, recollections of speeches by Richard Stallman, and others – which we summarize into several categories. Tables 8a and 8b report the results. The interest of these tables lies in the respects in which they enrich the picture that emerges from the responses to Q4a-Q4k. (in Figure 1a, and Table 4) while remaining consistent with its main features. To give a few examples, Cluster 2's emphasis on bugs in Q12other fits its positive chosen response to fixing bugs in Q4a-Q4k; Cluster 3's emphasis on ideology in Q4other fits its responses to Q4a-Q4k; Cluster 4's emphasis on practical goals in Q12 other fits its responses to Q4a-Q4k; and Cluster 5's emphasis on giving back to community in Q4other and Q12other echoes this cluster's listing of this motive in Q4a-Q4k.

There are, however, some differences between the cluster characterizations and the "other" responses: Cluster 1 has been characterized on the basis of Q4a-Q4k as "non-ideological" but respondents who are assigned to that cluster wrote in ideological "other" motivations at a rate that was only slightly below the mean for the sample as a whole. To take another example, members of Clusters 2 and 5 have been characterized as not having important needs to modify existing software, but their responses to Q4other and Q12other frequently refer to their needing to "modify or create" software. Perhaps these developers needed to "create" but not "modify" software, and were responding in a very precise way to the conflation of the two activities in the questionnaire.

[41] The write-in option for Q4 did not distinguish whether this motivation applied to a respondent's current/most recent or to a respondent's first project.

Some differences in values across the clusters appear to have large magnitude, but a Pearson chi-squared test does not reject the hypothesis that clusters and response categories are independent, either using the aggregated categories (italics) or all sub-categories.

To facilitate comparison of these write-in motivations, we distinguish five categories of motivations – intrinsic, instrumental-knowledge, instrumental-visibility, instrumental- practical, and principle – and several specific motivations within categories. Intrinsic motivations include the many developers who wrote variants of “fun” and others who discussed desire to be part of a community or liking developers already in a project (“wanted to be part of the community,” “friendly community,” etc.). These motivations emphasize the pleasure inherent in the development of FLOSS without focus on its consequences. We distinguish three categories of instrumental motivations because most written-in responses have instrumental focus. Instrumental-knowledge responses focus on developing FLOSS for acquiring programming knowledge or for academic purposes. Instrumental-visibility responses discuss hope of developing a reputation among peers or signaling skills to future employers. Instrumental-practical responses emphasize concrete needs: a developer needed to modify existing software or create non-existing software, worked on FLOSS for earnings or following an employer’s mandate, recognized the prohibitive cost of developing or purchasing proprietary code, valued the high quality and short development time of FLOSS code, or required collaboration to develop a project or extend its lifetime. The fifth category of principled responses focuses on positive FLOSS ideology, including three mentions by name of Richard Stallman; negative ideology towards proprietary software, including three mentions of Microsoft; and emphasis on desire to help others and give back to community.

In Q4, 20 percent of respondents wrote in a motivation and most of these write-ins fit into one of the above five categories (see Table 8a: col.1). About three percent of all developers wrote an intrinsic motivation, almost all focused on fun or challenge and few focused on the value of community. About one percent of all developers wrote in an instrumental motive focused on knowledge acquisition, and an additional one percent discussed signaling or reputation. Over six percent of all respondents discussed an instrumental-practical motivation. The need to modify or create software accounted for nearly half of this group. Fewer developers discussed ideology, and a respondent was twice as likely to write positive comments about FLOSS as to write negative comments about proprietary software

In Q12, 20 percent of all respondents wrote in a motivation. These responses had a similar distribution to those given on Q4, but with greater emphasis on the need to modify or create a program, and more discussion of the need to fix bugs (Table 8b: col. 1). Among developers who wrote in a response, the clusters emphasized somewhat different categories, although as in the responses to Q4 (see Figure 3), clusters 1 and 2 are similar in the relative prominence assigned to intrinsic motives, and the similiarity of the comparably high relative frequency of practical instrumental reasons in clusters 3, 4, and 5 is notable.

When it comes to reasons for project choice, there is less differentiation among the clusters in the salient reasons. Bug-fixing, the need to create/modify software, and employment-required participation are salient in all clusters (taking the 3 most frequent specific reasons, and including ties).

Interestingly enough, in comparison with other clusters, Cluster 1 looks little different in most respects apart from the greater relative importance assigned to "fun", although its members supplied a comparatively higher proportion of "other" answers in Table 8a, even if that was not the case in the responses on Q12, as shown in Table 8b.

One further point of interest is the overall frequency of "employment required it" statements among the "other reason" cases in this table. It is essentially the same proportion (3-4%) that is observed citing this as very important among the stated options for participating in responses to Q4 – but is not cited among the "other" reasons on that question. This consistency supports the conclusion that employed contributors are a very small core in the overall developer population. That this reason is particularly prominent in Clusters 1, 2 and 4 is partially consistent with the anecdotal evidence that sponsored contributions are directed toward the larger projects, since it is found (see Table 12, below) that Clusters 2 assignees form a significantly bigger share of the developers in the larger projects than in the very small ones. But the data also supports the qualification that business "sponsorship" of participation in FLOSS production also figures at the level of small enterprises, such as software services and consultancies.

4. Who are the I-mode and C-mode Developers?

4.1 Finding and classifying the project sizes of survey respondents

To measure a project's size, we use data obtained by matching survey responses with data from SourceForge.Net and other platforms. A search of the roughly contemporaneous Source Forge archive identified the number of active developers in project groups named by FLOSS-US respondents.. In some cases, the reported name from FLOSS-US resembled multiple possible projects on the platform. When these multiple entries had similar project sizes, the modal size represented a majority of observations, and the mode differed substantially from the mean (e.g., three matched SourceForge projects had size 14 and one group had size 1), we identified the project with the modal size. In other cases where multiple entries for the same project had different group sizes, we identified size as the mean of non-zero project sizes, rounded to the nearest integer. When SourceForge indicated that a project had zero or an unknown number of developers, we did not use this source of information on project size.

Analysis of project size requires identification of developers in large and small projects, a decision which requires definition of "large" and "small." These categories reflect extremes of a latent characteristic of project size. In the extreme, one can imagine a small project as a student who develops a program as a class assignment and posts it on the web, while Debian's 1,300 developers (Robles, Gonzalez, and Michlmayr 2005) represent an extremely large project. Several reasons, however, suggest that large and small projects represent distinct forms of organization rather than small changes along a continuum. First, structure: to coordinate activities among many developers, large projects must introduce modularity, which could substantially change the dynamics of FLOSS programs and their associated developers.[42] Second, communication: research emphasizes that dynamics of groups – including online communities – changes sharply as group size increases (see Butler 2001 and references contained therein). Mailing lists also encounter this challenge, as coordination requires directed communication between individuals rather than open pronouncements to groups, and mailing lists rarely eliminate need for binary interactions. Finally, public interest: large projects like Apache and Linux have received more public attention than the many one- and two-person projects for outperforming proprietary software, and it may be useful to know whether attracting differently motivated developers helps these large projects succeed.

No research on open source development communities provides any clear demarcation for how large a "large project" has to be in terms of it current contributing membership size. Some references discussed in Butler (2001) suggest that group dynamics change nonlinearly at groups of between 5 and 10 persons, but the evidence seems too general and far-removed from FLOSS to directly apply. More general research on social interaction capabilities of humans and their implications for the sizes of cooperating groups gives some imprecise guidance as to the constraints of group sizes. Richard Dunbar's much-acclaimed correlation of primate communities and brain sizes suggests that human brains can only maintain relationships with 150 others (Dunbar, 2003). This magnitude has been designated the "Dunbar's number" for maximum sustainable group size by more than one prominent recent writer on the subject of group interactions (see Gladwell 2002, Watts 2004). While it is well known that the number of interactions within a group increases nonlinearly in group size, the nature of the "connections" among the members also matters when one is concerned to locate the boundary beyond which the group's complexity of become unmanageable. A group with N members will have $(N^2-N)/2$ binary interactions among its members if one suppose that the latter are directional (Bossard 1945), and it is easy to see that the response of the interaction possibilities to increases in group size is quite non-linear in the size range from 20 to 30.

Figure 4 about here

Looking at the SF distribution, in Figure 4, we see the distribution of the SourceForge project sizes to which we could match our FLOSS-US survey respondents is highly skewed, with the mode being single member projects, and the mass in the 1-2 membership range. Figure 4 demonstrates that choice of an exact size *for distinguishing small projects* does matter, since so many projects have size of 1-2 people. Since the archetypal small project includes a developer posting a solo work or perhaps collaboration with a partner, we define small projects to include either 1-2 developers.

[42] Dalle and David (2005, 2006); see Lerner and Tirole's (2002) discussion of Mozilla and Netscape.

The exact lower bound size that is selected for demarcating large projects has limited importance—as Figure 3 shows that very few projects have known size with more than 20 developers. Some other developers participated in clearly large projects, even if their project has no SourceForge listing. This criterion defines participants in 19 such projects as community-mode.[43] Thus, we were able to classify an additional number of survey respondents as participants in large projects like the Linux Kernel, Apache, and Mozilla (see the list in Table A2) without needing to establish their membership sizes precisely. On this basis it is possible for us to assign as many as 847 of the 1459 FLOSS-US respondents (for all of whom we have complete motivations data, and hence motivational cluster assignments) to one or another of the three size ranges: the very small *I-mode* projects with 1 to 2 members, the "large*"* *C-mode* projects whose lower bound is set at 30 members, and the remainder in the range from 3 to 29.

4.2 Movements of developers across the project size range

The sub-sample of 384 FLOSS-US respondents for whom we have information on the size of their first and their current (main) project allows makes it possible to construct transition matrices describing the pattern of developers' movements. Two kinds of mobility are involved in this "capture-recapture" data, one that crosses project boundaries, and the other that crosses the boundaries we have defined in the distribution of project sizes. Considering all developers with known size, a chi-squared test based on the data in Panel A of Table 9 firmly rejects the hypothesis that the sizes of first and current projects are independently distributed: the entries in the cells forming the principal diagonal are disproportionately high, indicating significant inertia, or persistence within the size-strata. Indeed, Panel A of Table 9, on its face, appears to be telling us that the probability of a developer remaining within the same stratum of the project size distribution is extremely high: for the large project strata it is about 0.47, whereas the corresponding within-strata persistence probabilities are higher still, at 0.72 for those starting at the lower end, and 0.62 for starting projects that lie in the middle range.

Table 9 about here:

But appearances in this case are deceptive, because a substantial number of developers list the same project as first and most recent/current, so that rather than moving within the same part of the size distribution, they may not have changed projects at all.[44] This could be the case either because their initiation into open source development was very recent, or their commitment to the project on

[43] The projects include Linux kernel, Debian, Perl, Mozilla, Postfix, Sendmail, KDE, Gnome, Emacs, Crystal space, Samba, Apache, Mplayer, Freebsd, Mono, Openoffice.org, Openbsd, Php, and Xfree86. See Appendix 2 for the distribution of FLOSS respondents that were matched to these projects.

[44] In the FLOSS-US sample population as a whole almost 17 percent of respondents reported having contributed to only a single project, as can be seen from the frequency distribution based on the answers to Q9, in David, Waterman and Arora (2003), p. 29. In the sub-sample on which Table 9 is constructed, however, the bias toward the inclusion of single project developers is strong, because it is more likely that one will be able to have found the project size for one project than the sizes of both projects in a pair. Therefore, the single-project developers' contribution to the mean overall rate of within-stratum persistence (0.36) implied by the diagonal cells in Panel A of Table 9 is likely to be substantially above 0.17.

which their FLOSS activities had begun was truly more durable. Panel A therefore reflects the presence of "movers" and of "stayers" of different kinds, given that the time intervals separating the first and current projects differed among individuals, and the high persistence rates in the cells forming that table's principal diagonal are in large part reflecting truncation bias due to the short time elapsed between the dates at which those individual had started working on FLOSS and the survey.[45]

Consequently, Panel B is focused exclusively on the subset of 244 respondents among the 384 (almost two-thirds of those in Panel A) whose current and first projects were not the same. These are the "movers" in the organizational dimension. It is striking that a repeat of the chi-square test now cannot reject the hypothesis that movers' pair of project sizes are distributed independently. Rather than persisting within their size stratum of origin, those who start on very small projects have a 0.25 probability to going to a large project, which is 70 percentage points higher than the probability that they will go to a project of intermediate size, and almost 300 percentage points greater than the probability that they will move to a different but equally small project. For those who start developing FLOSS in the context of large projects, the probability that those who start there will move to another large project is 0.20, which is 78 percentage points greater than the probability of their moving to the bottom end of the size distribution, and 45 percentage point higher than the probability of their moving into a project in the intermediate range of the size distribution. The situation among those whose first project was situated in the latter range is even more striking, for the probability of their moving the higher stratum (at 0.19) is 6 time larger than the probability that they will go to a very small project.

The large project stratum therefore emerges from this analysis as an attractor in the circulation dynamics of those who change projects, While these communities may well be regarded as sites of software skills development and organizational know-how that foster open source production at large, it appears that they are also absorbing, and enhancing the programming abilities of developers who made a start on individual projects, undertaken without formal instruction in their capacity as students.

5. Project Size and the Distribution Developer's Motives and Characteristics

We are now able to bring together the findings about the characteristics of the FLOSS developers in the different motivational clusters and the distribution of those motivational types across

[45] Among the respondents to the FLOSS-US survey who answered Q9 about the number of projects to which they contributed, about one third reported having worked on only 1 or 2 projects. So, it should not be supposed that no additional instances of project joining intervened between the observations on first and current (main) project participation from which Table 9 has been derived. Indeed, from the frequency distribution of the number of projects to which they had contributed, one can calculated that for roughly another third (34 percent) of the FLOSS-US developers had joined 1or 2 intervening projects, and for another 24 percent the intervening number of projects was either 3 or 4. Indeed, in the uppermost quintile of that frequency distribution, 7 is the minimum number of projects on which developers said they worked. See David, Waterman and Arora (2003: Fig.37, p. 29).

the small, medium and large projects, which is what we need to know to answer the questions that spurred this inquiry. This can be done in several steps, looking first at the issue of whether the mixture of motivational factors of the developer populations is much the same or exhibits distinct differences as one moves across the range of their project sizes. Secondly, we compare the descriptive statistics of developers at the upper and lower ends of the project size distribution to see whether there are significant differences between those who are contributing to FLOSS production in *C-mode* and those who are working in *I-mode*, considering both their demographic, occupational and experience characteristics, and the variation of expected proportions of motivational types and motivational intensities across the range from the large to the very small projects. Lastly, we undertake to learn whether the initial motivations of developers and their objective characteristics have significant predictive power in regard to the sizes of the FLOSS projects on which they choose the work. The independent variables selected to estimate the marginal effects on project size choice in this model include experience in FLOSS, age upon first developing FLOSS, occupational status, earnings from FLOSS, expected future job roles, country of residence, and educational attainment.

5.1. *Project size-associated variations in developers' motives and attributes*

The boundaries defining small, and large projects have been drawn somewhat arbitrarily, so it is of interest to start by observing that the heterogeneity distribution of the motivations for beginning to participate in FLOSS, which we have argued can be viewed as "historically fixed" characteristics of the individual developers, offers support for the partitioning of the size distribution that has been established by those boundaries. This may be seen from Figure 5, which has been obtained by making use of results from the motivational factor score distribution that was presented by Figure 2 (in Section 3.3). Given the factor-loadings in Appendix Table A1, and the observations on the 847 on the known sizes of the respondents' projects, it is simple to arrange the individual factor-scores in ascending order of project size. One may then test in a simple way whether or not there are statistically significant differences between the distributions of factor scores that lie above and below each project size in the array.

Figure 5 about here

Figure 5 displays the results of the series of Kolmogorov-Smirnov tests computed for the distributions formed by all the possible size partitions, showing the K-S distinctiveness test statistic plotted against project size. The leftmost point, for example, shows the distinctness between of the constructed motivation factor score for developers in one-person projects and those in all the other projects of known sizes. These data suggest some change in motivation between two- and three-persons, although this change continues up to a project size of five. The data also show a change in distinctness of motivation when using a partition at projects with slightly over 30 developers. This partition reveals a quite distinct break that indicates some underlying difference between the mix of motivational profiles typical of the developers in the large projects and those in the rest of the size distribution. Before looking at that possibility explicitly, is it pertinent to see whether there are significant differences in other attributes of the participants in large and small projects. The descriptive statistics in Table 10 reveal that such differences do existing, although only in some of the characteristics of interest.

Table 10 about here

Table 10 compares the mean values for non-motivation characteristics of respondents whose project sizes are known to fall into the small (1-2 member) range and the large (>29 member) range. Because there are some missing observations on these variables for 63 respondents out of the 602 identified in those projects, the sample sizes in the cells of the table for some variable are smaller than the N's shown at the bottom of the tables first two columns; the third column reports the results of two-tailed t-tests of the differences between the means for the size groups (assuming unequal variances).

It will be recalled (from Table 1a) that the mean respondent in the entire FLOSS-US sample started to develop open source software at the age of 24, in 1998. The age and experience means from Table 10 imply the same starting age for those participating in the large projects, whereas those in small projects appear to have started when they were 23. Making the same calculations for the developers participating in medium size projects shows that they have 5.3 years of experience, much the same as that of the average respondent, and were a year older when they started developing FLOSS. Thus, the mean ages of those on medium and large project are close to 30 in both cases, and exceed those of the participants on the very small projects by 2.7- 2.9 years. But none of these differences are large enough to be statistically significant. Although students are a distinct minority among FLOSS developers, constituting only 29 percent of the survey respondent, compared with the the 68 percent who were employees, it seems that the greater frequency with which students are found among the contributors to 1 and 2 person projects accounts for the younger average starting ages that are observed there.[46]

A minority of respondents earned money from FLOSS, and the paid respondents are approximately evenly divided among those receiving payment for support, development and administrative work. About a third of these respondents have graduate degrees, and a majority has some higher education. Since these data represent a sub-sample of all respondents that may have some selection bias, they do not even represent all FLOSS-US developers, and these statistics differ somewhat from descriptive statistics for all respondents (David, Waterman, and Arora 2003).

To help interpret the distinctiveness of motivational factor-scores across the project size distribution, we can use the method of twice normalizing motivation-intensities of responses to the individual questions in the survey (Q4). Table 11 displays the normalized intensity maps for the three

[46] The classification "unemployed" often includes only individuals who are not enrolled as students, lack employment and were seeking paid work. Since the surveys do not require non-student respondents who check "unemployed" to satisfy the latter condition, we refer to these developers simply as "not employed".

domains of the project size distribution, marking the cells in Panel A with the three highest intensity scores in each size class by dark shading, and leaving those with the three lowest scores un-shaded.

Table 11 about here

The mappings of normalized motivational intensities for participants in the three project size ranges reveal quite disjoint patterns in the locations of high and low intensity levels for the populations groups in these parts of the project size distribution. In Panel A there is only one instance of concurrence at the low intensity level – between those in small the medium size projects in regard to Q4j, which concerned the importance of wanting to know how a particular program worked. Similarly, there is only a single instance of concurrence at the high intensity level –between the distributions of developers on medium and large projects, in this case on the importance of needing to needing to patch bugs in existing software as a reason for working on open source code.

But, unlike the normalized intensity maps constructed on the basis of Q12 responses for the different clusters (Table 4), or the map for the whole FLOSS-US survey sample (Table 3), Panel A of Table 11 does not exhibit discernable patterns in which high intensity values are grouped toward the top of or the bottom of the columns, with the low intensity value tending to have the opposite grouping. The assignment of strong relative importance to normative and ideological reasons beginning to develop open source software, or to individuals' technical and professional are not found to be clearly concentrated in different ranges of the project size distribution.

That observation prepares us to find from Table 12 that no signle motivational cluster-type represents a majority among either the *C-mode* or the *I-mode* populations, although in the latter case cluster 3 ('social learners') comes close. The cluster-mix in large and small projects is significantly different, mainly in the greater weight of cluster 2 ('aspiring hackers') participating in *C-mode* FLOSS production.

5.2 Predicting the size range of projects to which developers choose to contribute

We estimate the correlates of a developer's project size by ordered probit rather than by OLS for three reasons. First, for several large projects (KDE, Linux Kernel, Gnome, etc.), we know that a project has more than 30 developers but did not find its exact membership size. Second, project sizes frequently change, but plausibly remain in a single size category (small, or medium, or large) over time, so we may measure exact project size with substantial error but measure size categories far more accurately. Third, the decisions of developers described here represent individuals choosing modes of work rather than exact sizes, and a categorical variable distinguishing these modes rather than a continuous variable identifying exact project sizes reflects this decision process. While a multinomial or categorical logit recognizes the categorical nature of the dependent variable, these models ignore the inherent ordering of project size from small to medium and large, and the ordered probit's use of this additional information makes it a more informative model for our purposes.

For each developer i, we observe the ordered response $y_i=\{0,1,2\}$ representing respectively small, medium, and large projects. The following process determines the latent variable y^*_i:

$$y^*_i = \mathbf{x_i}\boldsymbol{\beta_i} + e_i$$

where β is a K x 1 vector and $[e|\mathbf{x}]\sim N(0,1)$. The ordered response depends on two unknown threshold parameters α_1 and α_2:

$$\begin{aligned}&y=0 \text{ if } y^* \leq \alpha_1\\&y=1 \text{ if } \alpha_1<y^*\leq\alpha_2\\&y=2 \text{ if } \alpha_2<y^* \qquad .\end{aligned}$$

The response probabilities have the following distributions:

$$\begin{aligned}&P(y=0|x) = \phi(\alpha_1\text{-}\mathbf{x}\boldsymbol{\beta})\\&P(y=1|x) = \phi(\alpha_2\text{-}\mathbf{x}\boldsymbol{\beta})\text{-}\phi(\alpha_1\text{-}\mathbf{x}\boldsymbol{\beta})\\&P(y=2|x) = 1\text{-}\phi(\alpha_2\text{-}\mathbf{x}\boldsymbol{\beta})\end{aligned}$$

where $\phi(\cdot)$ represents the standard normal cumulative distribution function, and the three probabilities add to one (Wooldridge 2002, p. 505). Table 13 (below) presents the partial, or marginal effects $\partial p_m(x)/\partial x_k$ (denoted mfx in the table) for $m=0,1,2$ rather than the regression coefficients, since the coefficients do not have practical economic interpretation. Estimation of this ordered probit system utilizes more data than the comparisons between large and very small projects presented in Table 10, mainly by including 229 observations on developers in projects with known size larger than 2 and smaller than 30.[47]

Table 13 about here

From the results (in the form of the partial effects) are displayed in Table 13) it is seen that developers with the motivational profile of "aspiring hackers" (in cluster 2) have a probability of beginning their FLOSS work on small project that is 15 percentage points greater than that for "social learners" (in cluster 3); and the proportionate differential in their probability of starting on a small project is 16 percentage points lower than those of "social learners."[48] There are also non-motivational characteristics that have a palpable and statistically significant marginal effects on the portion of the project size distribution in which developers chose to contribute. Compared with the "not employed," for developers that are employees the probability of initially participating in a large project is 37 percentage point lower; and the probability of initial participation in a small project is 29

[47] Some observations had to be dropped because of incomplete responses to questions from which right-hand variables in the regressions were constructed. Table 12 shows 245 respondents on projects in the medium size range to have provided complete responses to Q4's questions about motivation, of which 16 had to be excluded from the regression underlying Table 13.

[48] These are the only motivational difference effects that are statistically significant at or above the 95 percent confidence level, and the latter of the pair is the one that is more precisely estimated as a result of the substantially larger number of observations for developers at the lower end of the project size range.

percentage points lower -- both differences being significant at the 99 percent level of confidence.[49] Educational attainment above the high school level has a positive marginal effect on the probability of initially joining a large project: the effect of a college education contributes a 10 percentage point increase, which is statistically significant, and the probability is an additional 6 percentage points higher for those at the post-college (graduate) level – although that marginal effect is imprecisely estimated due to the comparatively small number of observations of those with graduate education. Lastly, it is seen receiving pay and the choice of the size of the FLOSS projects in which such developers work are not unrelated. The probability of participating in a large project is 8 percentage points higher for developers that are being paid directly (compared with the effect of being paid at all). Although this differential effect is not significant, the 10 percentage point reduction in the in the probability of working on a very small project when one is being directly paid for contributing to FLOSS development is significant. There is a weaker, but nonetheless statistically significant positive effect of paid status on the probability of selecting a project that is in the medium size range, most like towards its upper end. But the form in which income is received for producing open source code doesn't appear to matter noticeable in regard to the observed tendency to work on larger projects. Whether developers are paid directly or indirectly, the marginal effects are much the same: the foregoing effects' magnitudes are if anything, slightly larger for those receiving indirect pay – possibly as officers or consultant to open source project foundations, or owners of companies engaged in smaller development projects. It is certainly reassuring that these regression results are not at variance with the anecdotal evidence that business firms' sponsorship of programmers to collaborate in producing FLOSS code is being targeted mainly to support the larger community-based projects.

6. Concluding discussion

This paper has closed at least some part of the gap in the present state of empirical knowledge about the motivations, personal attributes and behavioral patterns that characterize members of the many voluntary communities that work on open source software development projects. The empirical strategy devised to address the problem classifies the respondents to an extensive web-survey (FLOSS-US 2003) according to the approximate membership sizes of the principal projects on which these individuals were working, thereby permitting separation and analysis of sub-populations associated with different portions of the distribution of project sizes. Our analysis introduced a further methodological innovation, designed to capture significant heterogeneities in motives of the general population of FLOSS developers: hierarchical cluster analysis is used to extract a set of distinctive "motivational profiles" from the entire web-sample's responses to a battery of questions concerning their reasons (Likert-scaled on "importance") for beginning to develop FLOSS. This procedure

[49] The calculations are made adding the effects of differences between the indicated employment status variables and the reference status, which in this case is seen to be that of "student".

assigns each individual to one or another among the set of the identified "profiles," which are interpreted with the aid of normalized motivational intensity maps.

To briefly recapitulate the highlights of what has been learned: significant contrasts in the mixtures of motivational profiles have been found between the participants in community-based projects participants and those working essentially independently or on very small projects. Analysis of the resulting dataset establishes that "project size matters" in other, non-motivational dimensions: the sub-populations contributing to the large and the very small FLOSS projects exhibit differences in demographic characteristics, educational attainments, experience, involvement in technically demanding project, the likelihood of receiving direct monetary compensation, and in still other regards. These differences suggest that 'representative agent' thinking, and *a fortiori* the construction of formal models describing the population of FLOSS developers as homogeneous actors or "agents" are likely to sacrifice empirical understanding for analytical simplicity.

The 2003 FLOSS-US survey asked respondents to recall attitudinal aspects of their initial engagements with open source software development activities, as well as those surrounding subsequent choices of projects to which they would contribute. Far from being uniform, the constellation of individual's avowed motives for involvement in FLOSS and project selections is found to be heterogeneous; when reduced to a scalar index by application of factor analysis, the distribution of factor-scores is continuous and symmetrical, varying widely between the scores associated with a strong importance being attached to normative and ideological aspects of the open source movement, instrumental technical needs and interests, and intrinsic satisfactions of addressing the challenges of creating new programs and patching and modifying those that already exist.

Moreover, our study has marshaled a variety of evidence micro-level and meso-level data that exhibits and quantifies the mutabity of motives held by open source developers. These findings are consitent with the view that individual motivations are subject to changes in this context under the influence of the accumulation of relevant experience. The aspect of endogeneity raises some methodological problems for econometric analyses of the role of motivation in the observed behavior of developers with regard to work roles, effort and acceptance of payment for work on FLOSS projects. To the extent that these behaviors are formed concurrently, their value as "explanatory variables" is likely to be diminished.

Issues of the latter kind appear to be especially complicated as well as important in regard to efforts to describe and explain the patterns in the circulation of developers among projects of different kinds and sizes, which is the system-level view of the problems of personnel recruitment and retention with which leaders of FLOSS projects have to contend. Where in a diverse landscape of projects FLOSS developers find it possible to substantially improve their software skills, and where they take those skills if they change the projects to which they contribute, are no less important questions that deserve more systematic research on a scale larger than the exploration offered on this occasion. Despite the limited scale on which we were able to illustrate the potentialities of using capture-recapture approaches to describing the inter-product movements of FLOSS developers, that exercise has brought to light indications that the large projects form an powerful field of attraction, retaining developers who start there and drawing in others whose initial efforts and skill acquisition were first acquired in very different (independent and very small project) contexts.

The distinctions among the profiles that were derived using hierarchical cluster analysis of developer motivations appear to be robust from several different perspectives. First, the profiles lend themselves to interpretation, something that is by no means guaranteed in the application of clustering methodology. Second, demographic variables not used in the derivation of the profiles are quite consistent with their interpretations. Third, the clusters accord in important ways, but not invariably, with the additional information provided by respondents regarding their motivations. Fourth, when information about the size of the projects are used to sort profiled developers, there is a consistency in the interpretation of ‘professionals’ and ‘aspiring hackers’ cluster profiles as more being likely to be engaged in larger projects while the other three profiles are associated with smaller projects. Fifth, and finally, the use of ordered probit analysis to examine factors affecting project choices finds one difference in motivational profiles to be influential: that is the difference between membership in the cluster of “aspiring hackers” and that of the cluster of “social learners” does exert a positive differential effect upon the probability of working on large projects, and a negative effect on probability of being a contributor to a very small project. Other differences in motivation are quantitatively weaker as well as failing to reach conventional levels of statistical significance.

These latter results, when coupled with the heterogeneity of participation in each size class may indicate that the effects of different motivations are more useful for marginal analysis than as a structural variable – i.e., initial motivational orientations, at least, are not sufficient to govern choices of among projects of different sizes, nor does project size itself dictate the profiles of the developers that are attracted to that part of the size distribution. Further analysis of the motivational profiles and other attributes of developers who move to projects in a markedly different size range is a topic that clearly calls for further research. But, as has been pointed out, a general attack on it with longitudinal data would have to address the complications arising from the mutability and endogeneity of individuals motives – issues that have been finessed in this study by basing our motivational profiles on survey respondents’’ retrospective reports of their reasons for starting to develop FLOSS.

The results of this paper provide strong evidence that heterogeneity of motivation is a key feature of open source communities. How this heterogeneity is managed, accommodated, or resisted seem likely to be important influences on the stability, persistence, and outcomes of open source development efforts. In particular, it suggests that communities that find ways of mobilizing individuals with quite different motivations to join and to persevere in their contributions as well as making effective use of each of the different motivational types may expect greater success in their efforts. Evaluation of this prediction and further elaboration of the implications of developer heterogeneity appear to be the frontier to which research should now direct efforts in studying open source communities.

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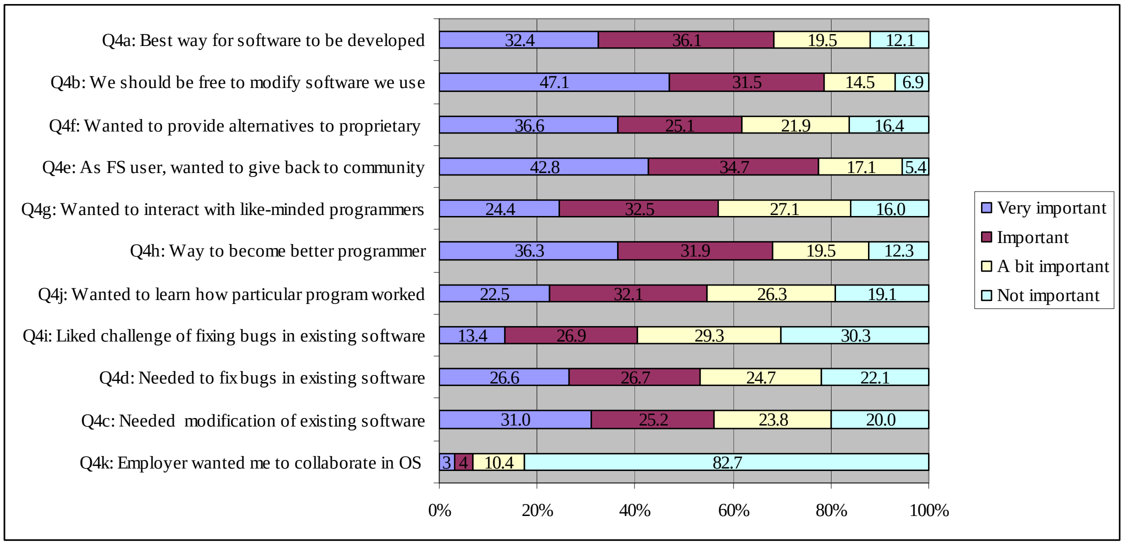
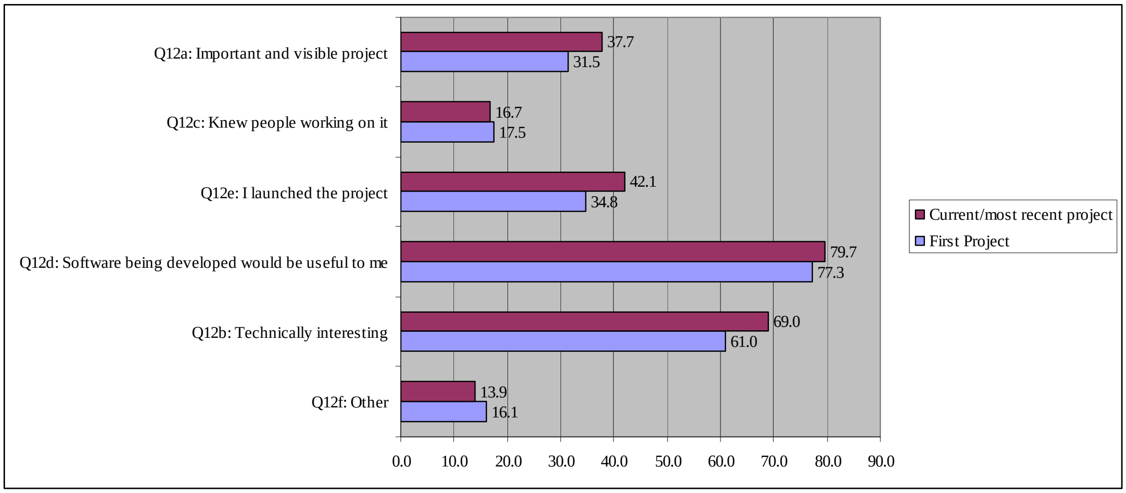
Figure 1a. Motivation for first developing FLOSS (Q4)



Source: David, Waterman and Arora (2003), based on analysis of 1,459 respondents to the FLOSS-US survey who answered every sub-part of Q4.

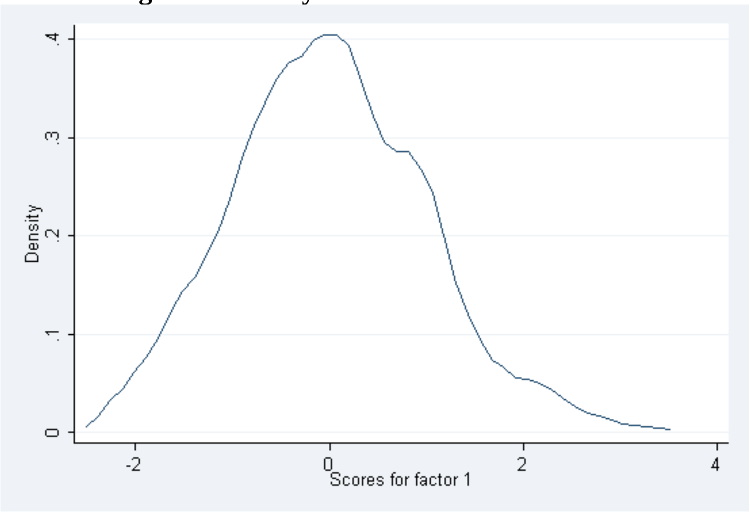
Of the 1459 respondents to Q4, 289 or approx. 20 percent, also marked the option "Other" and wrote in another reason, indicating its position on the Likert scale. The distribution of importance rating on this answer was as follows: Very important: 59.2%:, Important: 9.2%; A bit important: 1.4%; Not important: 30.2%

Figure 1b. Motivation for choosing project (Q12)



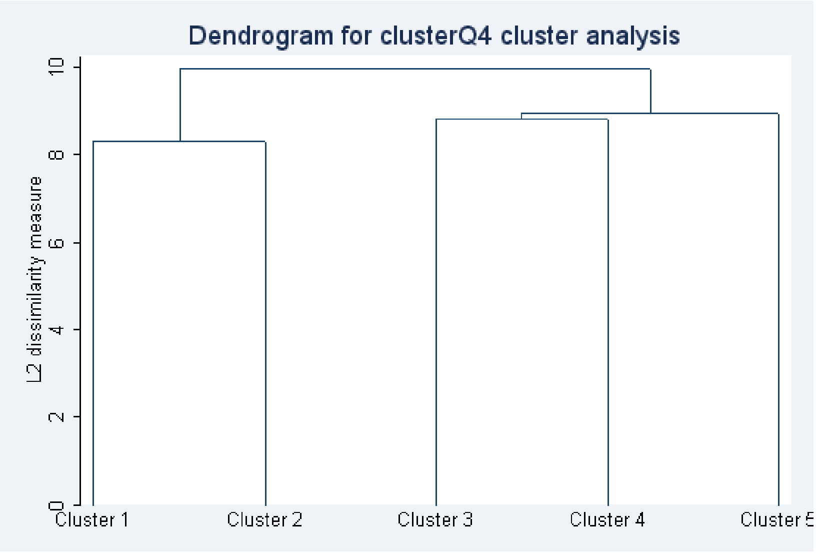
Source: Analysis of FLOSS-US. For current project, statistics include 1,394 respondents who listed some motivation for their current project choice and answered every part of Q4. For first project, statistics include 1,232 respondents who listed some motivation for first project and who answered every part of Q4.

Figure 2. Density of motivation factor scores



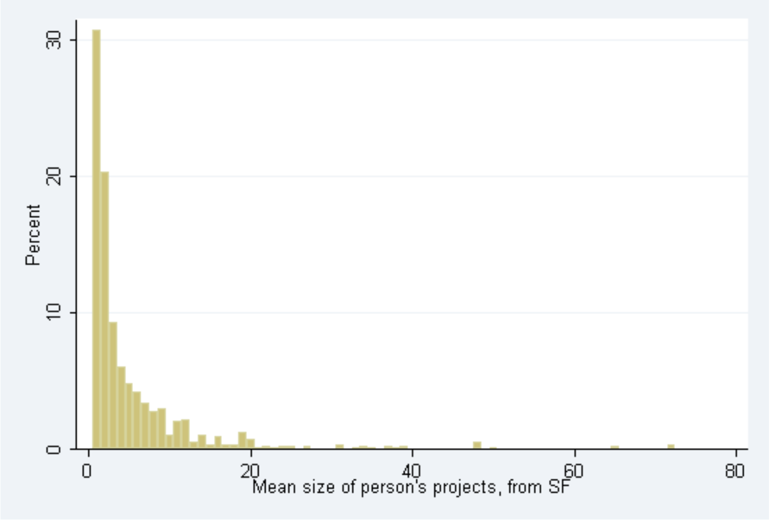
Source: Analysis of FLOSS-US. 1,459 observations. Density depicted using epanechnikov kernel with half-width of 0.15 evaluated using 50 points.

Figure 3. Dendrogram of five clusters constructed from Q4 only.



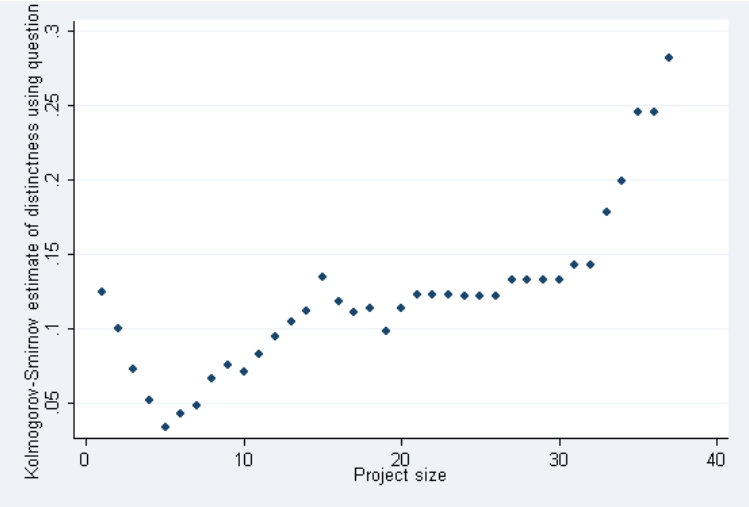
Source: Hierarchical cluster analysis of total set of complete FLOSS-US survey responses to motivational question set (Q4) on reasons for beginning to contribute to FLOSS development.

Figure 4. Histogram of sizes of respondents' projects found on *SourceForge*



Source: Analysis of FLOSS-US and search of SourceFourge.Net (SF). Histogram bins have width one. If only one of a developer's projects has known size, this figure plots the developer according to that size. If both a developer's current and first projects have known size, this figure plots the developer according to the mean of the two projects' sizes, rounded to the nearest integer. Obviously large projects (Linus Kernel, Apache, etc.) not included.

Figure 5. Distinctness of project sizes: estimated from the distributions of individuals' motivation factor-scores arising from alternative binary partitions of the FLOSS-US Survey subsample whose project sizes are known



Source: Based on assigned individual "motivational factor scores", using estimated factor loadings (see Table A1 and Figure 3) computed for all respondents to the FLOSS-US Survey who gave complete answers to question-set Q4: reasons for beginning to contribute to FLOSS development. See the text for further discussion.

Table 1. FLOSS-US compared with other pre-2005 surveys of FLOSS developers

Type	*Online survey, website posts, emailed lists*				*Emailed developers*			*Emailed developers from a single project*	
Survey title	*TU Berlin*	*FLOSS-EU*	*FLOSS-US*	*FLOSS-ASIA*	*BCG*			*Apache*	*Linux kernel*
Reference if different from title	*Robles et al. (WIDI 2001)*	*Ghosh et al. (2002)*	*David, Waterman, and Arora (2003)*	*Mitsubishi (2004)*	*Wolf et al (2002); Lakhani and Wolf (2005)*	*Hars and Ou (2002)*	*Haruvy, Wu, & Chakravarty (2003)*	*Lakhani and von Hippel (2002)*	*Hertel, Nieder, and Herrman (2003)*
Data collection	June 2001 to Aug 2001	Feb 2002 to Apr 2002	Jan to June 2003	Dec 2003 - Jan 2004	Oct 2001, Apr 2002	-	-	Oct 99 to Feb 00	Feb-Apr 2000
Method	Online survey, website posts, emailed lists	Online survey, website posts, emailed lists	Online survey, website posts, emailed lists	Online survey, website posts, emailed lists	Emailed SourceForge project contributors	Emailed developers	Emailed developers	Emailed developers	Linux mailing list announcements
Usable responses (rate)	5478	2784	1588	138	684 of 1994 (34%)	79 of 389 (20%)	160 of 2000 (8%)	336 of 1709 (19.6%)	141 (half developers)
Motivation questions	None	Reasons for joining FLOSS community; reasons for staying in FLOSS	Reason for developing FLOSS, reasons for specific project	Reason for developing FLOSS	Reasons for working on specific FLOSS project	Reasons for developing FLOSS	Reasons for developing FLOSS or working on specific project	None	Reasons for working in Linux community
Number of projects	-	-	1811 *	-	287	41 (with 25% from Linux)	More than 90	1	1
Respondents per project	-	-	0.88 *	-	2.38	1.93	1.78	-	-

Table 1 continued on next page.

Table 1 continued from previous page.

Source	*TU Berlin*	*FLOSS-EU*	*FLOSS-US*	*FLOSS-ASIA*	*BCG*	*Hars and Ou (2002)*	*Haruvy, Wu, & Chakravarty (2003)*	*Lakhani and von Hippel (2002)*	*Hertel, Nieder, and Herrman (2003)*
Location									
North America (%)	35%	13%	27%	1%	45%	-	-	-	48%
Western Europe (%)	47%	71% (EU)	53%	2%	38%	-	-	-	37% (all Europe)
Number continents	-	-	6	3	6	-	5	-	
Number countries	94	-	65	16	52	-	"At least 18"	-	28
Age (mean)	27	27	29.0 *	27	29.8	-	-	-	-
Male	1	98.9%	98.4%	98.5%	97.5%	95%	-	-	-
Employment status									
Not employed	-	4%	4%	-	-	-	11%	-	5%
Employed	-	79%	68%	-	-	-	89%	-	72%
Student	0	17%	29%	16%	-	14%	32%	-	23%
Highest Education									
High school	-	-	19%	-	-	-	-	-	-
Bachelor's degree	41%	33%	36%	-	-	48%	31%	-	-
Master's degree	11%	28%	43%	-	-	21%	16%	-	-
Ph.D.	4%	9%		-	-	3%	21%	-	-
FLOSS experience	-	4.1	5.1	4	5.3	-	4.7	-	-
Mean effort	-	-	10.0	-	14.1	-	-	-	18.4

Note: response rate shows number of usable observations out of total number solicited. FLOSS experience in years, mean effort in hours per week. "Employed" includes self-employment or work at a firm. BCG randomly chose 10 percent of SF projects with both more than one developer and reported maturity stage of Alpha, Beta, or Production/Stable, and they emailed developers listed in these projects to obtain 526 responses. BCG also emailed all participants in SF projects with reported maturity stage of Mature who had multi-person teams to obtain 158 additional responses. Hars and Ou (2002) obtained email addresses from "discussion lists and news groups ... both general open source communities and specific open source programmers' forums" (p. 5). Haruvy et al. (2003) emailed "2000 programmers listed as contributors on open source web pages and on selected open source developer lists" (p. 16). They provide no further details or exact websites. Haruvy, Wu, & Chakravarty (2003) do not count modules as separate projects. Hertel, Nieder, and Herrman: half of respondents were active developers, others merely read the Linux kernel mailing list. They have no defined response rate since they emailed lists recent/current projects (and their paper does not declare the lists' membership size) rather than directly contacting a set number of individual developers. FLOSS-EU, FLOSS-US, BCG: FLOSS experience is years since first FLOSS contribution. FLOSS-US: mean commitment averages current/most recent and first projects.
* implies new estimates from underlying FLOSS-US data rather than stated in David, Waterman, and Arora (2003). Number of projects: FLOSS-US counts first and current..

Table 2. Stability of reasons for selecting a project: different first and current projects compared

Panel A: Chosen motivations from list

	Response for first project							
	Q12a	*Q12c*	*Q12e*	*Q12d*	*Q12b*	*ANOVA*	*P value*	*N*
Response for current project								
Q12a: Important and visible project	**0.39**	0.18	0.30	0.68	0.58	8.62	0.00	426
Q12c: Knew people working on it	0.40	**0.30**	0.26	0.66	0.60	5.65	0.00	191
Q12e: I launched the project	0.25	0.14	**0.38**	0.65	0.50	9.09	0.00	481
Q12d: Software would be useful	0.27	0.17	0.28	**0.73**	0.54	6.10	0.00	909
Q12b: Technically interesting	0.29	0.17	0.28	0.70	**0.59**	5.52	0.00	783
Pearson chi-squared (16)	14.38							
Prob > chi-squared	0.57							

Panel B: Other written motivations

	Response for first project							
	Intrinsic	*Knowledge*	*Visibility*	*Practical*	*Principle*	*Other listed*	*None listed*	*Total*
Response for current project								
Intrinsic	**10**	0	0	0	0	0	8	18
Instrumental-knowledge	0	**16**	0	0	0	0	6	22
Instrumental-visibility/signaling	0	0	**3**	0	0	0	1	4
Instrumental-practical	0	0	0	**50**	0	0	34	84
Principle	0	0	0	0	**13**	0	18	31
Other listed	0	0	0	0	0	**12**	21	33
None listed	4	8	0	63	4	10	1,178	1,267
Total	14	24	3	113	17	22	1,266	1,459
Pearson chi-squared(36)	3,400							
Prob > chi-squared	0.00							

Notes: Analysis using FLOSS-US survey responses to Q12.

In Panel A, each row shows distribution of responses for current project across responses for first project. An observation in Panel A may appear in multiple cells. Chi-squared (degrees of freedom) tests independence of rows and columns on the basis of a 1,459 observation dataset with the same cell frequencies appearing in Panel A, but with each observation appearing in only one cell – assigned on the basis of being “very important” or “important:”

Panel B shows a cross-tabulation of responses supplied to under the option of writing in an “Other reason”, and these are tabulated using the elaboration of the intrinsic-extrinsic (instrumental) motive framework shown more fully in Table 6a and 6b. In Panel B, an observation can appear in only one column, being the first-stated “other reason” in those cases where more than one distinct motive was volunteered. In both panels, diagonal entries (indicating same response for first as for current project) appear in bold. All entries exclude observations with same first and current projects.

Table 3. Heterogeneities in developers' motivations among the FLOSS-US survey respondents: bootstrap estimates

	Population Mean	*Standard error: 30 obs*	*Standard error: 100 obs*
Q4a: Best way for software to be developed	0.32	0.08	0.05
Q4b: We should be free to modify software we use	0.47	0.09	0.05
Q4f: Wanted to provide alternatives to proprietary	0.37	0.09	0.05
Q4e: As free software developer, wanted to give back to community	0.43	0.09	0.05
Q4g: Wanted to interact with like-minded programmers	0.24	0.08	0.04
Q4h: Way to become better programmer	0.36	0.09	0.05
Q4j: Wanted to learn how particular program worked	0.23	0.08	0.04
Q4i: Liked challenge of fixing bugs in existing software	0.13	0.06	0.03
Q4d: Needed to fix bugs in existing software	0.27	0.08	0.04
Q4c: Needed modification of existing software	0.31	0.08	0.05
Q4k: Employer wanted me to collaborate in OS	0.03	0.03	0.02
Q12a: Important and visible project	0.38	0.09	0.04
Q12c: Knew people working on it	0.17	0.07	0.04
Q12e: I launched the project	0.42	0.09	0.05
Q12d: Software being developed would be useful to me	0.80	0.08	0.04
Q12b: Technically interesting	0.69	0.08	0.04

Notes: Analysis using FLOSS-US. Bootstrap uses 200 draws with replacement, number of observations drawn indicated in each column (30, 100). Q4 “Population Mean” values show the proportions responding "very important" in the entire populations of FLOSS-US respondents on which Figures 1a, and 1b, respectively, are based.

Table 4. Measured salience of motivations for first developing FLOSS and for Project Selections: Normalized intensity maps for FLOSS-US Survey population

Survey item		
Panel A: Reason for first developing FLOSS (Q4)		
Q4a: Best way for software to be developed	1.16	
Q4b: We should be free to modify software we use	2.33	
Q4f: Wanted to provide alternatives to proprietary	0.77	
Q4e: As free software developer, wanted to give back to community	2.93	
Q4g: Wanted to interact with like-minded programmers	0.73	
Q4h: Way to become better programmer	1.14	
Q4j: Wanted to learn how particular program worked	0.58	
Q4i: Liked challenge of fixing bugs in existing software	0.27	
Q4d: Needed to fix bugs in existing software	0.49	
Q4c: Needed modification of existing software	0.57	
Q4k: Employer wanted me to collaborate in OS	0.02	
Mean across Q4 sub-questions	1.00	
N	1,459	
Panel B: Reason for choosing specific project (Q12)		
	Current/ most recent project	*First project*
Q12a: Important and visible project	0.77	0.71
Q12c: Knew people working on it	0.34	0.39
Q12e: I launched the project	0.86	0.78
Q12d: Software being developed would be useful to me	1.62	1.74
Q12b: Technically interesting	1.41	1.37
Mean across Q12 sub-questions	1.00	1.00
N	1,459	1,459

Source: Analysis of FLOSS-US. Higher values represent greater importance assigned to question. With each column of each panel, shading represents relative importance: most important items have darkest shade while least important items have no shading. Panel A shades 3 most important items, while Panel B shades 2 most important items, and leaves the least important un-shaded. See text for formulae used to compute normalized intensity scores, which are defined differently for Panel B questions than for questions in Panel A.

Table 5. Normalized Motivational Intensity Maps for the Cluster Profiles based on Reasons for Beginning to Contribute to FLOSS development and for Choice of Project

Survey item	**C1**	**C2**	**C3**	**C4**	**C5**
Panel A: Reason for first developing FLOSS (Q4)					
Q4a: Best way for software to be developed	0.06	0.05	1.48	1.12	1.09
Q4b: We should be free to modify software we use	0.19	0.05	0.95	1.91	2.22
Q4f: Wanted to provide alternatives to proprietary	0.06	0.04	1.02	0.54	1.44
Q4e: As FS software user, wanted to give back to community	0.42	0.09	0.44	0.88	3.00
Q4g: Wanted to interact with like-minded programmers	0.10	0.29	0.83	0.17	1.13
Q4h: Way to become better programmer	0.54	1.08	2.86	0.12	0.76
Q4j: Wanted to learn how particular program worked	0.13	2.51	1.54	0.24	0.36
Q4i: Liked challenge of fixing bugs in existing software	0.16	1.97	0.77	0.24	0.20
Q4d: Needed to fix bugs in existing software	1.29	3.44	0.37	3.86	0.14
Q4c: Needed modification of existing software	1.02	1.50	0.45	9.43	0.06
Q4k: Employer wanted me to collaborate in OS	7.03	0.00	0.29	0.93	0.61
Mean across Q4 sub-questions	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
Number of respondents	59	145	696	234	325
Panel B: Reason for choosing current/most recent project (Q12)					
Q12a: Important and visible project	0.93	0.99	1.10	0.84	0.82
Q12c: Knew people working on it	0.75	1.02	1.04	1.01	0.82
Q12e: I launched the project	1.45	0.52	0.88	0.90	1.56
Q12d: Software being developed would be useful to me	0.87	1.35	0.92	1.59	0.75
Q12b: Technically interesting	1.00	1.11	1.06	0.67	1.05
Mean across Q12 sub-questions	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
Number of respondents	59	145	696	234	325

Source: Analysis of FLOSS-US survey. Panels A and B present "twice-normalized" scores for each of the five clusters generated by hierarchical complete linkage cluster analysis of responses to question 4. Higher scores reflect greater relative importance assigned to the indicated reason. See text for definitions of "twice-normalized" motivational intensity scores for individual clusters.

Table 6. Key characteristics of motivational clusters

Cluster	*Profile*	*Key characteristics*
1	Professionals	Non-ideological, expert, self-employed or company-sponsored to collaborate on FLOSS projects
2	Aspiring hackers	No need to modify existing code but like fixing bugs and learning new programs
3	Social learners	Become better programmers, learn how programs work, work with like-minded, "give back to community," support FLOSS ideology
4	Social programmers	Experienced, employment related needs to use, modify existing code and fix bugs; project choice influenced by social connections with other developers
5	"User-innovators"	Modifying existing software unimportant, learning & interacting with like-minded others unimportant; wanted to "give back to community," and launched own project.

Source: See text discussion for labeling of cluster-profiles based on intensity maps (Table 5), and comparisons of within-cluster distributions of "other reasons" from Tables 8a, 8b.

Table 7: Demographic & Occupational Characteristics of Clusters-- Descriptive Statistics

						ANOVA	*ANOVA*
	C1	**C2**	**C3**	**C4**	**C5**	*F-stat*	*P-value*
Age	30.0	28.8	28.5	30.7	28.5	3.86	0.00
	(7.8)	(7.2)	(8.0)	(8.5)	(8.0)		
Years experience in FLOSS	5.6	6.4	5.1	5.4	4.1	8.60	0.00
	(3.9)	(4.9)	(4.2)	(4.7)	(3.3)		
Began developing FLOSS in year 2000 or later	0.29	0.30	0.42	0.38	0.51	6.41	0.00
Began developing FLOSS before the year 2000	0.68	0.66	0.54	0.58	0.46	5.56	0.00
Highest formal education: high school	0.20	0.14	0.22	0.12	0.23	4.42	0.00
Highest formal education: undergraduate	0.42	0.39	0.38	0.36	0.37	0.26	0.91
Highest formal education: graduate	0.35	0.42	0.34	0.46	0.35	3.11	0.01
Highest formal education: professional	0.04	0.05	0.06	0.07	0.05	0.36	0.84
Female	0.00	0.00	0.02	0.03	0.01	1.29	0.27
No children	0.69	0.84	0.77	0.76	0.81	2.07	0.08
Children under age six	0.14	0.09	0.12	0.12	0.11	0.44	0.78
Children over age six	0.12	0.04	0.09	0.14	0.07	3.22	0.01
Unmarried, without partner	0.42	0.38	0.42	0.34	0.36	1.34	0.25
Unmarried, not living with partner	0.16	0.16	0.13	0.10	0.18	1.43	0.22
Unmarried, living with partner	0.16	0.15	0.19	0.20	0.16	0.53	0.71
Married, not living with spouse	0.00	0.00	0.01	0.01	0.00	0.56	0.69
Married, living with spouse	0.26	0.30	0.24	0.32	0.29	1.19	0.31
Separated/divorced	0.00	0.00	0.01	0.03	0.02	1.08	0.37
Student	0.19	0.27	0.30	0.24	0.32	1.79	0.13
Employee	0.56	0.59	0.49	0.55	0.50	1.66	0.16
Self-employed	0.19	0.13	0.16	0.18	0.15	0.70	0.59
Not employed	0.07	0.01	0.04	0.02	0.04	1.95	0.10
Expected future FLOSS role: consultant	0.46	0.59	0.54	0.56	0.50	1.45	0.22
Expected future FLOSS role: employee	0.47	0.57	0.56	0.61	0.62	1.74	0.14
Expected future FLOSS role: company owner/ officer/ director/"other"	0.53	0.43	0.53	0.57	0.48	2.43	0.05
N	59	145	696	234	325		

Note: ANOVA tests the null hypothesis that all clusters have same mean value. Standard deviations for continuous variables appear in parentheses below mean values. Each cell presents mean for all individuals answering the relevant survey item, and nonresponse causes some cells to represent less than the total number of observations (N) shown for the relevant cluster. For the age and experience variables, the figures in parentheses given the standard deviations around the respective cluster means.

Table 8a. Listed "other" motivations: total FLOSS-US sample and distribution within motivational clusters

	Total	*Cluster 1*	*Cluster 2*	*Cluster 3*	*Cluster 4*	*Cluster 5*
Panel A: Other reasons for first developing FLOSS (Q4): Percentages of all "other reasons"						
Fun	13.64	28.57	28.57	11.11	13.51	8.11
Enjoy community	1.4	0	3.57	1.59	0	1.35
Total intrinsic	***15.0***	***28.57***	***32.14***	***12.7***	***13.51***	***9.46***
Instrumental-knowledge	***6.64***	***0***	***3.57***	***7.94***	***8.11***	***6.8***
Instrumental-Visibility/reputation/signaling	***6.64***	***9.52***	***7.14***	***3.97***	***8.11***	***9.5***
Needed to modify or create software	16.43	19.05	21.43	11.9	18.92	20.3
FLOSS best quality	6.29	0	10.71	5.56	8.11	6.8
Cost	8.39	9.52	14.29	9.52	5.41	5.4
Collaboration essential / extend project lifetime	3.85	0	0	7.14	0	2.7
Total instrumental-serve practical goal	***35.0***	***28.6***	***46.4***	***34.1***	***32.4***	***35.1***
Positive ideology	7.34	4.76	0	10.32	2.7	8.11
Negative ideology	3.85	0	0	6.35	5.41	1.35
Give back to community	2.1	0	0	0.79	2.7	5.41
Total instrumental-serve "principles"	*13.3*	*4.8*	*0.0*	*17.5*	*10.8*	*14.9*
Another listed reason	***23.43***	***28.57***	***10.71***	***23.81***	***27.03***	***24.32***
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
N writing in any other reason	286	55	91	93	21	26
Pearson chi-squared(20), subtotals in italics	25.55					
Prob > chi-squared	0.18					
Pearson chi-squared(44), all groups	50.66					
Prob > chi-squared	0.23					

Table 8b --distribution of "other motivations" for project choices						
		Cluster	*Cluster*	*Cluster*	*Cluster*	*Cluster*
	Total	*1*	*2*	*3*	*4*	*5*
Panel B: Other reasons for choosing specific project (Q12)						
Fun	6.54	12.5	9.68	4.9	5.56	8.06
Enjoy community	1.31	0	0	1.4	0	3.23
Total intrinsic	***7.9***	***12.5***	***9.7***	***6.3***	***5.6***	***11.3***
Learn	6.54	6.25	3.23	9.79	0	6.45
Needed in academic work	3.59	0	3.23	2.8	3.7	6.45
Total instrumental-knowledge	***10.1***	***6.3***	***6.5***	***12.6***	***3.7***	***12.9***
Instrumental-Visibility/reputation/signaling	***1.31***	***0***	***0***	***2.8***	***0***	***0***
Needed to modify or create software	16.01	12.5	9.68	18.18	20.37	11.29
Bugs	16.99	31.25	22.58	14.69	24.07	9.68
FLOSS best quality	1.31	0	6.45	1.4	0	0
Required by employment	16.01	18.75	25.81	11.19	22.22	16.13
Cost	0.98	0	0	1.4	0	1.61
Total instrumental-serve practical goal	***51.3***	***62.5***	***64.5***	***46.9***	***66.7***	***38.7***
Ideology	2.94	6.25	3.23	2.8	1.85	3.23
Help others / give to community	9.8	0	9.68	11.19	5.56	12.9
Total instrumental-serve "principle"	***12.7***	***6.3***	***12.9***	***14.0***	***7.4***	***16.1***
Another listed reason	***16.67***	***12.5***	***6.45***	***17.48***	***16.67***	***20.97***
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
N writing in any other reason	306	43	113	91	36	23
Pearson chi-squared(20), subtotals in italics	22.77					
Prob > chi-squared	0.30					
Pearson chi-squared(48), all groups	49.76					
Prob > chi-squared	0.40					

Source: Analysis of FLOSS-US. Italics denote sub-totals. Chi-squared (degrees of freedom) tests the independence of responses, excluding developers in "none listed" from the clusters.

Table 9. Transition matrix for developers' movements among projects of different membership sizes

	First project		
Current/most recent project	*Small*	*Medium*	*Large*
	1-2	*3-29*	*>29*
Panel A: All developers			
Small	111	42	32
Medium	30	80	22
Large	13	7	47
Pearson chi-squared(4)	140.58		
Prob > chi-squared	0.00		
Panel B: Developers for whom first and current/most recent projects were different			
Large	51	42	32
Medium	30	29	22
Small	13	7	18
Pearson chi-squared(4)	7.96		
Prob > chi-squared	0.09		

Source: See text discussion. Data includes only developers for whom both their first and current/recent project membership sizes are known.

Table 10. Characteristics and work patterns of FLOSS developers populations:
differences between participants in “Large” (>29 member) and “Small” (1-2 member) projects

Project size	*Small*	*Large*	*Diff*	*Source*
Directly paid	0.24	0.34	*	Q33
	(.43)	(.48)		
Age	27.59	30.28	**	Q1
	(7.5)	(7.81)		
Years of experience in FLOSS	4.45	6.36	**	Q1
	(3.38)	(4.68)		
Separated, divorced, or unmarried	0.75	0.71		Q40
Children under age 6	0.13	0.11		Q39
Worked on >5 projects	0.22	0.40	**	Q9
Current and first projects overlap	0.57	0.62		Q11
Duration of first & current project overlap (mths)	31.04	45.04	**	Q11
Duration of current project: 0-1 years	0.45	0.33	**	Q11
Duration of current project: 1-5 years	0.49	0.54		Q11
Duration of current project: >5 years	0.06	0.14	**	Q11
Mean hrs/wk, current project	10.93	10.85		Q13
	(12.05)	(11.72)		
Max hrs/day, current project	10.79	11.78		Q14
	(5.52)	(6.17)		
Days of working at maximum intensity	12.66	9.86		Q15
	(44.8)	(22.76)		
Hours spent during most intense period	145.83	132.86		Q14,15
	(537.73)	(367.61)		
Total projects: one	0.11	0.09		Q9
Total projects: multiple, current=first	0.74	0.17		Q9
Total projects: multiple, current & first differ	0.13	0.70		Q9
Current project: role 1	0.30	0.21	**	Q16
Current project: role 2	0.27	0.21		Q16
Current project: role 3	0.32	0.38		Q16
Current project: role 4	0.20	0.14		Q16
Current project: role 5	0.27	0.36	*	Q16
Current project: role 6	0.14	0.18		Q16
When work on FLOSS: before work	0.14	0.24	**	Q37
When work on FLOSS: after work	0.72	0.77		Q37
When work on FLOSS: at work, during work hours	0.33	0.48	**	Q37
When work on FLOSS: on weekends	0.74	0.72		Q37
When work on FLOSS: at work, off work hours	0.19	0.34	**	Q37
When work on FLOSS: unemployed, so anytime	0.18	0.13		Q37
N	422	180		

Notes: Standard deviations appear in parentheses. N shows the number of observations in each column, though some variables have missing observations and hence individual cells may represent fewer than N observations. Developers with one project reply in Q9 that they have only worked on one project. A developer has different first and current projects if in Q10 the developer writes in different names for the first and current projects.

Project roles defined as follows: 1=coding and project maintenance and algorithm design; 2=coding and algorithm design and user interface; 3=debugging and testing and feedback; 4=project maintenance and communication and algorithm design; 5=coding but not project maintenance and not algorithm design; 6=documentation and public relations and communication. Experience equals years since first developing FLOSS.

***** indicates that a two-tailed t test assuming unequal variance rejects the null hypothesis of equal values for developers in small and large projects at 95% confidence; ****** at 99% confidence.

Table 11. Normalized relative intensity scores indicating the relative importance of different motivations among FLOSS Developers, showing averages by respondents' project size

Survey Questionnaire Items:			
Panel A -- Reason for first developing FLOSS (Q4)			
	Small	***Medium***	***Large***
Project Size (number of people in respondents' current project)	*1-2*	*3-29*	*>29*
Number of Respondents in Project Size Group: N	422	245	180
Q4b: We should be free to modify software we use	0.96	1.20	0.76
Q4f: Wanted to provide alternatives to proprietary	1.07	1.03	0.71
Q4e: As free software developer, wanted to give back to community	1.01	0.83	1.20
Q4g: Wanted to interact with like-minded programmers	1.07	1.02	0.74
Q4h: Way to become better programmer	1.11	1.01	0.70
Q4j: Wanted to learn how particular program worked	0.84	0.92	1.61
Q4i: Liked challenge of fixing bugs in existing software	0.88	1.03	1.14
Q4d: Needed to fix bugs in existing software	0.77	1.09	1.57
Q4c: Needed modification of existing software	0.78	1.37	1.03
Q4k: Employer wanted me to collaborate in OS	1.21	0.50	0.98
Mean across Q4 sub-questions	*1.00*	*1.00*	*1.00*
Panel B: Reason for choosing current project (Q12)			
	Small	*Medium*	*Large*
Q12a: Important and visible project	0.92	0.89	1.24
Q12c: Knew people working on it	0.80	1.09	1.25
Q12e: I launched the project	1.49	0.86	0.37
Q12d: Software being developed would be useful to me	0.91	0.99	1.16
Q12b: Technically interesting	0.88	1.17	0.98
Mean across Q12 sub-questions	*1.00*	*1.00*	*1.00*

Source: Analysis of FLOSS-US 2003 Survey: values on normalized intensity scores, derived for each question from the ratio between the proportion of respondents who coded the motive as "very important" and the proportion coding it as "not important." Within each column of each panel, higher values indicate greater relative importance is assigned to the motivation. Panel A shades the 3 most important items darkest, and leaves the three least important un-shaded; Panel B shades the 2 most important items darkest, and leaves the1 least important un-shaded. See text for formulae.

Table 12. Distribution of Small- and Large-Project Participants by "Motivation Profiles" Identified by Cluster Analysis of FLOSS-US Survey Respondents

		Small Project and Large Project Populatons Only		
Cluster		*Small (1-2)*	*Large (>29)*	*Total*
1 (*Professionals*)	%	**5.2%**	**5.5%**	**5.3 %**
	N	22	10	32
2 (*Aspiring hackers*)	%	**7.6%**	**16.7%**	**10.3%**
	N	32	30	62
3 (*Social learners*)	%	**49.1%**	**45.0%**	**47.8%**
	N	207	81	288
4 (*Social programmers*)	%	**14.0%**	**12.8%**	**13.6%**
	N	59	23	82
5 (*User-innovators*)	%	**24.2%**	**20.0%**	**22.9%**
	N	102	36	138
Total	%	**100.0%**	**100.0%**	**100.0%**
	N	422	180	602
Pearson chi-squared (4)			11.09	
Prob > chi-squared			***0.03***	
Chi-squared goodness-of-fit (4)			60.75	
Prob > chi-squared			***0.00***	

Source: See text discussion. Total column includes only developers in these two known membership size ranges, and percentages add to 100 within each column.

Pearson chi-squared tests reject the null hypothesis that project size (small/large) and cluster assignment are independent. Chi-squared goodness-of-fit tests rejects the null hypothesis that developers in large projects have the same distribution across clusters as the combined large and small project population of developers.

Table 13. Association of motivation and participation small, medium and large projects: ordered probit estimates

	mfx:		*mfx:*		*mfx:*	
	Prob	*Robust*	*Prob*	*Robust*	*Prob*	*Robust*
	small	*se*	*medium*	*se*	*large*	*se*
Cluster 1: ‘professionals’	0.08	(0.10)	-0.02	(0.03)	-0.06	(0.07)
Cluster 2: ‘aspiring hackers’	**-0.16**	**(0.06)****	**0.01**	**(0.01)**	**0.15**	**(0.06)***
(Reference: Cluster 3) :’social learners’						
Cluster 4: ‘social programmers’	-0.02	(0.06)	0.00	(0.01)	0.02	(0.05)
Cluster 5: ‘user innovators’	0.00	(0.05)	0.00	(0.01)	0.00	(0.04)
Age	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
First project differs from current	0.02	(0.05)	0.00	(0.01)	-0.02	(0.04)
Max hrs in a day: current project	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Max hrs in a day: first project	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Female	0.06	(0.27)	-0.01	(0.08)	-0.04	(0.19)
(Reference: student)						
Employee	-0.01	(0.06)	0.00	(0.01)	0.01	(0.05)
Self-employed	0.03	(0.08)	-0.01	(0.02)	-0.03	(0.06)
Not employed	**-0.30**	**(0.07)****	**-0.08**	**(0.07)**	**0.38**	**(0.14)****
Paid directly for FLOSS work	**-0.10**	**(0.05)***	**0.01**	**(0.01)***	**0.08**	**(0.05)**
Paid indirectly for FLOSS work	**-0.11**	**(0.04)***	**0.01**	**(0.01)***	**0.09**	**(0.04)***
(Reference: not paid for FLOSS)						
(Reference: future role is none)						
Future role: owner	-0.02	(0.05)	0.00	(0.01)	0.01	(0.04)
Future role: company director	-0.01	(0.05)	0.00	(0.01)	0.01	(0.04)
Future role: company officer	0.00	(0.05)	0.00	(0.01)	0.00	(0.04)
Future role: employee	0.05	(0.05)	-0.01	(0.01)	-0.04	(0.04)
Future role: consultant	0.08	(0.04)	-0.01	(0.01)	-0.06	(0.04)
Future role: other	0.14	(0.20)	-0.04	(0.08)	-0.10	(0.12)
Highest education: high school	**0.14**	**(0.06)***	**-0.04**	**(0.02)**	**-0.10**	**(0.04)****
(Reference: highest edu is college)						
Highest education: graduate	-0.07	(0.05)	0.01	(0.01)	0.06	(0.05)
Highest education: professional	-0.09	(0.11)	0.01	(0.00)	0.08	(0.11)
--						
N	506					
Wald chi-squared(34)	66.74					
Prob > chi-squared	0.00					
Pseudo R-squared	0.06					
Probability of outcome	0.40		0.35		0.25	

Source: Analysis of FLOSS-US. Dependent variable = 1 for small project, = 2 for medium project, = 3 for large project. Regression includes fixed effects for 11 country categories, not shown here. Marginal effects evaluated at mean values of independent variables.
 * Statistically signficant at 95% confidence, ** at 99%.

APPENDIX

Table A1. Factor analysis of individual motivation responses to Q4

Variable	*Factor loadings*
Q4h (Way to become better programmer): very important	0.49
Q4h: important	-0.05
Q4h: a bit important	-0.21
Q4h: not important	-0.40
Q4g (Wanted to interact with like-minded programmers): very important	0.44
Q4g: important	0.11
Q4g: a bit important	-0.20
Q4g: not important	-0.42
Q4b (We should be free to modify software we use): very important	0.41
Q4b: important	-0.11
Q4b: a bit important	-0.20
Q4b: not important	-0.33
Q4f (Wanted to provide alternatives to proprietary): very important	0.41
Q4f: important	-0.01
Q4f: a bit important	-0.10
Q4f: not important	-0.40
Q4e As FS software user, wanted to give back to community): v important	0.37
Q4e: important	-0.07
Q4e: a bit important	-0.22
Q4e: not important	-0.29
Q4a (Best way for software to be developed): very important	0.36
Q4a: important	0.10
Q4a: a bit important	-0.20
Q4a: not important	-0.42
Q4j (Wanted to learn how particular program worked): very important	0.36
Q4j: important	0.15
Q4j: a bit important	-0.06
Q4j: not important	-0.50
Q4i (Liked challenge of fixing bugs in existing software): very important	0.28
Q4i: important	0.31
Q4i: a bit important	0.09
Q4i: not important	-0.59
Q4d (Needed to fix bugs in existing software): very important	0.10
Q4d: important	0.22
Q4d: a bit important	0.08
Q4d: not important	-0.42
Q4c (Needed modification of existing software): very important	0.05
Q4c: important	0.13
Q4c: a bit important	0.15
Q4c: not important	-0.35
Q4k (Employer wanted me to collaborate in OS): very important	0.05
Q4k: important	0.10
Q4k: a bit important	0.31
Q4k: not important	-0.33
Factor scores: median	0.02
Factor scores: standard deviation	1.00
Shapiro-Wilk W test for normality: Prob > z	0.00
N	1,459

Source: Analysis of FLOSS-US.

Table A2. Frequency distribution of FLOSS-US Survey respondents matched with projects found in the SourceForge archive for 2001-2003

Project name	*Total number of survey respondents*	*Percentage of large number projects*
Apache	3	0.89
Debian	46	13.69
Emacs	9	2.68
Jboss	3	0.89
Jedit	3	0.89
Linux kernel	48	14.29
Mozilla	29	8.63
Mplayer	5	1.49
Openoffice.org	15	4.46
Perl	6	1.79
Php	9	2.68
Python	4	1.19
Samba	6	1.79
Xfree86	3	0.89
Projects with 1 survey respondent	131	38.99
Projects with 2 survey respondents	16	4.80
Total	336	100

Note: See text for matching project names and from the 2003 FLOSS-US survey respondents with project membership sizes obtained from the SourceForge archive for the years 2001-2003. This table lists a project name only if the project had more than three respondents in the survey. Table counts two responses if a developer writes in large current and large first projects that differ. Table counts one response if a developer writes in the same large project as first and as current.