Human agency, social networks, and FOSS project success

Submission: February 2010

Revision: November 2010

Acceptance: April 2011

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ABSTRACT

The development model of free open source software (FOSS) provides important managerial lessons for knowledge creation, innovation, and software and new product development. Yet many unanswered questions exist regarding why certain FOSS projects succeed while others fail. Drawing on social capital theory and human agency theory, this study proposes that FOSS projects stand a better chance of success if they possess desirable social network capital and adopt effective strategies. It further argues that valuable social network capital and effective strategies produce greater returns together than they do alone. The results of an empirical analysis of FOSS projects reveal significant positive interactions between social capital variables and human agency/strategy variables, highlighting the importance of complementarity between social network ties and adopted strategies in shaping the outcome of FOSS projects.

Keywords: Free Open Source Software, Project Success, Social Networks, Human Agency

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1. Introduction

Free Open Source Software (FOSS) is emerging as a significant economic, social, and cultural phenomenon (von Hippel and von Krogh, 2003). The number of FOSS projects is rapidly growing. A significant amount of software developed by commercial firms is being released under open-source licenses. Many companies such as IBM, Google, and Oracle have considered open-source as integral to their business. With little or no marketing, open-source software has become the dominant platform for many categories of business applications. According to a survey by Netcraft, as of August 2009, 47% of the web server market had been captured by the open-source Apache software, compared to 22% by the proprietary Microsoft web server (Netcraft, 2009). Other successful examples of open-source software include GNU/Linux, Sendmail, and the Perl programming language (von Hippel and von Krogh, 2003).

Despite the major success enjoyed by some FOSS projects, many FOSS initiatives fail. This phenomenon raises a critical question: "why do certain FOSS projects succeed while others fail?" Drawing on social capital theory and human agency theory, this study develops an integrative model of FOSS project success and investigates the extent to which start-up FOSS projects' network ties, together with the strategies they adopt explain their success. FOSS projects are connected with each other via networks of relationships because their developers participate in multiple projects and collaborate both within and across projects. Such connectedness could have major performance ramifications for a project as research has found that social networks significantly impact the performance of individuals, groups, and firms (Nahapiet and Ghoshal 1998). Gien the potential importance of social exchanges in the success of FOSS projects, recently a few studies have examined FOSS project success through a social network perspective (Grewal et al., 2006; Hahn et al., 2008; Singh et al., 2007). While these efforts are a step in the right direction, their sole emphasis on FOSS projects' social network operates from the assumption that network ties determine performance: centrally located projects will certainly succeed and peripheral projects will inevitably fail. Such assumption ignores the possibility of human agency, the capability of FOSS projects to pursue strategies. In other words, centrally located FOSS projects may or may not use their network advantages while peripheral projects may pursue strategies to transcend the disadvantages of their network position. A better understanding of FOSS project success may thus require a perspective that emphasizes the complementarity of social capital and human agency. To this end, this paper posits that social ties and human factors play a critically complementary role in shaping FOSS project outcome: social ties complement human actions by providing opportunities for advantages while human actions complement social ties by increasing the likelihood that the advantages will materialize.

Consequently, this research extends this line of work by examining the complementary role of social ties and human actions in the success of FOSS projects. Section 2 briefly reviews the literature. Section 3 integrates social capital theory and human agency theory to develop a model of FOSS project success. Sections 4 and 5 evaluate the proposed model. Finally, section 6 discusses the findings, implications, and limitations of this research.

2. Literature review

Research on FOSS success factors has recently gained popularity although the literature is still limited. Elements commonly cited as significant for FOSS project success include the devotion of developers and market structure (Bonaccorsi and Rossi, 2003), a critical mass of developers (Mockus et al., 2002), software quality and community service quality (Lee et al., 2009), license strategy and organizational sponsorship (Stewart et al., 2006), developer and user interest (Subramaniam et al., 2009), collective identity and trust (Stewart and Gosain, 2006). Earlier work in this area is typically anecdotal in nature and focuses on well-known FOSS projects. For example, Mockus et al. (2002) find that a critical mass of core developers, together with peripheral developers who provide service support is crucial to the success of Apache and Mozilla. Bonaccorsi and Rossi (2003) suggest that FOSS systems are less successful in the client market than in the server market because Microsoft products have already dominated the client market. Valuable as these efforts have been, the lack of a generalizable empirical sample could ultimately result in disagreement regarding factors significant to the success of FOSS projects.

More recently, studies with larger sample sizes have begun to emerge. For example, Stewart et al. (2006) examine how license restrictiveness and organizational sponsorship influence FOSS user interest and development activity and find that users are most attracted to projects that employ nonrestrictive licenses and are sponsored by organizations. Stewart and Gosain (2006) address the issue of what leads to the effectiveness of FOSS development teams in the absence of formal control. They find that team members' adherence to the FOSS ideology influences team effectiveness by enhancing trust and communication quality.

Recent progress notwithstanding, important gaps remain. Most extant studies identify project or developer related characteristics as the antecedents of FOSS project success, adopting a view that considers FOSS projects as being isolated from their larger social environment. Such a perspective ignores the fact that each FOSS project is embedded in and shaped by networks of relationships. Hence, several studies have recently sought to raise the awareness of the central role social networks play in the success of FOSS projects (Grewal et al., 2006; Hahn et al., 2008;

Singh et al., 2007). Nevertheless, a sole emphasis on the importance of network ties in shaping FOSS project success operates from the assumption that centrally located projects will inevitably succeed and peripheral projects are powerless and will fail. Such assumption ignores the possibility of human actions: the ability for FOSS projects to actively use strategic responses to materialize the structural advantages or to overcome the structural disadvantages (Stevenson and Greenberg, 2000). To address this limitation, this research takes an alternative theoretical direction to synthesize network structural and human agency analyses. Instead of focusing on the independent effect of network structure, this study examines the complementary synergy between social network ties and human agency in explaining FOSS outcomes.

3. Theoretical underpinning and hypotheses development

Clearly, while the theory of social capital and the human agency perspective each represents a nuanced understanding of factors significant to FOSS project success, none completely succeeds by itself in addressing this issue. Thus, this research synthesizes these two perspectives and emphasizes that the optimal outcome of FOSS projects results from the complementary synergy between the projects' social ties and their human action. The objective here is not to generate a longer list for the antecedents of FOSS project success, but rather to explore the complementary role of social networks and human agency in explaining FOSS project performance. Figure 1 summarizes the proposed model and hypotheses.

Figure 1 here

3.1 Indicators of FOSS project success

Based on the DeLone and McLean (2003) model of information systems success, Crowston et al. (2003) identify a range of measures applicable for assessing the success of FOSS projects.

Some of these measures have been widely used in the literature, including process-level measures (e.g., level of activities, number of developers, and team effectiveness) and project-level measures (e.g., adoption rate, user satisfaction, user net benefit, and technical success). Focusing on project-level outcome, this study examines both adoption rate and technical success as they have a slightly different orientation (market- and technical-oriented). Adoption rate refers to the market popularity of a FOSS product and technical success refers to the level of technical and functionality improvements a FOSS project has accomplished (Grewal et al., 2006) . Inclusion of these criteria is consistent with the literature on FOSS project success (Grewal et al., 2006; Singh, 2007). The user-reported success measures such as user satisfaction and net benefits are not considered here because it is difficult to select a true random sample of FOSS users as this population is generally unknown (Crowston et al., 2003).

3.2 Social capital theory and FOSS project success

The notion of social capital initially appears in the studies of communities where networks of interpersonal relationships develop over time and provide the basis for trust, cooperation, and access to resources. More recently, researchers have applied this concept to studying its performance implications for firms and have suggested that the embeddedness of a firm in its social networks constitutes a valuable resource for the firm (Nahapiet and Ghoshal, 1998).

By providing structural, relational, and cognitive benefits, social capital may also play a crucial role in the success of FOSS projects. Structural benefits result from structural configuration including centrality and boundary-spanning (Luo and Hassan, 2009; Ma et al., 2009). For instance, being located at the confluence of information flows, a central project will have a better understanding of current design problems of different modular architectures, related solutions, and successful and/or failed approaches (Singh et al., 2007). Relational benefits stem from interpersonal relationships project members develop through history of cooperation and collaboration. Due to its voluntary nature, the FOSS community is characterized by the lack of formal governance and control (von Hippel and von Krogh, 2003). Studies indicate that relational assets (e.g., trust, gift giving, obligation, and reciprocity) that a FOSS project builds over time serve as an alternative to formal governance to ensure the project's day-to-day functioning and long-term success (Kuk, 2006). Cognitive benefits arise from resources such as shared language, representation, and systems of meaning (Nahapiet and Ghoshal, 1998). These resources facilitate smoother collaboration, coordination, knowledge sharing and are particularly important given the distributed nature of the FOSS development model.

FOSS projects could cultivate their social capital through different types of social networks. This research focuses on the affiliation networks (overlapping membership). Figure 2 is an illustration of an affiliation network. As is shown in the figure, projects A and B form networks because of the common developers (e.g., D3) the projects share. Developers D1, D2, and D3 are connected because of the common project (e.g., Project A) they are a member of. The focus on the affiliation networks is due to the premise that even though research suggests that overlapping membership in the board of directors exerts significant performance impact (Peng, 2004), the understanding of how affiliation networks impact FOSS success remains unclear.

Figure 2 here

Although FOSS projects could benefit from the structural, relational, and cognitive aspects of their social capital, this research focuses on the structural dimension. A FOSS project has an internal social structure formed among developers within the project and an external social structure formed between its own members and members of other FOSS projects. This study considers both the internal and external structures given their documented influence on the performance of a collective actor (Adler and Kwon, 2002; Oh et al, 2006). Specifically, this research considers the internal and external network sizes of a FOSS project since network size has been found to impact the performance of various organizations (Nahapiet and Ghoshal, 1998). Further, the degree to which a FOSS project can benefit from its network ties is also a function of the quality and value of the resources possessed by its ties. When a FOSS project is connected to well-endowed projects, it may benefit more than if it were not. However, the concept of the degree of ties' endowment has largely been ignored in the FOSS network literature and it is reasonable to believe that the possibility of positive performance impact arising from ties to well-endowed projects warrants investigation. Thus, the following section discusses the impact of a FOSS project's internal and external network size and the degree of endowments from its ties on the project's success.

3.2.1 Internal network size

A FOSS project's internal network size is analogous to the number of developers working on the project (See Figure 2). With a larger internal network size, a project would have access to more resources due to the larger number of developers working on it. Because software development is associated with various complex tasks including code development and debugging, studies have suggested that sufficient human resources are essential for the success of the software product (Mockus et al., 2002). With a larger internal network size, the project team is able to spread complex tasks and cognitive strains over more developers, resulting in faster and better technical improvements. It is also more likely that the team will produce higher quality software products due to the simple fact that "given enough eyeballs, all bugs are shallow" (Raymond, 2001). High quality code implies a better chance of being adopted. Additionally, researchers indicate that FOSS developers tend to devote substantial amounts of time and energy not only to software development, but also to promoting their projects (Bonaccorsi and Rossi, 2003). Hence, a larger internal network size also implies that a project has more informal marketing staff promoting and campaigning for its products, resulting in a higher acceptance rate. In many cases, FOSS developers are also FOSS users. A larger internal network size equates to a larger user base and thus a greater adoption rate.

H_{1a}. FOSS projects' internal network size will positively impact their adoption rate.

H_{1b}. FOSS projects' internal network size will positively impact their technical success.

3.2.2 External network size

A FOSS project's external network size refers to the total number of outside projects with which the focal project's developers are affiliated. Social capital theorists posit that a unique source helps people gain novel knowledge and information from distant parts of their social system, and can to some extent be more valuable than knowledge sources shared by everyone (Granovetter, 1983; Merlo et al., 2006). Hence, with a large external network size, a FOSS project enjoys greater broker and bridging advantages (Adler and Kwon, 2002; Oh et al., 2006) as its members can be exposed to unique sources of knowledge and can elicit new ideas and insights from its diverse external networks (Oh et al., 2006). Such teams may thus be better able to facilitate innovation and improve technical success. A FOSS project's large external network size can also expose the team to current design problems of different modular architectures, related solutions, and successful approaches (Singh et al., 2007). This exposure could lead to greater technical success as code contribution in FOSS development involves, to a large extent, a recombination and modification of existing modular architecture (MacCormack et al., 2006). Projects with large external networks have the potential to access important information and knowledge sooner (Nahapiet and Ghoshal, 1998), leading to faster technical success. Further, as developers are more inclined to help and exchange information with those who have interacted with them before (Hahn et al., 2008; Kuk, 2006), FOSS projects could benefit from their large external network size through the reciprocation of their ties. Such reciprocation ensures a high level of support and help, leading to faster technical success. Also, members' direct involvement in and subsequent familiarity with other projects helps a FOSS team build up their absorptive capacity to recognize the value of new knowledge, assimilate it, transfer it, and apply it to improve the project technically (Cohen and Levinthal, 1990). The external ties can also be important channels to disseminate information concerning the project and to increase the visibility of the project, which in turn could lead to a higher acceptance rate for the project.

H_{2a}. FOSS projects' external network size will positively impact their adoption rate.

H_{2b}. FOSS projects' external network size will positively impact their technical success.

3.2.3 Degree of endowment from the external ties

The positive effect of a large external network size could be even more pronounced when a project is connected to well-endowed projects which have valuable and quality resources and capabilities. Clearly, connections to well-endowed projects with talented developers, deep knowledge base, and valuable FOSS project coordination experience can afford the focal project greater opportunities to learn and receive quality help and support, positively impacting the technical success of the focal project. Such connections also enable the focal project to tap into the large user-base of its well-endowed ties and improve its adoption rate. Connection to well-endowed projects could also be interpreted as reputational endorsement for focal projects (Nahapiet and Ghoshal, 1998), positively impacting software users' perception on the quality of the project and consequently leading to a higher adoption rate. Hence, if a project is connected to well-endowed projects, the magnitude and value of the social capital available through its external network will be far greater than if the project is connected to poorly-endowed projects. The recent social capital literature has increasingly recognized the significant impact of ties' resources and capabilities on the focal actor's performance (Adler and Kwon, 2002; Nahapiet and Ghoshal, 1998; Zaheer and Bell, 2005). In essence, ties' capabilities and resources set the upper bound to the benefits the focal actor can derive from its social networks, hence they are consequential to performance (Zaheer and Bell, 2005). Clearly, the argument that FOSS projects' success is a function of the degree of ties' endowment is consistent with this line of research.

H_{3a}. The degree of ties' endowment is positively related to FOSS projects' adoption rate.

H_{3b}. The degree of ties' endowment is positively related to FOSS projects' technical success.

3.3 The theory of human agency and FOSS project success

Even with the same structural endowment from their social networks, FOSS projects can differ in terms of the actions pursued to use the advantages, or to overcome the disadvantages, of their social networks, resulting in performance variations across them (Stevenson and Greenberg, 2000). Therefore, another factor that is critical to the success of a FOSS project is the discretionary human action it takes.

This research examines two human factors: user/developer participation and user orientation. User/developer participation refers to the extent to which users/developers are involved in the development of the software. User orientation is the speed at which the project team satisfies the needs and requirements of the software users through the addition of new features, patches, and fixing of bugs. Given the voluntary nature of FOSS development, the ability of a FOSS project to involve uses/developers and to meet user needs could be essential for the project's success.

The literature has recurrently documented the importance of user participation in software development (Ives and Olson, 1984). As the FOSS development model does not involve formal protocols for the collection of user requirements, user involvement enhances a FOSS project's ability to acquire user knowledge and requirements, leading to greater technical improvements. User/developer participation helps the project foster user ownership and loyalty, leading to greater acceptance of the software (Bhattacherjee, 1998). Researchers have suggested that devotion and support from both developers and users are critical for the success of Apache and Mozilla (Mockus et al., 2002). User orientation captures the speed at which the project team resolves bugs, adds features, and meets user requirements. Greater user orientation leads to faster technical improvement and greater user satisfaction, which in turn improves user acceptance of the software. Researchers have suggested that concerns over reliable ongoing software updates and technical support are a major barrier to FOSS adoption (Goode, 2005). Greater user orientation could help mitigate such concerns, leading to a greater adoption rate. In some respects, user/developer participation and user orientation are indicators of FOSS projects' dynamic capability since they reflect a FOSS project's ability to gain and mobilize resources (developers/users) to adapt to the constantly changing user needs and technological environment, and hence should be important sources of FOSS project success (Teece et al., 1997).

H_{4a}. User/developer participation is positively related to FOSS projects' adoption rate.

H_{4b}. User/developer participation is positively related to FOSS projects' technical success.

H_{4c}. User orientation is positively related to FOSS projects' adoption rate.

H_{4d}. User orientation is positively related to FOSS projects' technical success.

3.4 The complementary role between social network capital and human agency

While social network ties provide potentials for success, the extent to which FOSS projects can realize this potential also depends on the actions the projects pursue. Thus, valuable social network capital rarely acts alone and the optimal outcome of FOSS projects results from the complementary synergy between the projects' social network ties and their human action. Complementarity arises in the sense that social network capital and human action produce greater returns in conjunction with each other than they do alone.

Desirable network structures such as large internal and external network sizes and connections to well-endowed ties may confer FOSS projects with benefits such as resource availability and access of communication channels. Human action complements social networks in such a way that FOSS projects that take appropriate actions will be at an advantage compared to those which do not in using network advantages or transcending network disadvantages. Specifically, a FOSS project will be more likely to fully materialize the potential of its large internal network size when its members are committed to contributing to the project (user/developer participation) and attending to user needs and requirements efficiently (user orientation). If not managed effectively, a focal project's large network size resulting from its developers working on too many projects simultaneously could divert the developers' focus and efforts, and prevent them from full-heartedly advocating for the focal project and engaging in in-depth knowledge sharing and intensive code submission, testing, and reviewing (Kuk, 2006). In this case, one way for a project to fully realize the benefits of its large external network size is to have members who strategically join multiple projects in order to have access to the valuable resources, while prioritizing the focal project by maintaining a high level of participation and by actively attending to user needs and requirements (user orientation). Further, a FOSS project will be more likely to take fuller advantage of the valuable and high quality resources and capabilities of the well-endowed ties when the members prioritize the focal project. Taken together, a project's human action improves its ability to create, mobilize, and leverage social capital to achieve greater gain. For these reasons, it is critical to focus on the complementarity between social network ties and human action as a feasible path to FOSS project success.

H_{5a}. Desirable network structures with large internal and external network sizes and well-endowed ties, in conjunction with greater user/developer participation and user orientation, will have a greater impact on FOSS projects' adoption rates than they do alone.

H_{5b}. Desirable network structures with large internal and external network sizes and well-endowed ties, in conjunction with greater user/developer participation and user orientation, will have a greater impact on FOSS project technical success than they do alone.

4. Methodology

The research hypotheses are evaluated analyzing panels of data drawn from SourceForge.net. SourceForge.net, the largest repository of open-source projects, provides free services to open-source developers and has maintained detailed data on over 100,000 projects and 1 million registered users' activities. Only data from January 2005 to December 2009 is available when this research is conducted. From the start-up projects registered between January and March of 2005, a stratified random sample of 2458 projects is drawn, which is the monthly average of the total registered projects from January to March of 2005.

4.1 Dependent variables

Consistent with prior research (e.g., Grewal et al., 2006), the number of downloads is used as the measure for *adoption rate.* FOSS developers retrieve the source code of a particular project from the Concurrent Versioning System (CVS) to make improvements and add functionality to software. A commit occurs when a developer uploads the improved source code file to the CVS. Thus, the number of code commits to CVS is used as the proxy for *technical success* since code commits reflect meaningful additions and refinements to the functionality of the software. Because the mean and standard deviation of the two measures are fairly large and their distributions are highly skewed, their natural logarithm (after adding unity to eliminate zeros) is used in the analysis.

4.2 Independent and control variables

In analyzing the network size of the 2458 projects, snowball sampling is used in which all the ties (the second set) of the initial set of 2458 projects (focal projects) is traced and then all the ties (the third set) of the second set of projects is further traced until no new ties could be traced.

The internal network size is indeed the number of developers that participate in this project. The *external network size* is operationalized as the average number of projects in which a project's developers participates. SourceForge.net uses a scoring system to rank all the projects listed on its website. The ranking score is calculated based on traffic, development, and communication. Traffic could be an indication of users' interest in the project; development suggests the effectiveness of the team in generating codes and improving the software; communication captures the degree of communication and collaboration among developers and users. To be ranked well, a project must be endowed with devoted developers who possess great technical know-how to produce high quality software that attract users. Hence, this ranking score is used as the proxy for *the endowment* of each project as it, to some extent, is an indicator for the quality of the developers of a project team. For a particular project, *the degree of endowment from its ties* is operationalized as the average ranking score held by the ties of this project.

The number of feature requests, new features, bug reporting, bug fixings, forum messages, and tasks etc. submitted by users and developers is used as the proxy for *user/developer participation* because it indicates the amount of time and effort users/developers devote to the project. *User orientation* is calculated as the total number of solved artifacts (bugs, patches, and features and services requested) divided by total number of artifacts. *Complementarity between social network ties and human agency* is operationalized using the multiplicative interaction terms between the network variables and human agency variables.

The problem of simultaneity could exist due to possible confusion in the direction of causality between the dependent and independent variables. For example, network properties may influence project success while success is likely to feedback and influence network properties. Therefore, lagged rather than contemporaneous independent variables are specified in an attempt to alleviate the possibility that project success and the independent variables are jointly determined. Second, the specification of lagged independent variables also draws on theoretical rationale because the impacts of social networks and human factors might require a certain time lag before they manifest themselves. Hence, a one year lag is used for the independent variables.

Developer experience and license restrictiveness could influence the success of the project and are included as control variables. *Developer experience* is measured by the duration of time (in terms of month) a developer has been registered on SourceForge.net. The average of this measure for all developers of a particular project is used as the developer experience measure at the project level. *License restrictiveness* is a categorical variable and is coded as 1 if the license terms have highly restrictive or restrictive provisions and 0 if otherwise.

5. Analysis and results

Among the 2458 projects, 595 of them were purged from sourceforge.net by December 2009 and are not included in the analyses. Table 1 displays the means, standard deviations, and correlation coefficients of all the variables used in the analyses. The correlations among the independent variables are low, indicating structural differences between these variables. In general, the correlations between internal and external network sizes and the dependent variables range from low to medium. The degree of endowment is strongly correlated with adoption rate, but only weakly correlated with technical success. The agency variables are either strongly or moderately correlated with both dependent variables.

Table 1 here

Although technical success and adoption rate may be co-determined, the low correlation coefficient (0.09) between these two variables (in their original scales) indicates that the issue of co-determination is not a major concern. Through the overlapping developer members, FOSS projects in the sample are potentially interconnected and can hence draw from common sources of knowledge. Thus, the error terms may be correlated and estimates obtained using ordinary least squares regression (OLS) may be biased. Thus, the seemingly unrelated regression (SURE) parameters are estimated using a feasible generalized least squares (FGLS) procedure that allows for correlations of disturbances (Zellner 1962). The hypotheses are tested with hierarchical regression analyses, entering the control variables in model 1, independent variables in model 2, and the multiplicative interaction terms in model 3 and tracing changes in the multiple squared correlation coefficients (R^2) from model to model. Following Aiken and West (1991), the variables are mean centered to minimize the distortion due to high multicollinearity between the interaction terms and their component variables. After mean centering, the interaction term *degree of endowment * participation* was still found to be highly correlated with *participation* and was hence dropped from further analyses.

Table 2 here

Table 2 reports the results of the SURE analyses. Models 1a and 1b show the effects of the control variables and explain a small amount of the variance in both adoption rate (0.7%) and technical success (1.1%). While developer experience positively and significantly impacts adoption rate (p<0.01), no relationship is detected between license restrictiveness and adoption rate. Developer experience also positively impacts technical success (p<0.01). License restrictiveness negatively impacts technical success (p<0.05).

Models 2a and 2b report the results of the main effects and they explain 53% and 26.5% of the variance in adoption rate (ΔR^2=52.3%, F=409.16 p<0.001) and technical success (ΔR^2=25.4%, F=128.04, p<0.001) respectively. As indicated by the ΔR^2 values, the addition of the main effects significantly increases the explanatory power of models 2 over models 1. For adoption rate, the coefficient for the degree of endowment is significant (*p<0.01*), suggesting that FOSS projects connected with well-endowed ties are more likely to be adopted (H_{3a} is supported). But FOSS projects' internal and external network sizes do not independently contribute to adoption rate (H_{1a} and H_{2a} are not supported). The coefficients for both of the agency variables are positive and significant (*p<0.01*), confirming hypotheses 4a and 4c which respectively predict that FOSS projects with greater user/developer participation and user orientation are more likely to be adopted. For technical success, hypotheses 1b, 2b, and 3b respectively state that a project's internal, external network sizes, and the degree of endowment from its ties will positively impact FOSS technical success. The coefficients for internal network size and the degree of endowment are significant ($p<0.01$), supporting hypotheses 1b and 3b. However, the coefficient for external network size is not significant. Thus, hypothesis 2b is not supported. The coefficients for both of the agency variables are positive and significant ($p<0.01$), confirming hypotheses 4b and 4d which respectively predict that FOSS projects with greater user/developer participation and user orientation are more likely to achieve technical success.

Models 3a and 3b add the effects of the interaction terms and they explain 55.9% and 36.4% of the variance in the adoption rate (ΔR^2=3%, F=25.53, p<0.001) and technical success (ΔR^2=9.9%, F=55.19, p<0.001). Hypotheses 5a and 5b postulate that desirable network structures, in conjunction with greater user/developer participation and/or user orientation, will have a greater impact on the FOSS project adoption rate and technical success than they do alone. For the adoption rate, the interaction coefficient between participation and internal network size is positive and significant ($p<0.01$) while the interaction coefficient between participation and external network size is not. The interaction coefficients between user-orientation and the two network size variables are positive and significant ($p<0.01$), while the interaction coefficient between user-orientation and the degree of endowment is not. Thus, hypothesis 5a is partially supported. It is important to note that although internal and external network sizes by themselves do not contribute to the adoption rate, they interact respectively with user/developer participation and user orientation, jointly exert a positive impact on the adoption rate. These results highlight the importance of the complementary effect between social capital and human agency in shaping FOSS project outcomes. For technical success, except for the interaction coefficient between user-orientation and external network size, all the other interaction coefficients are positive and significant (*$p<0.01$*). Thus, hypothesis 5b is partially supported. Although external network size by itself does not contribute to FOSS technical success, it interacts with participation to positively impact FOSS technical success. These results again support the general argument that social capital and human action could exert a significant reinforcing interaction effect in shaping FOSS project outcomes.

Figure 3 here

To better understand the nature of the complementarity synergy, the interactions which are statistically significant are plotted (See Figure 3) at one standard deviation above (high) and below (low) the mean (Aiken and West, 1991). Graphs a and b indicate that the positive effect of internal network size on both dependent variables is much stronger with high user/developer participation. As shown in graphs c and d, the positive effect of internal network size on both dependent variables only exists with high user orientation. When user orientation is low, larger internal network size does not lead to a higher adoption rate or greater technical success. The positive effect of external network size on the adoption rate is much stronger with high user orientation (graph e). As shown in graphs f and g, the positive effect of external network size and endowment on technical success only exists with high user orientation. When user orientation is low, a larger external network size actually negatively impacts technical success. These results confirm the complementarity of social capital and human actions.

6. Discussion, conclusion, and future research

While prior research has examined the role of social capital in FOSS success, this study advocates for an integrative approach that coalesces social capital theory and human agency theory. This approach stresses that FOSS projects are socially embedded in network relationships and performance should not be assessed in a social vacuum. With human agency theory, FOSS projects are allowed to act. Rather than being passive nodes in their social networks, FOSS projects' human action complements social ties to impact performance by determining the degree to which the projects are able to use/overcome their network advantage/disadvantage.

6.1 Implications for research and practice

FOSS development has some unique features that distinguish it from other software development approaches (von Hippel and von Krogh, 2003). Such uniqueness suggests a need for new perspectives in the investigation of FOSS critical success factors. This study makes significant contributions to the growing body of research on FOSS success given that the importance of the complementary synergy between social capital and human agency is not yet explored. Consistent with earlier research (Grewal et al., 2006; Singh et al., 2007), this study provides further evidence that social capital plays an important role in shaping FOSS outcome. However, prior research applying network analysis in FOSS success has mainly focused on the attributes of network structure, ignoring the characteristics of the ties comprising the network. This study adds to the extant literature by examining how ties' characteristics such as ties' endowment combine with network sizes to impact FOSS performance. As predicted, ties' endowment is found to impact FOSS project adoption rate and both internal network size and ties' endowment are found to impact technical success. Perhaps the most telling story of this study concerns the importance of human agency and the presence of the complementary synergy between social capital and human agency. Internal and external network sizes are found to jointly influence FOSS outcome with the agency variables although in some cases they are not found to independently impact the outcome variables. The two agency variables are found to both independently and jointly impact FOSS outcome. These findings are interesting given that previous research has focused on the independent effect of network structure in explaining FOSS outcomes, without addressing the possibility of human agency being able to overcome network disadvantages or to reinforce and enhance network advantages.

This study provides four important implications for practice. As demonstrated by the theoretical discussion and empirical evidence, isolated efforts seeking to establish social network capital may not be sufficient in improving FOSS project performance. Rather, alignment between desirable social ties and appropriate strategies is important. Therefore, FOSS projects must do more than simply nurture their network capital. It is important for them to understand the advantages and disadvantages of their network ties and formulate effective strategies to fully realize/overcome these advantages/disadvantages. Second, the significant impacts of ties' endowment on FOSS success highlight the importance of building contacts that possess valuable capabilities and resources. Third, findings of this research will not only help FOSS projects succeed but also help commercial software firms learn how to structure their software development teams more effectively in order to produce high quality products. Finally, from a broader perspective, the research findings also have rich implications for innovation management and new product development as the FOSS development model has been referred to as a user-driven innovation (von Hippel and von Krogh, 2003).

6.2 Limitations and directions for future research

As with all studies, this research has some limitations. First, only two strategies are explored here. It would be an interesting research undertaking to develop a fuller understanding of the strategies projects could adopt to change the effects of their structural position. Some intriguing and key questions for future research could include but are not limited to: whether all projects equally benefit from or are constrained by the inherent (dis)advantages of their network ties, how projects in peripheral network positions which are generally thought to be powerless adopt strategies to overcome undesirable network positions, and why some projects are more adept at capturing the social capital inherent in their networks than others. These questions are important because while social networks provide possibilities, answers to these questions can guide a FOSS project to realizing these possibilities and opportunities.

Second, this research hypothesizes a positive relationship between social capital and FOSS performance. But social capital may bring the projects both benefits and disadvantages. Although internal and external network size could benefit the projects through resource availability and control benefits, an extremely large external network could divert the developers' focus and efforts (Kuk, 2006), resulting in a low developer participation level and slow technical improvements. This in turn sends negative signals to the users that the project is not sufficiently active, adversely influencing users' participation and their perception and intention to adopt the software. On the other hand, an extremely large internal network could lead to diseconomies of scale, information overload, and rising coordination and communication cost. Excessive communication leads to increased process loss and reduced productivity and may adversely impact projects' technical success. Hence, an optimal configuration may exist for the network structures of FOSS projects (Luo & Hassan, 2009). Future research could explore the possibility of such optimal network configurations.

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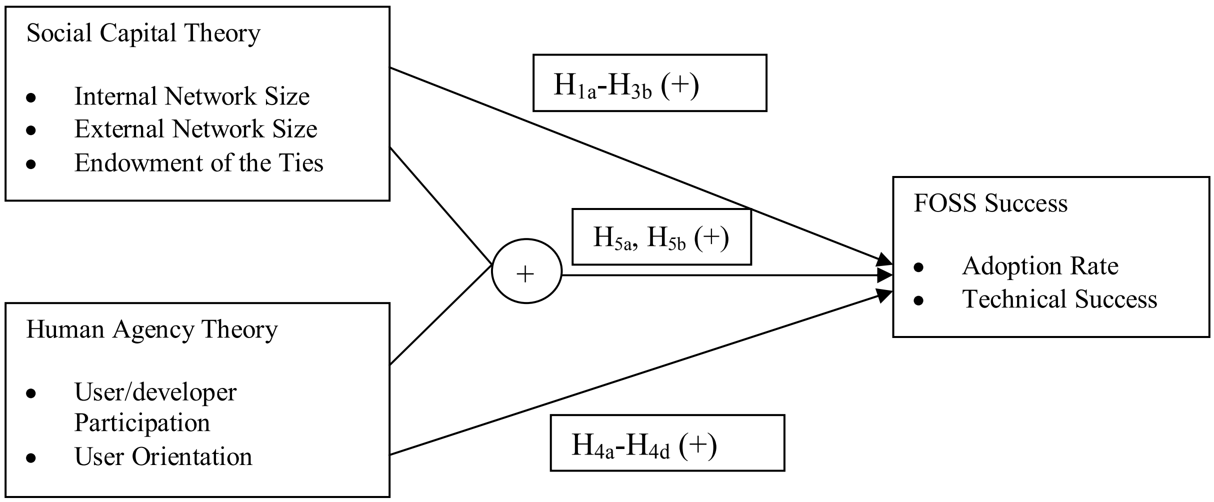

Figure 1: A model of FOSS success

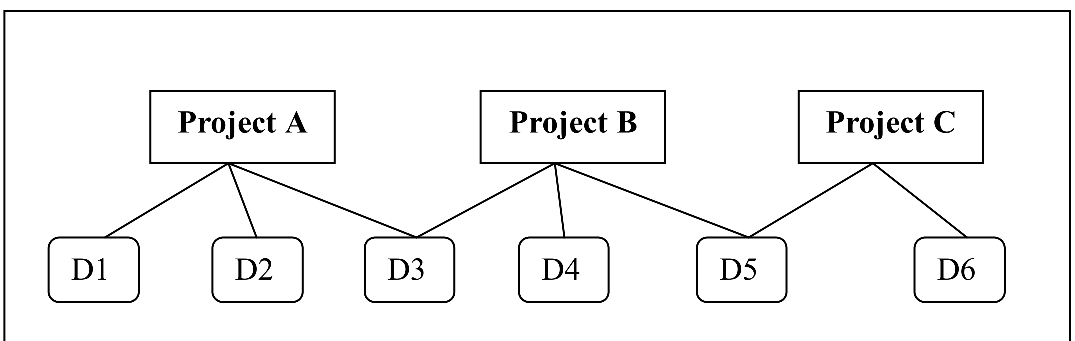

Figure 2: FOSS Affiliation Networks

Table 1: Correlation Matrix

		Mean	SD	log(1)	log(2)	3	4	5	6	7	8	9
1	Downloads	12172.1	254982.0	1								
2	Code Submission	21.9	115.5	.33**	1							
3	Developer Experience	13.4	16.7	.09**	.09**	1						
4	License Restrictiveness	.8	.4	.02	-.06*	-.02	1					
5	Internal Network Size	1.7	1.7	.15**	.36**	.01	-.19**	1				
6	External Network Size	2.1	2.0	.17**	.06**	.40**	.00	-.02	1			
7	Degree of Endowment	78211.8	63523.4	.62**	.17**	.17**	.02	.09**	.28**	1		
8	Participation	8.6	34.8	.23**	.25**	.11**	-.04	.05*	.08**	.14**	1	
9	User Orientation	-.7	.6	.53**	.40**	.09**	-.03	.21**	.05*	.28**	.24**	1

** *p*<0.01, * *p*<0.05 N= 1836

Table 2. Results of Seemingly Unrelated Regression Models Predicting Adoption Rate and Technical Success

	Adoption Rate			Technical Success		
Variables	**Model 1a**	**Model 2a**	**Model 3a**	**Model 1b**	**Model 2b**	**Model 3b**
Control Variables						
Developer Experience	0.009***	0.005***	0.006***	0.003***	0.001	0.001
License Restrictiveness	0.073	0.092	0.057	-0.075**	-0.016	-0.026
Independent Variables						
Internal Network Size		0.023	-0.017		0.095***	0.053***
External Network Size		0.019	0.018		0.004	0.010
Degree of Endowment		0.000***	0.000***		0.000	0.000***
Participation		0.003***	0.003***		0.003***	0.003***
User Orientation		1.029***	0.930***		0.282***	0.160***
Interactions						
Internal Network Size * Participation			0.002***			0.001***
External Network Size * Participation			0.000			0.000***
Internal Network Size * User Orientation			0.081***			0.100***
External Network Size * User Orientation			0.187***			-0.006
Degree of Endowment * User Orientation			0.000			0.000***
Constant	1.328***	1.492***	1.493***	0.177***	0.155***	0.123***
Adjusted R^2	0.007	0.530	0.559	0.011	0.265	0.364
F	7.591***	296.837***	195.382***	10.660***	95.561***	87.000***
ΔR^2		0.523	0.030		0.254	0.099
ΔF		409.162***	25.527***		128.044***	55.186***

*** *p*<0.01, ** *p*<0.05, * *p*<0.1 N= 1836

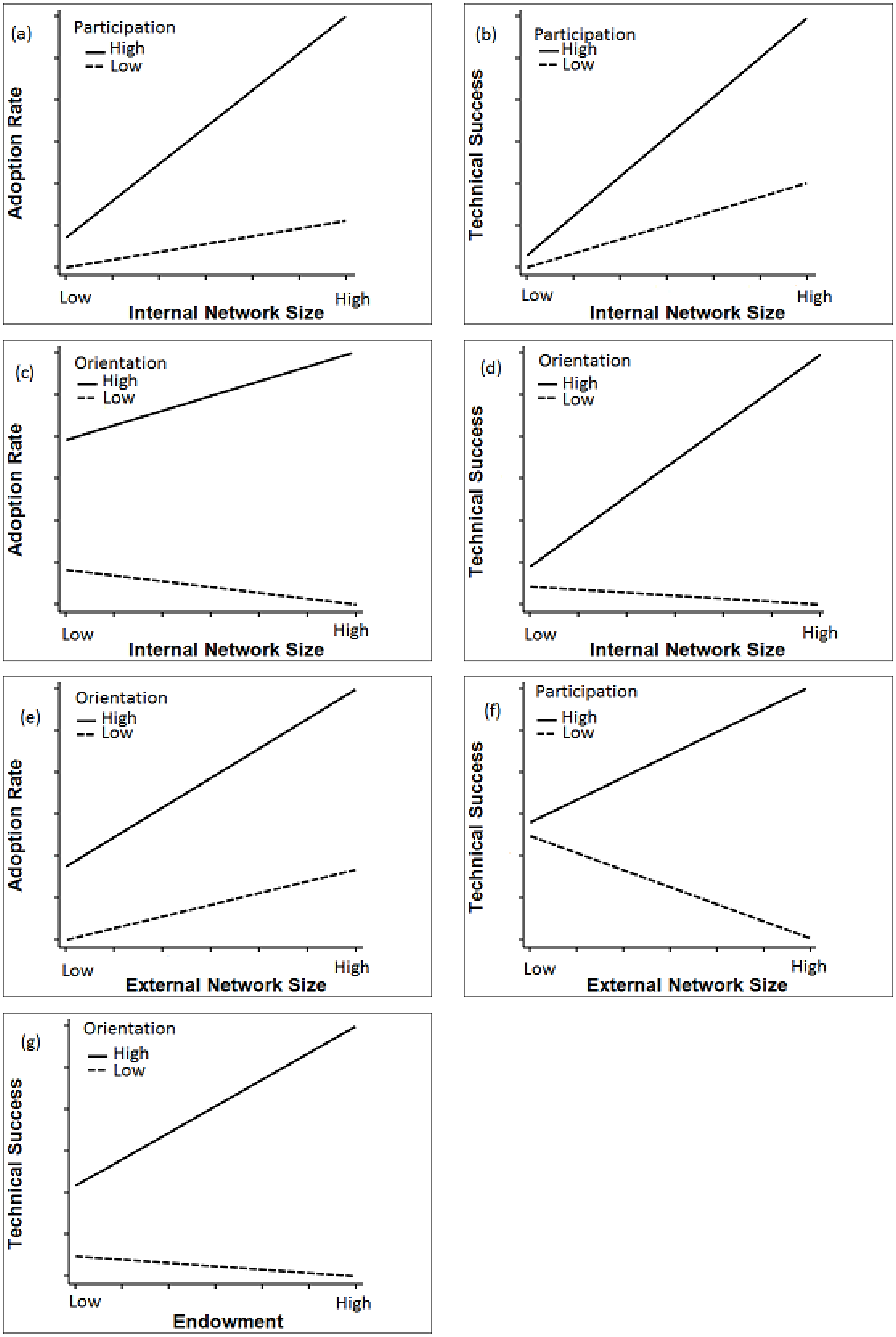

Figure 3: Plots of interaction effects