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Absorbing knowledge from unconventional sources. How collaborations with the Open Source community shape the innovation performance of entrepreneurial ventures

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Abstract

Practitioners generally assert that collaboration with the Open Source software (OSS) community enables young software firms to achieve superior innovation performance. Nonetheless, to the best of our knowledge, scholars have never extensively speculated about this assertion or rigorously tested it. In this paper, we attempt to do so. First, we root on the entrepreneurship literature and on the OSS research stream to discuss and empirically investigate whether entrepreneurial ventures collaborating with the OSS community (OSS EVs) achieve innovation performance superior to that of their non-collaborating peers. Then, we refer to the concept of absorptive capacity to determine which factors make OSS EVs better able to leverage their collaboration with the OSS community for innovation purposes.

Our econometric estimates use a sample of 230 firms and indicate that OSS EVs collaborating with the OSS community achieve superior innovation. At the same time, the impact of community collaborations on innovation is stronger for EVs that are endowed with more skilled human capital, have experience with firm-OSS community collaboration, and actively contribute to the community.

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1. Introduction

Communities of users and developers are becoming increasingly important sources of scientific and technological knowledge (Hargrave and Van de Ven, 2006). More and more firms use community-produced knowledge and technological artifacts as inputs in their innovation processes. A particularly intense and vibrant web of collaborations links the community of users and programmers that develops Open Source software (hereafter, OSS community) and the firms that operate in the software sector. The OSS community has taken up the fight for *software freedom* as an ideological battle (Stallman, 1984) and has acquired progressively greater economic importance (Fitzgerald, 2006). Nowadays, many entrepreneurial ventures[1] (EVs) collaborate with the OSS community (Dahlander, 2007). OSS EVs market products and services based on the open code and knowledge made freely available by the thousands of OSS programmers who participate in OSS software projects.[2] A survey of Italian software firms (ELISS I survey, see Bonaccorsi and Rossi, 2004 for further details) analyzes the motivations driving firm-OSS community collaborations. The top-ranking motive selected by the 146 respondents was that *collaborating with the OSS community allows even young and small firms to be innovative* (Rossi and Bonaccorsi, 2006). This result was confirmed by a second wave of the survey (ELISS II, see Bonaccorsi et al., 2005 for further details) of around 900 European software firms. Moreover, a great deal of anecdotal and case study evidence indicates a positive relationship between firm-OSS community collaborations and EV innovation performance (see e.g., Benussi, 2006).

Although the owner-managers of OSS EVs generally assert that community collaboration enhances firms' innovation performance, scholars have not investigated this assertion to the best of our knowledge. In this paper, we seek to do exactly that. First, we discuss and empirically

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[1] We define *entrepreneurial ventures* (EVs) as *young* and *independent* firms established to commercialize novel ideas developed by their founders (Hart, 2003). Although many EVs are small, EVs are not the same of small firms. Following the Schumpeterian view, we claim that the distinguishing elements of EVs are novelty and dynamism.
[2] An OSS project is "any group of people developing software and providing their results to the public under an Open Source license" (Evers, 2000). OSS projects are generally made available online in so-called repositories. Repositories are dedicated web sites that also provide an environment for software development and interaction between programmers.

investigate the impact of firm-OSS community collaborations on the innovation performance of software EVs. In so doing, we integrate insights from the entrepreneurship literature with ideas from the research stream analyzing the economic and managerial aspects of OSS. Then, we rely on the concept of *absorptive capacity* to determine which factors make OSS EVs better able to leverage community collaborations for innovation purposes. Specifically, we address two research questions*: (i) Do EVs collaborating with the OSS community achieve innovation performance superior to that of their non-collaborating peers*? *(ii) Which factors make OSS EVs better able to absorb the knowledge produced by the OSS community and thus achieve superior innovation performance?*

In the empirical section of the paper, we answer these questions by estimating both Logit cross-sectional data models and Poisson panel data models using a unique dataset. The dataset contains detailed information on firm-OSS community collaborations and innovation activities that took place at a sample of 230 EVs from 2005 to 2008.

The contribution of this paper to the literature is fourfold. First, it contributes to the discourse on how entrepreneurs are affected by community contexts. By addressing the impact of EVs-OSS community collaborations on innovation, we provide rigorous evidence of the role of *unconventional partnerships* (O'Mahony and Bechky, 2008) as sources of sustained competitive advantage for young firms. The literature on young ventures in high-tech sectors indicates that these firms frequently enlarge and complement their knowledge base through technological partnerships (Colombo, 2003; Hamel, 1991; Loasby, 1998). Collaborating with communities of users and developers is a low cost alternative to in-sourcing valuable innovation inputs. Secondly, this paper uses a well-established construct in the field of economics and management: *absorptive capacity*. It thus heeds the call to establish closer links between the literature investigating the OSS phenomenon and the mainstream concepts in management and economics (Dalle et al., 2007). Thirdly, this paper analyzes community collaborations by explicitly emphasizing the specific qualities of EVs. In so doing, it contributes to the literature on OSS entrepreneurship, which

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remains underdeveloped. The puzzling issue of firms' involvement in the OSS arena has given rise to a flourishing strand of research (von Krogh et al., 2009). However, scholars' efforts have rarely been informed by the entrepreneurship discourse (see e.g., Gruber and Henkel, 2006 for one exception). Finally, this paper contributes to the innovation literature by providing evidence of the innovative results of firm-community collaborations. Few academic studies have addressed innovation in the OSS realm (see Rossi-Lamastra, 2009 for a review of this literature), and none has explicitly focused on EVs. Rossi-Lamastra (2009) has compared the innovativeness of OSS and proprietary solutions produced by small Italian firms collaborating with the OSS community. However, the author refers to the *software solution* and not to the *firm* as the unit of analysis. Stam (2009) has analyzed the effects of participation in OSS projects on firms' innovation performance. However, the author has neither explicitly considered the particularities of EVs nor compared the innovation performance of collaborating and non-collaborating firms. Our paper adds to this latter line of research.

The paper proceeds as follows. In section 2, we present our conceptual framework and theoretical hypotheses. Section 3 illustrates the dataset and describes the sample used in the empirical analysis. In section 4, we specify the econometric models and describe the variables that they include. Section 5 summarizes the results of the econometric estimates. Section 6 synthesizes the main findings, acknowledges the limitations of the study, and indicates directions for further research.

2. Conceptual background and research hypotheses

Nowadays, the vast majority of firms develops innovations by relying on both internal R&D and knowledge generated outside firm boundaries (Chesbrough, 2003; Laursen and Salter, 2006). EVs in high-tech sectors are not an exception. They typically acquire innovation inputs and complementary assets through licensing (Gans et al., 2002), alliances with other companies (Colombo et al., 2006; Soh, 2003), collaborations with universities and research centers (Wang and

Shapira, 2009), and mergers and acquisitions. Recently, EVs have begun to source external knowledge through collaborations with communities of users and developers. In particular, a growing number of EVs collaborate with the OSS community (hereafter, *OSS EVs*) and take advantage of the OSS code that is freely available on the Web in developing their software solutions (Bonaccorsi et al., 2006; Dahlander, 2007; Dahlander and Magnusson, 2005; Dahlander, 2008; Gruber and Henkel, 2006)

The entrepreneurship literature often describes EVs as starting at a disadvantage in the innovation race (Parker, 2005, p. 301). We argue that firm-OSS community collaborations help EVs to overcome the obstacles that hinder them from innovating thus facilitating superior innovation performance.

First, EVs suffer from financial constraints (Carpenter and Petersen, 2002; Hall, 2000) that have a detrimental effect on innovation. EVs have limited internal liquidity to invest in R&D. Moreover, EVs fail to attract external capital for their innovation projects because it is difficult for young firms to signal their quality (Stuart et al., 1999). Collaboration with the OSS community may make up for EVs' lack of financial resources. The OSS community indeed offers a common pool of code and knowledge that everyone can access at (almost) no cost (Bonaccorsi and Rossi, 2004). These freely available external resources can be used by EVs as inputs for developing new products and services. All else being equal, this is likely to result in superior innovation performance by EVs.[3] Moreover, the availability of free inputs reduces the costs of EVs' daily operations. For instance, EVs collaborating with the OSS community pay no license fees (Lerner and Tirole, 2005) for the OSS programs used in the software production process. In other words, firm-community collaborations generate *pecuniary externalities*, thus freeing up resources to be diverted to innovation activities (see e.g., Antonelli, 1995 for a similar argument). Finally, since the entrance into the OSS arena of

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[3] It is worth noting that scholars and practitioners have often presented OSS solutions as more reliable than their proprietary equivalents (Wheeler, 2007). Although evidence of the superior performance of OSS software is rather controversial, the accessibility of OSS code and its decentralized production clearly have a positive effect on the software production process (Raymond, 2001).

large players in the software sector (e.g., IBM and Sun), OSS has favorably impressed practitioners and venture capitalists (Feller and Fitzgeral, 2002; Alexy, 2008). By developing valuable OSS solutions, EVs can signal their quality, thus encouraging external donors to finance their innovation projects. This signaling effect is made more effective by the openness of the OSS code, which everybody can inspect to assess its quality (Lerner and Tirole, 2005).

Secondly, EVs frequently lack the resources and competences needed to *internally* develop the complementary assets that they require to profit from innovation (Teece, 1986; see also Colombo et al., 2006 for a discussion of the role of complementary assets for young ventures). OSS EVs can easily access the many *external* complementary assets available from the OSS community (Dahlander and Wallin, 2006). These firms do not have to develop from scratch or license from other firms the software packages that complement their innovative focal solutions. Indeed, they can pick applications that complement their innovation projects from the OSS common pool. Moreover, the OSS community is a low-cost channel for distributing and marketing software programs (West and O'Mahony, 2006). OSS EVs can take advantage of the OSS distribution infrastructure based on online software repositories and dedicated Web sites, which may potentially enable firms to reach a very large customer base.

Finally, collaborations with the OSS community may enable EVs to successfully complement the skills of their owners-managers and key employees. These skills constitute the source of EVs' distinctive capabilities (Alvarez and Busenitz, 2001; Cooper et al., 1994). However, in the current competitive environment, which is uncertain and turbulent, internal skills may not be sufficient to nourish the flow of innovation that assures EVs' survival (Geroski et al., 2009) and growth (Colombo and Grilli, 2005). OSS EVs have the chance to complement the skills of their owner-managers and employees by talent-scouting brilliant OSS programmers (Eilhard, 2008; Henkel, 2009) whom they can recruit to develop innovative software solutions. Hence, firm-community collaborations are an effective way for EVs to fill the *competence gap* (Colombo and Piva, 2008) they suffer from.

Based on the previous discussion, we argue that collaborations with the OSS community reduce EVs' disadvantages in the race for innovation, thus resulting in superior innovation performance. Hypothesis H1 follows.

H1. OSS EVs achieve better innovation performance than their non-collaborating peers.

To proficiently leverage the OSS community for innovation purposes, EVs must skillfully navigate the OSS common pool to identify valuable knowledge to be used in their innovation processes. Then, the external knowledge *acquired* from the OSS community must be *assimilated* and *transformed* so that it can be *exploited* (Zahra and George, 2002, p. 190). In other words, OSS EVs must develop an OSS community-specific *absorptive capacity* (*OSS absorptive capacity*). We posit that *OSS absorptive capacity* has both *firm-level* and *interorganizational-level* antecedents (Volberda et al., 2010). That is to say, it depends not only on EVs' characteristics, but also on the way in which EVs interact with this particular external source.

Since the seminal contribution of Cohen and Levhintal (1990), the literature has indicated internal knowledge and experience to be relevant firm-level antecedents of absorptive capacity (Lane and Lubatkin, 1998). Mainstream research has mainly equated internal knowledge with R&D investments (Lane et al., 2006). As we aim to conceptualize absorptive capacity in the EV context, we depart from this approach. Due to their young age and small size, EVs feature a low-complexity form of organization (Spencer and Kirchoff, 2006) that often does not include a separate R&D function. Moreover, as previously argued, EVs' distinctive capabilities are embedded in their key employees. Hence, the EV knowledge base is not accumulated through structured R&D investments but rather coincides with the human capital of the firm staff. Educated and experienced individuals are undoubtedly better able to value, assimilate, and apply new knowledge.

Based on the above arguments, we conclude that the absorptive capacity of an EV with regard to OSS resources increases with the human capital of its staff and that this results in better innovation performance. We thereby formulate hypothesis H2.

H2. All else being equal, the innovation performance of an OSS EV increases with its human capital.

Moreover, Cohen and Levinthal (1990, p. 136) suggest that to facilitate the absorption of external knowledge, a firm's prior knowledge must be *basic*. This means that internal knowledge allows the absorbing firm to understand the main principles upon which the external knowledge is based. To put it simply, individuals employed as software programmers are in a better position than other employees to evaluate the software code and knowledge produced by the OSS community. These employees serve as gatekeepers who span the boundaries between EVs and the OSS community (Volberda, 1996), allowing for a proficient in-source of the external knowledge used in EV innovation processes. Hence, we state that such absorptive capacity is greater when the firm has hired more software programmers. Once again, greater absorptive capacity leads to better innovation performance. Hypothesis H3 follows.

H3. All else being equal, the innovation performance of an OSS EV increases with the number of its software programmers.

Let us now turn our attention to EVs experience. The institutional peculiarities of the OSS community make the experience that an EV gains in collaborations with the community (*OSS experience*) particularly valuable for the development of *OSS absorptive capacity*. An experienced OSS EV is better able to navigate the OSS common pool for in-sourcing valuable innovation inputs. Indeed, it is likely that such an entrepreneurial venture has already identified the best OSS programmers, the most valuable pieces of code, and the best OSS development projects for the software developed internally. In short, experienced OSS firms are more able to absorb community knowledge, thus achieving superior innovation performance. On this basis, we suggest hypothesis H4.

H4. All else being equal, the innovation performance of an OSS EV increases with its OSS experience.

However, the institutional peculiarities of the OSS community can be challenging for OSS EVs, and OSS experience may not be enough. First, the OSS community is by definition *open*: everyone can join and freely contribute to the OSS common pool. Currently, thousands of OSS projects receive contributions from a large number of members from all around the world (Wheeler, 2007). The technical skills of these individuals and the quality of their contributions are highly variable. Moreover, a large body of literature has acknowledged that these contributors have heterogeneous motives (von Krogh et al., 2009). Some OSS project members may be eager to signal their talent through their OSS coding activity to obtain better jobs (Lerner and Tirole, 2002), whereas others may develop software code just as a hobby (Hertel et al., 2003, Lakhani and Wolf, 2005). Therefore, programmer motivations are likely to influence the quality of the produced software code, but these motivations will be unobservable to outsiders.

Secondly, software development in OSS projects is not governed by contracts. No enforceable agreement among project members specifies what the final output of a project should be. Project members autonomously decide the amount and content of their efforts within the project. In some cases, they may receive monetary compensation for their OSS development activities, as frequently happens in OSS projects sponsored by companies (Hars and Ou, 2002). However, the project members are not *employees* (O'Mahony, 2003, p. 1179). Hence, it is difficult to determine whether and when they will carry out their software development activities. Project discontinuation and departure from the initial specifications are concrete risks (Feller and Fitzgerald, 2002). Finding trustworthy OSS development teams committed to reliably carrying out software development is quite difficult.

Thirdly, although each OSS project has its own administrators who lead the project, being in contact with them might not be sufficient to make project outsiders aware of the quality of the software produced through the project and of its potential future development. In OSS projects, leadership usually develops from the bottom up and is frequently challenged by the most active participants. These participants play a leading role in the project and may possess relevant

information about the software development process that is unknown even to the project's administrators. Detecting who these lead participants are is not an easy task for project outsiders.

Fourthly, the OSS community was originally shaped by the ideological struggle for software freedom (Raymond, 2001). If these concerns are still prominent for the members of an OSS project, they will not be keen on collaborating with firms. To *guard their commons* (O'Mahony, 2003, p. 1179) from external meddling by for-profit entities, OSS project members may adopt an esoteric style of software documentation, refuse to answer questions posted by firms on project mailing lists, or prohibit other project members from collaborating with commercial firms. If these decisions are replicated over time, they may become unwritten norms: i.e., uncodified rules that govern the behavior of project members (Ågerfalk and Fitzgerald, 2008). Awareness of and compliance with such unwritten norms is mandatory for those collaborating with the OSS community. Firms that ignore these norms may waste time and effort attempting to participate in projects that do not welcome firms. Moreover, a firm that violates these norms in contributing to an OSS project will jeopardize further contributions to the project and may even experience difficulty contributing to other projects in which members of the focal project are participating.

Because of the aforementioned challenges, OSS absorptive capacity depends on *how* an EV interacts with the OSS community, i.e., on the *mode of collaboration*. To put it simply, an OSS EV may just make use of the OSS code and knowledge freely available on the Web and adapt it to meet customer needs. In such cases, the firm is not participating in OSS projects; it is operating in *taker collaboration mode.* Conversely, an EV can actively contribute to OSS projects, thus operating in *giver collaboration mode*, by releasing its code to OSS developers, modifying community code and reciprocating it back to the community, undertaking debugging activities, writing documentation, and answering users' questions through the mailing lists associated with OSS projects (Henkel, 2009). The real-world relevance of the *taker* and *giver collaboration modes* is documented by both anecdotal evidence and academic studies (see for instance Capra et al., 2010 for a survey of the literature on firms' participation in OSS projects).

We argue that by acting as *insiders* in OSS projects, *giver EVs* gain a first-hand, deeper experience of the OSS community and are thus better able to face institutional challenges when collaborating with the community. This results in better OSS absorptive capacity, which in turn engenders superior innovation performance. *Giver EVs* can more easily single out valuable OSS projects and make sense of their internal dynamics and future evolution. Moreover, in directly interacting with OSS programmers, these firms can better collaborate with them. Indeed, OSS programmers' knowledge is often tacit and sticky, thus requiring direct contacts for it to be absorbed (von Hippel, 1994). Furthermore, because of their reciprocating behavior, EVs are likely to receive more feedback from OSS programmers (Osterloh et al., 2002).[4] Hence, we formulate hypothesis H5.

H5. All else being equal, the innovation performance of an OSS EV increases if the firm uses the giver collaboration mode.

3. Data

Our theoretical hypotheses are tested on a sample composed of 230 software EVs. The sample was extracted from an original database developed in 2009 by the general administration of the Emilia-Romagna region and its Emilia-Romagna Open Source Survey (EROSS) workgroup within the "Emilia-Romagna survey on the characteristics and innovation performance of IT firms".[5] The database includes information on Italian software EVs located in the Emilia-Romagna Region The construction of the database went through a series of steps.

First, in-depth, face-to-face interviews were conducted with three firms' owner-managers working in the area of OSS at the beginning of 2009. Each informant was interviewed once. The duration of interviews was 45 to 60 minutes; they were conducted by two people, with one

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[4] Firms directly participating in OSS projects have also better chances to gain coordinating positions. Project coordination is likely to have additional positive effects on EVs' innovation performance. Indeed, coordinator firms can drive the software development project along directions in line with their own innovation purposes.

[5] See http://www.regionedigitale.net/projects-piter/research-and-development for further details.

researcher posing the questions and the other taking notes and asking supplementary questions. In the first 10 to 15 minutes of the interview informants were asked about their general experience with OSS in their organizations. In the second part of the interview, informants were asked for detailed experience based on a list of questions related to the specific interest of the research.

On the grounds of the results obtained in this preliminary step, we built up a questionnaire with the purpose to submit it to a representative sample of software firms located in Emilia-Romagna region. For this purpose the regional population of software EVs was identified by selecting from the Italian Classification of Economic Activities ATECO 2002 the industry segments that include software EVs. The resulting population included 7,355 firms. Then, a subset of 512 target firms was extracted. This subset was stratified according to firm province (NUTS3 level) of location and industry segment. Finally, between October and December 2009, the owner-managers of the 512 firms were contacted and 297 turned out to be available for a telephone interview (response rate: 58%). The interviews were based on a structured questionnaire aimed at collecting information on respondent firms' performance, OSS offering, external knowledge sourcing and IPR protection strategies.

The sample considered in this paper includes all the EVs established before 2005 for which we were able to build a complete dataset relating to the variables of interest (see Section 4.2). Moreover, we have not included any firms that have started collaborating with the OSS community in 2005 or after. The sample is representative of the regional population of software EVs by province, industry segment, and firm age ($\chi^2(7)$=5.5; $\chi^2(3)$=3.64; $\chi^2(3)$=4.17, respectively). Out of the 230 sample firms, 70 EVs supply OSS-based solutions, thus being OSS EVs.

Table 1 presents descriptive statistics for our sample of EVs by differentiating between OSS EVs and non-collaborating firms. Figures in the table reveals that (on average) OSS EVs perform better than their non-collaborating peers across three indicators of research performance during the period 2005-2008. In particular, an OSS EV has a higher probability of achieving radical and incremental innovations (0.53 against 0.29, and 0.51 against 0.41, respectively). At the same time, OSS EVs

present a higher number of radical innovations (1.73 against 1.45 products). Furthermore, OSS EVs are smaller and younger than other EVs. This is consistent with the fact that collaborations with the OSS community by for-profit firm is a relatively recent phenomenon (Bonaccorsi et al., 2006).

[Table 1]

4. Econometric analysis

4.1. The econometric methodology

In the econometric analysis, we measured firm innovation performance by using survey data on the introduction in the market of new software solutions by sample EVs. In particular, in the spirit of the CIS Community Innovation Survey, respondents were asked how many new software products/services their firms introduced in each year of the 2005-2008 period.[6] The structure of the survey is a retrospective panel design where time-variant information is obtained by gathering data at one time only but asking about more time points. As highlighted in De Vaus (2001) this design has the difficulty of selective memory and is open to the possibility that people will reinterpret the past in the light of the present (e.g. what they remember as one year ago might be two or more years ago). Nevertheless, we controlled for these problems by collecting time-variant information only for those variables that are less prone to subjectivity bias (i.e. exact quantities such as the number of innovative products or the share of employees in particular functions, etc.). Moreover, telephone interviews were anticipated by a mail or fax where the respondent was asked to prepare the relevant information needed for the interview. This information pertained to those variables that were more subject to selective memory problems.

We estimated two different econometric models. First, we tested whether the OSS EVs achieve superior innovation performance through the estimation of the following Logit models:

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[6] In particular, innovation measures were defined following the definitions of the Community Innovation Survey (CIS). Specifically, radical software solutions were defined as new software products/services that were introduced in a given year and that were new to the firm and the market (i.e. not previously introduced by competitors). Likewise, improved software solutions were defined as software products/services introduced in a given year and that constitute an improvement of existing products/services.

$DNewSolutions_i = \alpha + \beta DOSSCollaboration_i + \gamma Z_i + \varepsilon_i$ (1)

$DImprovedSolutions_i = \alpha + \beta DOSSCollaboration_i + \gamma Z_i + \varepsilon_i$ (2)

where $DNewSolutions_i$ and $DImprovedSolutions_i$ are dummy variables respectively equal to 1 if the EV i introduced any new and improved software solutions in the 2005-2008 period. $DOSSCollaboration_i$ is a dummy variable equalling 1 if the EV collaborates with the OSS community (i.e. if it is an OSS EV); Z_i indicates a series of firm-specific control variables; and ε_i is the error term.

Second, we investigated which factors make OSS EVs are better able to absorb the knowledge produced by the OSS community and thus achieve superior innovation performances through the estimation of the following Poisson model for panel data:

$NNewSolutions_{it} = \alpha + \beta OSSCollaboration_{it} + \gamma HumanCapital_i + \delta ProgrammersShare_{it} + \lambda X_{it} + \eta_i + \varepsilon_{it}$ (3)

where $NNewSolutions_{it}$ is the number of new software solutions introduced by the EV i in year t. $OSSCollaboration_{it}$ is a vector of variables measuring specific characteristics of the collaboration between i and the OSS community (see Section 4.2). $HumanCapital_i$ captures the human capital endowment of i's employees in year 2008. In line with the literature on labour and education economics (Heckman et al., 2003; Folloni and Vittadini, 2010) we proxy for the human capital construct by two different measures pertaining to off-the-job training. In particular, we use a continuous variable reporting the total number of years of schooling of employees and a dichotomous variable taking value 1 if all of the individuals employed by the EV in 2008 possessed at least a master level education. $ProgrammersShare_{it}$ denotes the share of programmers over the total of employees of the EV i in year t. This variable is often used to proxy for R&D investments in works studying the software industry (see Bessen and Hunt, 2007). X_{it} indicates a series of firm-specific control variables; η_i denotes the unobserved firm-specific fixed effects; and ε_{it} are the disturbance terms.

To take into account problems generated by the potential endogeneity of the explanatory variables, we also run the endogeneity tests and estimate the additional models described in Section

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4.2.   The independent variables

As we already mentioned, this paper aims at investigating (i) the effects of firm-OSS community collaborations on the innovation performance of software EVs and (ii) the factors that make OSS EVs better able to absorb the knowledge produced by OSS community and thus achieve superior innovation performances. In order to address the former issue, we introduced in equations (1) and (2) a dummy variable equalling 1 if before 2005 the EV had started collaborating with the OSS community and 0 otherwise (*DOSSCollaboration*). In accordance with hypothesis H1, we expected the coefficient of *DOSSCollaboration* to be positive.

In order to test hypotheses from H2 to H5, we introduced in equation (3) the dummy *DOSSCollaboration* and five additional explanatory variables. Hypotheses H2 and H3 were tested through the inclusion in the estimates of proxies for EV's human capital (*DHumanCapital*) and for the share of software programmers (*ProgrammersShare$_t$*), respectively. *DHumanCapital* is calculated as the interactive term between *DOSSCollaboration* and a dummy variable equal to 1 if all the individuals employed by the EV in 2008 possessed at least a master level education. Instead, *ProgrammersShare$_t$* is the interactive term between *DOSSCollaboration* and the number of software developers divided by the total number of employees for year t. We predict a positive coefficient for both *DHumanCapital* and *ProgrammersShare$_t$*.[7] The proxies for EV's human capital and programmers' share have been included also in the estimates of equations (1) and (2) as control variables. Note that to do so we had to transform the longitudinal variable *ProgrammersShare$_t$* into a cross-sectional one. In order to avoid reverse causality problems, we pose *ProgrammersShare* equal to the share of software developers in 2005. *OSSExperience$_t$* is a measure of the OSS experience that the OSS EV has gained. It is the interactive term between *DOSSCollaboration* and the number of years since the OSS EV has started providing OSS-based solutions. In line with

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[7] We used the total number of years of schooling of employees as an alternative proxy for EV's human capital. The results of the Poisson model are similar to those reported in the following.

hypothesis H4, we predict a positive coefficient for *OSSExperience$_t$*. *DGiverMode$_t$* indicates the use of the giver collaboration mode. It is calculated as the interactive term between *DOSSCollaboration* and a dummy variable equalling 1 if the EV has ever actively participated to any OSS projects before year *t*. In order to detect whether also the experience gained in contributing to OSS projects has an impact on OSS EVs' innovation performance, we inserted in equation (3) also the interactive term between *DGiverMode$_t$* and the number of years passed since the EV started participating to OSS projects (*ProjectExperience$_t$*).

Let us now present the remaining controls. In the following, we describe the controls inserted in equation (3). Equations (1) and (2) include the same time-invariant control variables we inserted in (3). As to the longitudinal controls, in (1) and (2) we included for each EV the value of the variable for year 2005.

As it is widely accepted, firm size and age are likely to affect firm innovation performance (see Becheikh et al., 2006 for a thorough survey). Therefore, we included as controls *LnSize$_t$* and *Age*. *LnSize$_t$* is the natural logarithm of the total number of employees plus one measured in year *t*, while *Age* is the number of years elapsed since firm foundation. Then, we included a dummy equalling 1 if the EV introduced any process or organisational innovation in the 2005-2008 period (*DOtherInnovation*). *DIPR* is another binary variable that equals 1 if the firm has ever used patents and/or trademarks. It was included to control for the use of formal instruments for the protection of intellectual property. As recent studies (see, e.g., Laursen and Salter, 2006) have shown that access to external information sources positively affects firms' innovation potential, we controlled for the total number of external information sources the EV had access to and could thus exploit for innovation purposes (*NInfSources*). *NInfSources* ranges from 0 to 6. The potential sources of information considered are: i) suppliers, ii) customers, iii) competitors, iv) public research organisations, v) professional associations and online communities, and vi) social networks. In order to control for the effect of agglomeration economies, we included a geographical dummy variable equalling 1 for the EVs located in the Province of Bologna. Indeed, out of the 9 provinces

of the Emilia-Romagna Region, Bologna is the area where most software EV are located (more than 28% of the whole population). Finally, we controlled for market segment-specific effects by including a series of industry dummies.[8]

Table 2 illustrates descriptive statistics for the independent variables, while Table 3 reports the correlation matrix for the independent continuous regressors. In general, the correlation across the independent variables is low, thus suggesting the absence of any relevant problems of multicollinearity.

[Tables 2 and 3]

5. Results

The results of the econometric analysis are illustrated in Tables 4 and 5. Table 4 presents the estimates of the Logit models testing the innovation impact of EVs' collaboration with the OSS community. Table 5 reports the estimates of the Poisson models investigating the factors that make EVs better able to absorb OSS external knowledge, thus resulting in superior innovation performance. In both tables Models 1 include only the controls, while Models 2 include also the key explanatory variables.

[Table 4]

Let us first consider the results shown in Table 4 and, in particular, the models where the dependent variable captures the introduction of new software solutions. In Model 1, both *HumanCapital* and *DOtherInnovation* exhibit positive coefficients, significant at conventional confidence levels. Reasonably enough, software EVs find it easier to introduce new solutions if they possess a superior human capital. Moreover, the positive effect of carrying out types of innovation

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[8] We considered four product and six service typologies. The four product market segments are the following: (i) management applications, (ii) software for office automation, (iii) content management systems, websites, portals, hosting, e-commerce solutions and (iv) other products. The six service typologies are the following: (i) installation, (ii) maintenance and support, (iii) training, (iv) integration of different components, (v) software customisation and (vi) other services.

other than product/service one supports the argument of complementarity among different innovation typologies (Cassiman and Veugelers, 2006). When *DOSSCollaboration* is added to the set of regressors (see Model 2), the signs and significance of the coefficients of the controls do not differ from those in Model 1. In addition, the insertion in the model specification of *DOSSCollaboration*, substantially improves the explanatory power of the model, as is documented by the increase of the McFadden's R^2 (from 0.16 to 0.18).[9] More interestingly, the positive and significant (at 10%) coefficient of *DOSSCollaboration* indicates that, as predicted by hypothesis H1, OSS EVs achieve superior innovation performance.

Let us now focus on the estimates where the dependent variable is *DImprovedSolutions*. In both Models 1 and 2, only *DOtherInnovation* is found to be significant at conventional confidence levels. The lack of significance of the coefficient of *DOSSCollaboration* in Model 2 leads us to conclude that while collaborations with the OSS community help EVs in developing more radical innovations (i.e., new products and/or new services), they do not play a role in stimulating incremental product/service innovation.

In order to control for the potential endogeneity of *DOSSCollaboration*, which might affect our findings, we performed two checks of robustness. First, we resorted to the following bivariate probit specification:

$$DNewSolutions_i = \alpha_1 + \beta_1 \, DOSSCollaboration_i + \gamma_1 Z_i + \varepsilon_{1i} \tag{4}$$

$$DOSSCollaboration_i = \alpha_2 + \beta_2 DOpenStandard_i + \beta_3 DOpenValues_i + \gamma_2 Z_i + \varepsilon_{2i} \tag{5}$$

The explanatory variables in the equation (5) include two dummies equalling 1 if the EV's owner-managers rated as highly important open source values (*DOpenValues$_i$*) and open standards

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[9] We also run Likelihood-ratio tests for the exclusion of additional variables from the restricted Logit models and Lagrange multiplier tests of generalized Logit. Both types of test are strongly rejected at the 1% significance level. This means that Model 2 is the most informative one and that linearity in the parameters can be confidently assumed. Results of the tests are available from the authors upon request.

(*DOpenStandard$_i$*).[10] A likelihood-ratio test of correlation of the residuals in the equations (4) and

(5) is not rejected ($\chi^2(1)$=0.02), thus suggesting the absence of endogeneity problems.

Second, we run a Hausman test comparing the coefficients of *DOSSCollaboration* estimated

through the Logit and the bivariate Probit estimators. This additional test ($\chi^2(1)$=0.12) speaks in

favour of the absence of endogeneity problems too.

[Table 5]

Let us now focus on the estimates of the Poisson models reported in Table 5. In both models we

resorted to a random-effects estimator. In Model 1, the positive coefficient of *LnSize$_t$* suggests that

larger EVs achieve better innovation performance. In Model 2, we added the explanatory variables

aimed at testing hypotheses from H2 to H5. The estimates support hypothesis H2. The coefficient of

DHumanCapital is indeed positive and significant, thus indicating that OSS EVs achieve better

innovation performance if they employ more skilled individuals. Conversely, we do not find

support for hypothesis H3. The coefficient of *ProgrammersShare$_t$* is indeed not significant at

conventional confidence levels. The positive and significant coefficient of *OSSExperience$_t$* provides

support to hypothesis H4. The greater the experience the firms gained through prior collaborations

with the OSS community, the greater the innovation performance the EVs achieve.

Although the collaboration mode itself does not affect firm innovation (*DGiverMode$_t$* is not

significant), the experience in participating to OSS community projects does play a role. The

positive and significant coefficient of *ProjectExperience$_t$* indeed indicates that the greater the

experience gained by an OSS EV, the better the firm innovation performance.

We performed two checks of the robustness of these results. First, we run the Poisson models

resorting to a fixed-effects estimator. Results are consistent with those obtained in Model 2 in terms

of signs, magnitude, as well as significance levels. Second, we run an Hausman-Taylor model to

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[10] We asked the respondents to rate their level of agreement on a 1-to-4 Likert scale (from 1 – strongly agree to 4 – strongly disagree) with the following statements: i) one of the key motives for interacting with the OSS community is sharing the OSS values and ii) one of the key motives for interacting with the OSS community is the possibility of exploiting the benefits of an open standard. Then, we assigned one to *DOpenValues$_i$* and *DOpenStandard$_i$* if the respondents rated 1 or 2 their level of agreement with statements i) and ii), respectively.

control for non observable heterogeneity. The results are again in line with the ones presented so far in terms of signs, while the significance levels of the explanatory variables are lower. The estimates are available from the authors upon request.

6. Conclusions

Strangely enough, the innovation impact of firms' collaborations with the OSS community has, up to now, received scant scholarly attention. The relationship between firm-OSS collaboration and innovation is of particular interest when involving EVs. The literature has often described these firms as entities affected by lack of resources, experience, and legitimacy (Carayannopoulos, 2009, p. 419), thus being at disadvantage in the race for innovation. As practitioners are well-aware, firm-OSS community collaborations may help EVs to overcome their shortcomings, thus resulting in better innovation performance.

This paper provides both theoretical arguments and rigorous empirical evidence in favour of a positive impact of firm-OSS community collaborations on EVs' innovation performance. Taking advantage of a unique dataset and running both cross-sectional and panel data estimations, we show that EVs collaborating with the OSS community achieve innovation performance superior to that of their non-collaborating peers. Moreover, our findings indicate that the innovation impact of OSS is stronger for the OSS EVs which are endowed with highly skilled human capital and have experience with both collaboration with the OSS community and active participation in OSS projects.

Our key intuition is that OSS EVs have access to a vast common pool of freely available and valuable innovation inputs and such an access results in better innovation performance. Our inquiring roots on the entrepreneurship literature. However, we acknowledge that a sounded analysis of the innovation impact of firm-OSS community collaborations cannot set aside the unique institutional characteristics of the community (Stewart, 2005). Being mainly formed by volunteers, who act out of a plethora of monetary and non-monetary motives (Lerner and Tirole,

2002), the OSS community is undoubtedly an *unconventional* source of external knowledge for profit-oriented firms (O'Mahony and Becky, 2008). Consequently, firms have to develop a proper *OSS absorptive capacity* to proficiently leverage the OSS community for innovation purposes. Such an *OSS absorptive capacity* depends not only on the characteristics of the focal firm but also on *how* it collaborates with the OSS community.

The paper has several limitations that open up avenues for future research. Firstly, we measure innovation performance through survey questions that resemble those of the Community Innovation Survey. Such a data collection method is well established in the innovation literature, but we are well-aware that measuring innovation is a rather challenging task in the software realm (see e.g. Rossi-Lamastra, 2009 for a discussion on this issue). Therefore, future studies on the relationship between firm-OSS community collaborations and innovation would benefit from the introduction of alternative indicators (e.g. based on expert assessment and case study evidence) of innovation performance. Second, our data cover a limited period. This is not so worrisome as EVs' involvement in the OSS arena is a relatively recent phenomenon. However, a longer time series would provide better information on the innovation impact of OSS and on the causal linkages between firm-OSS community collaborations and firms' innovation performance. Finally, the data considered here provide information on the innovation impact of firm-OSS community collaborations for surviving firms. Case study evidence on firms that ceased operations might be an interesting addition to our results.

In spite of its limitations, our paper has relevant implications for practitioners. Our data show that OSS deserves the confidence that entrepreneurs and EVs' managers place in it. The high-tech markets are nowadays globalized and highly competitive. Such hyper-competitive arenas not only magnify the traditional liabilities of young ventures, but also urge them to deeply engage in the race for innovation. Our findings indicate that establishing OSS community collaborations may be a winning strategy for the survival and growth of EVs. Unfortunately, the free availability of innovation inputs from the OSS community may turn out to be insufficient to succeed in the race

for innovation. The absorptive capacity that firms have to develop in order to leverage the community at its best, is highly source-specific. Such on absorptive capacity strictly depends on the way in which EVs interact with the OSS community. In particular, larger benefits from community collaborations can be reaped by reciprocating code and knowledge back to the community through a *giver collaboration mode.*

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Table 1 – Descriptive statistics on sample EVs on the 2005-2008 period.

	EVs not supplying OSS-based software solutions (N=160)				OSS EVs (N=70)			
	No. of firms		**%**		**No. of firms**		**%**	
Radical innovation	47		29%		37		53%	
Incremental innovation	66		41%		36		51%	
	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
No. of radical software solutions	1.45	10.36	0	96	1.73	4.79	0	30
No. of employees in full time equivalent	10.27	41.60	0	495	5.37	9.30	0	70.75
Age (in years)	10.53	6.32	2	31	7.68	4.66	2	23

Table 2 – Descriptive pooled sample statistics for the variables included in the econometric models (2005-2008 period)

Variable	No.	Mean	Std. Dev.	Min	Max
DOSSCollaboration	805	0.30	0.46	0.00	1.00
OSSExperience$_t$	805	1.68	3.07	0.00	17.00
DGiverMode$_t$	805	0.06	0.23	0.00	1.00
ProjectExperience$_t$	805	0.26	1.38	0.00	10.00
ProgrammersShare$_t$	805	66.97	35.71	0.00	100.00
DHumanCapital	805	0.50	0.50	0.00	1.00
LnSize$_t$	805	1.60	0.91	0.69	6.57
Age$_t$	805	11.60	7.35	1.00	39.00
DOtherInnovation	805	0.30	0.46	0.00	1.00
DIPR	805	0.16	0.37	0.00	1.00
NInfSources	805	2.02	1.35	0.00	6.00

Table 3 – The Correlation matrix of the explanatory variables

		(1)	(2)	(3)	(4)	(5)
(1)	$OSSExperience_t$	1.00				
(2)	$ProjectExperience_t$	0.38	1.00			
(3)	$ProgrammersShare_t$	0.10	0.08	1.00		
(4)	$LnSize_t$	-0.03	0.00	-0.23	1.00	
(5)	Age_t	-0.15	-0.09	-0.24	0.19	1.00
(6)	$NInfSources$	0.19	-0.02	0.07	0.02	-0.14

Table 4 – Results of the econometric estimates of the Logit models.

		DNewSolutions		DImprovedSolutions	
		Model 1	Model 2	Model 1	Model 2
a_0	Constant	-2.27***	-2.29***	-0.69	-0.69
		(0.83)	(0.83)	(0.69)	(0.69)
a_1	DOSSCollaboration	-	0.72*	-	0.13
			(0.39)		(0.41)
a_3	DHumanCapital	0.86**	0.86**	0.33	0.33
		(0.40)	(0.41)	(0.43)	(0.43)
a_2	ProgrammersShare	0.01	0.01	0.01	0.01
		(0.01)	(0.01)	(0.01)	(0.01)
a_4	LnSize	0.22	0.21	-0.17	-0.17
		(0.22)	(0.22)	(0.23)	(0.23)
a_5	Age	-0.04*	-0.03	-0.03	-0.03
		(0.02)	(0.02)	(0.03)	(0.03)
a_6	DOtherInnovation	0.79*	0.77*	1.01**	1.01**
		(0.40)	(0.40)	(0.43)	(0.43)
a_7	DIPR	-0.03	-0.08	0.56	0.55
		(0.47)	(0.45)	(0.52)	(0.53)
a_8	NInfSources	-0.07	-0.09	0.19	0.19
		(0.15)	(0.15)	(0.14)	(0.14)
	Geographical dummy	Yes	Yes	Yes	Yes
	Industry dummies	Yes	Yes	Yes	Yes
No. of observations		198	198	199	199
Wald χ^2		37.64(18)	37.88(19)	47.46(18)	47.45(19)
Log-likelihood		-109.11	-107.39	-102.92	-102.87
McFadden's R^2		0.16	0.18	0.25	0.25

Legend: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Standard deviation and degrees of freedom in round brackets. Note that both likelihood-ratio tests for the exclusion of additional variables and Lagrange multiplier tests of generalized Logit are strongly rejected at the 1% significance level.

Table 5 – Results of the econometric estimates of the Poisson models.

		NNewSolutions$_t$	
		Model 1	Model 2
a_0	Constant	-3.16***	-3.63***
		(0.82)	(0.97)
a_1	DHumanCapital	-	1.65**
			(0.65)
a_2	ProgrammersShare$_t$	-	0.00
			(0.01)
a_3	DOSSCollaboration	-	0.22
			(0.81)
a_4	OSSExperience$_t$	-	0.07**
			(0.03)
a_5	DGiverMode$_t$	-	-1.73
			(1.46)
a_6	ProjectExperience$_t$	-	0.29**
			(0.14)
a_7	LnSize$_t$	0.24*	0.13
		(0.13)	(0.14)
a_8	Age$_t$	0.02	0.00
		(0.02)	(0.02)
a_9	DOtherInnovation$_t$	0.76	1.38*
		(0.63)	(0.78)
a_{10}	DIPR	0.66	0.71
		(0.65)	(0.75)
a_{11}	NInfSources	0.19	-0.00
		(0.24)	(0.25)
	Geographical dummy	Yes	Yes
	Industry dummies	Yes	Yes
	No. of observations	907	805
	Wald χ^2	53.78 (16)	72.61 (22)
	Log-likelihood	-584.10	-538.53

Legend: * p<0.10, ** p<0.05, *** p<0.01. Standard deviation and degrees of freedom in round brackets.