Returns from Social Capital in Open Source Software Networks.*

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Abstract

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1. Introduction.

Social capital is one of the more important concepts in contemporary sociological research. Over the past two decades, the academic literature on social capital extends to explain differential patterns of economic growth as well as differences in organizational performance. Scholars interpret social capital as a metaphor about the gains individuals or groups may obtain by belonging and interacting in social network structures. These gains are widely understood as a unique competitive advantage created by personal interrelations that affect both individuals and groups (Burt, 2000). In spite of the use of alternative definitions on social capital and its effects on other variables, the success of social capital theories relates to the conclusion that being connected is beneficial for individuals, groups, firms and the working of a variegated number of institutions. Moreover, those benefits are the return to investment strategies oriented to institutionalize group relations into a social network (Portes, 1998).

From the sociological perspective, social capital serves as a cohesion mechanism on which individuals rely for coordinated collective activity (Putnam, 1995). Social capital facilitates access to better conditions (Browning et al, 2006), from job (Yakubovich, 2005) to education (Coleman, 1988; Hargens, 2000) and health (Kawachi et al., 1997). Economists have studied social capital as one of the main drivers for economic growth (Knack and Keefer, 1997; Miguel et al. 2005). Academic work on strategic management focuses on social capital both at individual and organizational levels finding that being connected have a positive effect on organizational performance. Koka and Prescott (2002) find that if social capital represents the possibility of gathering information through strategic alliances, then its volume and diversity contribute to superior firm performance. Oh et al, (2004) analyze the positive effect of social capital on teamwork effectiveness as result of networks of friendship. The result is an increasing and dense body of literature that uses social capital as an independent variable to explain a wide range of social phenomena concluding that individuals or firms interacting within a network show a better performance than when they are alone.

However, there is not a common definition of social capital and its operationalization; social capital is a multidimensional construct. Coleman (1988) recognizes as first dimension the social structure and as second the actions agents take within the structure. Burt (1997) postulates social capital relies on connections that involve trust, obligation and exchange reciprocity. Portes (1998) considers a socio-relational dimension of social capital where agents get access to resources, and a stock dimension comprising the quantity and quality of those resources. Nahapiet and Ghoshal (1998) posit social capital is three-dimensional, there is a structure, a set

of relations, and a cognitive bound about the exchange produced through structure and relations. Thus, social capital entails the underlying structure for exchange, where relations among individuals create and support a common understanding that promotes the generation of a public good exploitable by all individuals within the structure.

The lack of theoretical consensus shifts the attention to the relevance of social structures as the foundations where investment, accumulation and exploitation of social capital occur. Social capital is rooted in social networks, and more specifically in ties among agents that exchange information and provide access to resources. The structural dimension of social capital leads to a major emphasis on the density of connections and the relevance of strong ties in closed networks (Coleman, 1988). Meanwhile Granovetter (1973) and Burt (1992) state for a sparse network, or a network through indirect relationships and gaps among agents, that facilitates social capital when referred to access to resources. Nevertheless, the direction of connections is the least studied feature; most contributions about social networks' influence on social capital have assumed that ties involve a ***reciprocal relation.*** Both agents at each end of the tie bring the same attention to the relation, in the form of resources or commitment; and that both can benefit equally from the relation. In contrast, settings where relations are asymmetrical are common, a couple of friends where one calls the other more often; a strategic alliance, where one of the parties brings a higher amount of resources, and so forth. Consequently, the creation of social capital and its further effects could not be the same as where ties are assumed strictly reciprocal. Therefore, asymmetrical relations within a social network could produce diverse outcomes for network actors.

This paper addresses the impact of asymmetrical patterns of exchange, as sources of social capital, on performance. We postulate that different ties among actors of a network compose a set of investments strategies shaping the stock of social capital available. We use ties between open source software (OSS) projects to identify such patterns of exchange. The analysis of interaction among projects becomes relevant as the emergence of OSS movement leads to the creation of repositories for software development. Repositories usually are internet-based sites that provide an organizational infrastructure to allow asynchronous exchanges among programmers, mobilize contribution of people otherwise hard to reach, and screen the contributions from redundant knowledge. A repository integrates a community that benefits from the exchange of knowledge among its members.

The suitability of OSS repositories to identify the structural dimension of social capital comes from the structure a repository provides through knowledge exchange. OSS programmers

interact by contributing their knowledge to own and others' projects but they do not necessarily receive the same amount or quality of contributions from other network actors: yet they generate expectations about others behaviour for giving up their knowledge. Therefore, it is interesting to analyze the knowledge flows throughout the community and their communication paths that sustain and reinforce social capital.

Through a panel data analysis of 2,962 software game projects we identify the structure of the network from the flows of knowledge and information among projects and through their *members* –or programmers belonging to the project, and *contributors* –those who engage in programming activities, and its effects on the overall performance of the project. Our analysis indicates that knowledge flows among projects are asymmetric as result of individual behaviour of both members and contributors. Moreover, we do not find evidence on reciprocity as contended by social capital proponents. We found that connections through contributors who bring their programming expertise inbound the project, besides being a source of new knowledge, improve project success. Additionally, our findings reveal that connections through members who sign up in other projects hinder the *focal* project success, unless they carry on programming activities transferring their knowledge towards other projects. Finally, we found that ties through shared membership and contribution hamper project success.

The present study contributes to social capital theory and its empirical analysis in several ways. First, we claim there are different individual strategies for investing in social capital, and these strategies come often in shape of asymmetric interactions within a given social (open) network. And, secondly, we support that social capital influences project's performance only if *contributors* provide new valuable knowledge whether inside or outside the *focal* project.

This paper presents our analysis as follows. First, we introduce the theoretical framework for a network-based approach to social capital. In section 3 we discussed the data and variables used, and in section 4 the main results are shown. Finally, we conclude by discussing the findings, its limitations and further research implications.

2. Networks as Sources of Social Capital: Theoretical Framework.

2.1. On the nature of social networks and social capital.

Research in sociology elucidates social capital as a concept that seems to explain, from a collective action perspective, a variety of social concerns like development of human capital, differential access to relevant positions and unevenly distributed resources in society (Bourdieu, 1983; Browning et al, 2006; Coleman, 1988; Hargens, 2000; Kawachi et al., 1997; Putnam,

1995; Yakubovich, 2005). Most sociological and political scientists refer to James S. Coleman' work on social capital who framed the term within the theory of rational action, where actors have control over their resources and act according to their own interest. Therefore, actors consider investing on social capital because such investment might yield a return. Social capital is a productive resource integrating a social structure with interactions among social actors. The outcome of social capital is the value that actors may obtain from the use of the resource for accomplishing their own interest (Coleman, 1988).

Research on social networks has an established and long tradition in other social disciplines (Burt, 1992; Granovetter, 1973; Larson, 1992; Powell, 1990; Zaheer and Bell, 2005; Zajac and Westphal, 1996) because of both interest in patterns of exchange and the important implications of networks in the spread of information and knowledge. Its empirical relevance relates to the *"new economic sociology"* and the role of networks as channels of information and resources (Koka and Prescott, 2002; Owen-Smith and Powell, 2004; Zaheer and Bell, 2005). Works in this domain emphasize social networks as the foundations for embeddedness, joint ventures and strategic alliances, board interlocks and more general group processes where it is possible to observe knowledge and information exchanges (Borgatti and Foster, 2003) [[1]]. Social capital is a *unique resource*, and consequently a potential source of competitive advantage, coming from interpersonal relationships, which affect both individuals and the group or organization they belong. Then, accessing to external information and resources through social networks is a critical source of social capital (Burt, 1992).

Social capital applies to describe both the aggregate form and nature of relationships among organizational members (Coleman 1990, Leana and Van Buren 1999), and the linkages between the organization and its external stakeholders, competitors, or partners (Dyer and Singh 1998, Koka and Prescott 2002, Uzzi 1997).

The social network for an organization comprises the network of interactions created inside and outside the organization itself. An important branch of Sociologists and organization theorists such as Coleman (1990) tend look inside organizations and examine the relationship among individual members or groups (Koka and Prescott, 2002; Hansen 1999, Tsai and Ghoshal 1998). The social network of groups namely, active connections among group members,

[1] In management and organization studies, social networks denote a heterogeneous number of cooperative forms that vary from informal ties (Granovetter, 1985; Uzzi, 1996 and 1997) to formal and contractual arrangements such as strategic alliances (Ahuja, 2000; Larson, 1992). Organization's relationships, ranging from informal to formal or contractual, as well as the number of ties, all indicate the positive effects of network membership on firm's performance (Koka and Prescott, 2002; Mehra et al., 2006; Zaheer and Bell, 2005; Zajac and Westphal, 1996) and innovative outputs (Ahuja, 2000; Sorenson et al., 2002). Hence, technological partnerships –networks- are accurate predictors of firms' innovation and learning rates (Kogut, 2000).

contributes to the achievement of actors' goals at lower costs that in its absence. In such context, social capital refers to specific broad cross cutting interpersonal connections among all group members within [closed] networks. Closure of social networks provides collective sanctions and effective norms. Moreover, social capital within organization generates better knowledge sharing and transfer due to established trust, common language, and goals, through both formal and informal ties (Nahapiet and Ghoshal, 1998). Hence, prior studies found that knowledge sharing positively relates to factors such as strong [intra-group] ties (Wellman and Wortley 1990), co-location (Allen 1977), demographic similarity (Pelled 1996), status similarity (Cohen and Zhou 1991), and a history of prior relationships (Krackhardt 1992).

For those scholars who look the organization's outer social network, it relies on different sources, such as corporate board interlocks to obtain funding for non profits organizations (Galaskiewicz and Burt, 1991); or exchanges among scientists for producing innovations (Sorenson et al, 2002) and strategic alliances and cooperative agreements for commercialization or innovation (Ahuja, 2000). Most of these studies consider the advantage of a sparse network for the exchange of non-redundant information that leads to superior performance. Their basic arguments carry out two main concepts in social networks: *weak ties* and *structural holes*. In his study about how individuals obtain a job, Granovetter's (1973) makes a distinction between *strong* and *weak ties*; it has been widely used to refer to alternative sources of social capital. Strong ties refer to an actor's close friends; meanwhile weak ties refer to an actor's acquaintances; while the information an actor can get from strong ties is homogeneous across all her friends, the information she can get from weak ties is more heterogeneous and powerful (Granovetter, 1973). On the other hand, Burt (1992) defined *structural holes* as bridges among unconnected actors, structural holes enhance actors' brokerage activities by exploiting the empty spaces between dense areas of social interactions; they are gaps between non-redundant sources of information that increase social capital by avoiding constraints product of common knowledge.

Although all these studies recognize there are knowledge and information flows, they do not address directly the direction of the flow. Perhaps for empirical simplicity, the main assumption is both actors connected through a tie bring the same amount and quality of resources to the relationship, and both can jointly benefit. However, the outcome if only one of the actors supplies knowledge to a relationship could be different. Information and resources actors supply to the relation and thus, the knowledge available to all individuals in the network adopt a public good nature, where some of actors would free ride from the social capital created

(Coleman, 1988). This is more interesting when ties are weak, because agents cannot easily exert any type of sanction for sole actors free-riding from social relationships; besides, possibly agents do not care about sanctioning, but about developing a future expectation on the relationship (Nahapiet and Ghoshal, 1998). Thus, we should not underestimate that nature and direction of relationships might shape social capital and therefore their impact on benefit for actors.

2.2. On the nature of OSS networks and social capital.

Open Source Software (OSS) movement recently receives enormous attention because OSS development process, products' commercialization, and diffusion differ dramatically from proprietary software solutions. Moreover, issues on OSS intellectual property rights regimes cannot be isolated from its own development processes, grounded on the voluntary basis of programmers' contributions (Lerner and Tirole, 2001 and 2002).

Individual programmers contribute to the development of core tasks, the debugging and improvement of programs until their completion for different reasons (Raymond, 1999) for different reasons. First, self-interested behaviour –programmers need the software and its improvements for their own purposes- and, alternatively, expectations from reciprocity (Baldwin and Clark, 2006; Bergquist and Ljungberg, 2001; DiBona et al., 1999; Kollock, 1999). Second, reputation, and associated rents gained by those who make high quality contributions (Lakhani and Wolf, 2002). Third, philanthropic behaviour linked to the enjoyment of the contribution itself (Raymond, 1999).

Social capital also applies to give some answers about individual motivations to contribute; programmers consider useful to maintain the social network alive and nurture the relation by providing their knowledge. This assertion is consistent to Nahapiet and Ghoshal (1998), who postulate that the relational dimension of social capital induces actors to formulate an expectation on the value of the resources they supply to the structure [2].

The OSS movement gains prominence as projects, independently of their domain and scale, organize accordingly to the principles of a community of practice: open and self-organizing [electronic] networks in which values, norms and beliefs shared by software developers rest upon *generalized exchange* mechanisms. Those mechanisms consist on providing resources to the community through giving them to a focal actor, and not expecting

[2] Nahapiet and Ghoshal (1998) identify three social capital's dimensions that inhere in knowledge exchange and recombination: (1) structural, that reflects the impersonal pattern of ties; (2) relational, as a sense of trust, norms, obligations and expectations that actors develop along connections; and (3) cognitive, as the bonding force, such as shared understanding and identification that hold the group together. These three aspects of social capital mingle to improve information transmission and absorption among organizational members, thus enhancing overall organizational performance.

she will return the favour, but other actors belonging to the community will give you in return (Takahashi, 2000). Consequently, social scholars' focus on the mechanisms and foundations underlying the network formation since it represents a valuable setting for conducting research on basic aspects of the social organization, such as cooperation, and the emergence of open networks as enduring forms of governance (Lakhani and Von Hippel, 2003).

The aim of research on OSS has been to provide robust explanations to why individuals participate in generalized exchange systems characterized by unilateral resource giving (Lakhani and Von Hippel, 2003). [[3]] The study of generalized exchange within a wide number of social settings points out the presence of *[fixed] network structures* (closed) as well as the implementation of monitoring mechanisms on individuals' behaviour (Takahashi, 2000). In *non-fixed networks* (open), as those within OSS, *pure generalized exchange* might emerge where the collective sense of fairness allows for unilateral giving while preventing from free riding behaviour (Ekeh, 1974), and whenever gift givers may choose the recipients ("fairness-based selective giving"). However, Takahashi (2000) states that *"the fairness-based selective strategy is characterized by actors endowed with options for leaving the current relation and forming a new relation […] but it cannot really explain generalized exchange patterns when actors are strangers";* thus the OSS network challenges some of the established requirements emphasized by previous literature. First, cooperation takes place among a large, heterogeneous and ever changing number of individuals. This implies, OSS is by definition an open and flexible network [[4]]; where, typically, participants are strangers and, there are no long-term commitments. Second, membership relies on self-selection and, consequently, it downwards expectations on contributions, both at the level of individual programmers that should reciprocate and their reciprocation quality. Even in these tough conditions, they manage to work together over time in the building of complex and sophisticated software "artifacts". Moreover, without active contribution and participation collaborative knowledge will not succeed.

Alternatively, generalized reciprocity, from a social capital perspective, reflects a collective norm as product of social interaction (Putnam, 1995). Similarly, Nahapiet and Ghoshal (1998) argue that reciprocity, shared norms and values, mutual trust and identification with the community are the four critical components of the relational dimension of social capital.

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[3] Unilateral resource giving within social and economic exchanges may emerge because of: (1) pure altruistic behaviour; (2) collective norms that punish any form of free riding, and (3) rational choice under game theoretic frameworks in which predominates the existence of incentive structures to solve social dilemmas (Olson, 1965)

[4] Programmers are geographically distant; they come from different cultures, languages, traditions and differ in personal, professional and social features.

Previous studies about OSS relate social capital to the intrinsic nature of the movement. Meanwhile, studies about big OSS projects such as Linux and Apache support the presence of this background idea of social capital (Bergquist and Ljunberg, 2001; McKelvey, 2001); as big projects nurture themselves from individual contributions, thus the overall effect comes straight forward as soon as they capture new contributors. More recently, Long (2006) support the positive influence of social capital as measured by density of ties on collective activity and productivity. When referring to OSS networks, Zhang (2007) identifies previous ties among a group of programmers as a powerful predictor of further members' affiliation to specific projects. Consequently, the existence and density of prior ties, between the initiator of the project and developers positively influences the probability of a project to attract more individuals. All these studies support the influence of social capital on performance from a perspective of closed networks, meaning the there is reciprocity.

However, there is empirical evidence to suggest that the nature of ties explains additional variance in outcomes beyond that explained by structure alone (Lin 1999). Social capital is not just the network itself, nor the links among people that comprise it, but the resources created by the existence and character of those links.

Based on previous revision of the literature and the state of the art, this paper analyzes the effects of a heterogeneous set of ties on projects performance. The basic idea underlying this paper is close to Burt's (1997) hypothesis on structural holes "*new ideas emerge from selection and synthesis across structural holes*"; and Granovetter's (1973) hypothesis on weak ties "*whatever is to be diffused can reach a larger number of people, and traverse greater social distance when passed through weak ties rather than strong [ties]"*. Consequently, the research questions addressed are: (1) *Does a focal project that receives knowledge from other actors improves its performance? (2) Are these effects comparable to those obtain from giving knowledge to other actors? And (3) what are the effects on performance of a focal project where its members engage in generalized reciprocity towards other projects?*

3. Data and Analysis.

3.1. Data setting.

The data we use in this analysis come from the SourceForge.net Research Data (Department of Computer Science and Engineering, University of Notre Dame). SourceForge.net is the largest repository of open source software; it hosts over 140,000 projects and gathers over 1.5 million of registered users. SourceForge.net belongs to OSTG, Inc, who has

shared activity data with the University of Notre Dame for the purpose of academic research on OSS, under the condition to share further the data to other researchers interested in open source software phenomenon (Christley and Madey, 2005).

Sourceforge.net as a repository has several characteristics that promote network exchanges. The purpose of repository is to provide a platform for software development over a worldwide web infrastructure for knowledge exchange. They host projects and provide tools that allow asynchronous communication, stock people's contribution, and screen software from redundant knowledge. To host a project, an initiator should register on the network; and post a message to the platform indicating the type of software, its purpose and target public, the intellectual property regime, the programming language, the user interface, the phase of development and the team workforce who will be responsible for developing and controlling the software. Then Sourceforge.net administrators authorize the creation of a space for hosting the project, if it satisfies the main premises for the repository. Once the repository hosts the project, then it registers and controls all its activity. Every time there is a movement on the project, the repository electronically archives the information; these movements may include communications among members, forum posts, and more important, the *artifacts* –or modules of software code, produced by the people engaged in programming activities. As an important feature of a repository is to open the access to projects to everybody on the worldwide web, every single person, registered or not on Sourceforge.net, may see the project, look at the code, and contribute. For the purpose of this study, we label the team workforce appointed by the project initiator as *members* of the project; these members of the project may perform different roles, from project administrator to language translator. We denote all persons who contribute to software development as *contributors*. We should notice that not all *members* of the project are *contributors* and that not all *contributors* are *members* of the project. Another important feature of the repository is that it records changes in the team workforce, so it is possible to know if there are new members or if some of them have quitted the project. As repository tracks all artifacts records we can identify who are contributors and who are just members of the project. Moreover, we can identify if an individual who is member of a particular project is simultaneously member of another project. Hence, the social network for knowledge exchange comprises four pure forms of ties among projects[5]: "member"-"member", "contributor-member", "member"-"contributor", "contributor-contributor"; and five mixed forms of ties

[5] Woolcock (1998) classified ties as bridging, bonding, and linking social capital. Bridging refers to relations between more distant and heterogeneous members; bonding indicates higher levels of homogeneity, while linking relates to the capability to leverage resources and information beyond the community.

among projects: "member/contributor"-"member", "member/contributor"-contributor; "member/contributor"-"member/contributor", "member"-"member/contributor" and "contributor-"member/contributor".

Particularly, our dataset is a sub-sample of 2,962 valid observations over twelve months of projects aimed at developing games' software. To get this sample, we look at the monthly dumps of data and select all projects that belong to the category of GNU Public License (GPL) [6]. We restrict the sample to such license to guarantee that projects were not subject to any restriction for copy, adoption and distribution, so all software is equally prone to reach the same audience. Then, we limit the sample to games in a general category. This selection obeys to the purpose of tapping an appropriate measure of project performance. Although performance measures will be discussed below, we should advance we are interested in measuring performance as *market penetration of software*; thus, we should pick a category of projects whose target markets were not constrained by the programming skills and abilities of end users. Further, we restrict the sample for the projects that were alive during the whole sample, we make this decision because dataset classifies a project as "alive" –when the repository still host the project, and "dead" when they quit the repository. Unfortunately, it is impossibly to distinguish if the project has quitted the repository because it went independently, or moved to other repository, or just ended; thus, their disappearance does not necessarily relate to market demands, or product lifecycles, but to managerial premises. Finally, we look at those projects whose information on downloading activity is available, as the source of information comes from relational database, some observations could be missing in the joining process. We follow this procedure over twelve months running from February 2005 to January 2006, to build an unbalanced panel with 25,722 total observations.

To answer the research questions we chose "projects" as unit of analysis. Our concern is the effect of asymmetrical relationships on project's performance. The organizational structure of OSS projects resembles the organizational structure of a small enterprise, they have leaders and subordinates, they show labour division, they pursue a common goal, and they produce a tangible product. We also need a unit of analysis that reflects a common stock of knowledge. Software projects in general and OSS projects in particular, exhibit at least two properties: (1) they have a modular architecture and (2) outcomes may vary along the design process allowing the introduction of new modules and creating an option value for development. These two properties suggest projects themselves become a stock of social capital supplied by members and

[6] GPL grants the programmers and users of software the privileges on freedom to distribute and modify copies of the software, and transfers those privileges to further developments.

contributors. This unit of analysis is consistent with Ahuja (2000) and Larson (1992), when analyzing strategic alliances between firms.

3.2 Variables and analysis.

Dependent Variable. Performance.

We present *performance* as dependent variable, for that we use number of downloads as a measure of project performance. A download means one user retrieves the executable files of the software for her private use; thus downloads is an output measure of success or popularity along a mass of users. Number of downloads is consistent with the nature of a software game as a digital good through Internet, because downloading is the sole way to access it; besides, it is a common measure of performance in OSS (Crowston et al, 2003).

Independent Variable. Social network as a source of social capital.

Social capital measures are largely heterogeneous within academic literature, thus they vary as they refer to different social capital perspectives [7].In this paper our measure of social capital lies on knowledge flows and refers to the sum of [complementary] resources attainable through a social network that include both unidirectional and bidirectional relations. In our analysis, we test whether asymmetries in knowledge flows in the social network of projects generate different outcomes in terms of projects' performance.

Here we measure ties among projects through the individuals' member and contributor roles at projects on the network over time. The presence of such ties indicates knowledge flows that enhance performance of the focal project. Our research setting is consistent to Granovetter (1973) proposition about "*weak ties are more likely to link members of different small groups than are strong ones, which tend to be concentrated within particular groups"*. This perspective is also similar to much of previous research on strategic alliances and business partnerships and innovation performance (Ahuja, 2000; Kogut, 2000).

We focus on binary relationships since they represent ties between pairs of projects linked through at least one of their members or contributors; if projects share more than one member or a contributor we count just one tie. Accounting for sharing one or more members as just one tie reduce redundancy because we want to measure a transfer of knowledge; this

[5] For example, in the Putnam's tradition, social capital measures membership to voluntary organizations as an indicator of networks together with norms and social trust (Putnam, 1995; Tsai and Goshal, 1998). In a Granovetter's and Burt's tradition, social capital measures to some extent the information flows through exchanges among partners (Glaeser et al, 2000; Koka and Prescott 2002; Oh et al, 2004).

practice helps also to diminish a plausible effect of excess downloading just for having more members involved in both projects. For example, if the number of individual programmers from project ***A*** contributing to project ***B*** is three, it counts as one tie between projects ***A*** and ***B***. Thus, our measure for ties represents a linkage between the focal project and any other project within the SourceForge.net.

However, the important feature we want to test is the direction of the tie and the asymmetry in the knowledge flows. We distinguish between those ties that provide *inbound* knowledge –or ties through individuals who play the "contributor" or "member/contributor" role in the focal project, from those ties who give *outbound* knowledge to other projects –or ties through individuals who play the "contributor" or "member/contributor" role in other projects. Besides, we observe the sources of shared knowledge both inbound and outbound and separate them from strictly unidirectional knowledge flows. All categories of ties measure knowledge flows from the focal project's point of view, therefore, although above we define nine forms of ties we can group those that represent the same tie in terms of knowledge flow for the focal project. The independent variables include:

(1) *Shared-inbound* ties: It measures ties from individuals that simultaneously are members and contributors in a focal project and are members in another. They indicate all focal project non-redundant ties through the form of "member/contributor"-"member" ties.

(2) *Shared-outbound* ties: It measures ties from individuals that simultaneously are members and contributors in a focal project but contributors in another. They indicate all focal project non-redundant ties through the form of "member/contributor"-"contributor".

(3) *Active-inbound* ties: We consider ties from individuals that contribute to a focal project, not being members, and actively contribute to other projects. They measure all focal project non-redundant ties through the forms "contributor"-"contributor" and "contributor"-"member/contributor".

(4) *Active-outbound* ties*:* We consider ties from individuals members of the focal project that actively contribute to other projects. They measure all focal project non-redundant ties through the forms "member"-"contributor" and "member"-"member/contributor".

(5) *Inactive-inbound* ties: It measures ties from contributors to focal projects that are members in other projects. They measure all focal project non-redundant ties through the form "contributor"-"member".

(6) *Inactive-outbound* ties: It measures ties from individuals that are members in both focal and other projects. They measure all focal project non-redundant ties through the form "member"-"member".

Control variables

(1) *Project SIZE:* Number of members of focal project.

(2) *AGE:* Age of the project in days.

(3) *STAGE:* OSS projects included in our database are at different stages of development, going from planning, pre-alpha, alpha, beta, production, mature and inactive. The status of the project and its ability to attract programmers, and therefore the number of ties and contributions from outside, are strongly associated. At its first stage, the core process is the creation of an initial system that will evolve over time. At last stages, the core process is the diffusion of the product. Thus, we controlled for the evolution as the project may require different knowledge along its stages.

(4) *Characteristics*: We controlled for characteristics such as programming language, operating system, user interface, intended audience, and speaking language of the game.

In order to test our hypotheses on a dynamic approach, we use a differences-in-differences fixed effects estimator; it is taking differences in both dependent and independent variables in a monthly basis. Therefore, we condition a variation in performance at month $t+1$ respect to month t, to a variation on ties at month $t+1$ respect to month t, controlling for project's fixed effects over the period of study. We want to measure how a variation on a pattern of knowledge flows influences the monthly rate of downloading. The use of this type of regression method obeys to our intention of testing how differential rates of social capital investment strategies condition organizational performance –in our setting project performance.

	Variable	Expected effects
Dependent:	*Performance*	
Independent		
	Active-Inbound	(+)
	Inactive-Inbound	(+)
	Active-Outbound	(-)
	Inactive-Outbound	(-)
	Shared-Inbound	(-)
	Shared-Outbound	(-)
Controls	*Size*	(+)
	Age	(-)
	Stage	(-)

Table 1. Measures and expected effects

4. RESULTS

Table 2 reports basic descriptive statistics for the dependent and independent variables. Table 3 reports the results from differences-in-differences fixed effects on downloads. We conduced our empirical analysis aggregating ties at different levels of the possible "member" and "contribution" combinations. Here we show two basic regressions; Model 1 presents the base model with controls. The control variables do not significantly explain variation in rates of downloads by themselves. Model 2 contains all our measures for ties as explanatory variables. We obtain that *shared-inbound* ties have a negative and significant effect on performance. It indicates there is no such benefit in overall performance from having individuals who simultaneously play the "member"-"contributor" role in the focal project while they play only the "member" role on other projects. This particular result is consistent to our hypothesis. The results also show that *active-inbound* ties have a positive and significant effect on the rate of downloads. It means there is a benefit from receiving assistance from individuals who play the role "contributor" role in focal project while they also contribute in others. This result is also consistent to our hypothesis.

Variation in:	Mean	Std. Dev.	Min	Max.
Downloads	20.819	5004.585	-468651.500	463422.500
Share-inbound	0.002	0.157	-3.089	15.547
Active-inbound	0.005	0.095	-3.995	7.277
Inactive-inbound	0.010	0.209	-8.444	14.738
Shared-outbound	0.004	0.073	-1.178	5.458
Active-outbound	0.003	0.063	-3.270	3.003
Inactive-outbound	0.000	0.000	0.000	0.000
Size	0.007	0.175	-8.618	10.279

Table 2 Basic descriptive statistics

In Model 2, we observe *inactive-inbound* ties have a positive effect, meaning that focal project benefits from those "contributors" if they are just "members" in other projects. Meanwhile, *shared-outbound* ties a significant and strong negative effect on rate of downloads, it may mean that individuals that play the "member/contributor" role on focal project while they contribute to other projects distract resources and attention to focal project. These results confirm our hypothesis on shared knowledge inbound and outbound the focal project. The *active-outbound* ties show a surprising positive and significant effect; it means the focal project benefits from individuals who play the "member" role while they are "contributors" outside. Despite this result contradicts the theory and our expectations it may imply that those individuals attract the attention of other individuals because they create a good reputation on other projects. We should notice that an *active-outbound* tie for focal project means an *inactive-inbound* for other projects that we show they are beneficial too. The *inactive-outbound* ties dropped out from our regression, as this variable does not show variation over time. It means there is a fixed load of individuals who consistently do not contribute to any project.

Dependent variable: *Performance*	(1)		(2)	
Share-inbound			-795.161	***
			0.000	
Active-inbound			3309.617	***
			0.000	
Inactive-inbound			536.851	***
			0.002	
Shared-outbound			-1388.266	***
			0.002	
Active-outbound			2114.120	***
			0.000	
Inactive-outbound			-	
Size	227.829		61.482	
	0.329		0.767	
AGE	-29.841		48.125	
	0.663		0.425	
STAGE	-5224.484		-6018.581	
	0.035	**	0.005	***
controls included				
F	0.40		10.810	
P>F	0.976		0.000	
** significant at 5%	*** significant at 1%			

Table 3 Results from differences-in-differences fixed effects regressions.

5. Discussion and Implications for Future Research.

Social capital, generally defined as the actual and potential resources embedded in relationships among actors, is an important predictor of group and organizational performance (Adler and Kwon, 2002; Bourdieu, 1986; Leana and Van Buren, 1999; Nahapiet and Ghoshal, 1998). The structural dimension of social capital focuses on the nature and strength of relationships, and the communication flows in which individuals and organizations are embedded. The advantages ascribed to social capital include better group communication, more efficient collective action, enhanced stocks and use of intellectual capital, and better access to resources.

The structural dimension of social capital also reveals that it cannot be detached from social networks. Thus, a network of OSS projects is a fertile ground to test and support the sources of social capital. Contributions to projects are the sole mean to development and success, but their patterns differ widely across OSS projects; some projects attract a large number of contributors while others do not. There are projects in which most of the advances come from

the voluntary contributions of their own members, while others rely on contributions from actors initially assigned to other projects. Then, an asymmetric network structure is likely to emerge. Ties between OSS projects represent the network structure, and therefore they are able to indicate differential levels of social capital.

We identified social capital in the terms of the social network of OSS as the number of ties generated through members and contributors and the role they play by solving programming gaps in both focal and other projects.

In this research, the straightforward outcome is empirical evidence concerning the sources of social capital and its uneven distribution throughout the network, by identifying paths of communication across different projects. Moreover, we provide theoretical counterarguments to a social capital theory where underlies the main assumption about reciprocity as a condition for social capital, and provide empirical support that explains asymmetries play an important role if the purpose is to improve knowledge base and performance. Explicitly, we find that redundant ties representing resources of information not only do not contribute to performance but hamper it. We also find that knowledge and skills received through inbound ties lead to superior performance, whereas providing knowledge and skills to other projects is beneficial to own performance, only if individuals play an active role as contributors in other projects beyond pure membership.

The core of our contribution relies on the measurement and identification of asymmetric paths for the exchange of knowledge. Traditional social capital studies only look at the total number of ties an individual or organization has, regardless of the direction of knowledge flows. As our own results show, this measurement supports the generalized reciprocity exchange theory, therefore, on the aim of finding significant sources of social capital, it emerges the necessity for accounting differences in investment strategies or knowledge exchanges that complement the stock of capital.

However, one of the main limitations of the present study is we do not measure the quality of the exchange, but only its direction. While we know inbound ties provide new knowledge and improve performance, we do not know anything about the quality of that knowledge. Thus, a project may need to tie to a broad collection of projects because of the poor quality of inbound contributions. Equally, in the case of outbound knowledge, we could assume the contributions of project members make them visible to the network, but we do not know how valuable their contribution is for others. Neither do we account for modularity of the project; a

project with plenty of modules is more attractive to programmers because they clearly identify tasks and goals (Baldwin and Clark, 2006).

Another drawback relies on our lack for linking the different roles played by contributors and the type of ties they create. We claimed the presence of skills' complementarities [that should be positively associated to project performance] in networks of cooperation across OSS projects; nevertheless, we do not measure complementarities but assume they occur through ties. Different participants perform different roles that facilitate the rapid change and creation of stable releases, including testing, contributing new changes, coordinating releases, and maintaining documentation. An important aspect of the collaborative approach is to help individuals to find tasks in which they can better apply and exploit their talents. Moreover, self-selection and voluntary participation help projects to reach the required level of complementary skills, which we were unable to include in our analysis.

We foresee a promising vein on research about social capital and OSS networks, as they show a symbiotic environment. Research on social capital will nurture from findings derived from the study of open source software networks; meanwhile our understanding of open source software phenomenon enriches with a deep consciousness on the exchange processes for the creation of a valuable stock of social capital.

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