

**Is Open Source software about innovation? Collaborations with the Open Source community  
and innovation performance of software entrepreneurial ventures**

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## **Abstract**

Practitioners generally assert that collaborations with the Open Source software (OSS) community enable software entrepreneurial ventures to achieve superior innovation performance. Nonetheless, to the best of our knowledge, scholars have never tested this assertion. This paper takes a first step towards filling this gap. First, based on the high-tech entrepreneurship literature and the OSS research stream, we illustrate why collaborations with the OSS community are expected to exert a positive effect on entrepreneurial ventures' innovation performance. Then, we provide a rigorous quantitative analysis of the innovation impact of these collaborations using a sample of 199 Italian entrepreneurial ventures. Our econometric estimates indicate that entrepreneurial ventures collaborating with the OSS community exhibit superior innovation performance compared with their non-collaborating peers.

*Keywords:* Entrepreneurial ventures, Open Source software community, firm-community collaborations, innovation performance

*JEL codes:* L26, L17, O33

## 1. Introduction

Conventional wisdom in the entrepreneurship field recognises that entrepreneurial ventures<sup>1</sup> tend to have limited financial and human capital to devote to R&D activities (Becker and Gordon 1966; Stevenson and Gumpert 1985). Therefore, these firms usually complement their internal R&D efforts by networking intensively with external third parties (Stuart and Sorenson 2007) that have valuable knowledge and competences (“innovation inputs” hereafter).

Over the past decade, the astonishing developments in information and communication technologies (ICTs) along with the surge in new ICT-based methods of producing and circulating knowledge have embedded entrepreneurial ventures in an increasingly wide network of potential external collaborations. ICTs facilitate the access and in-sourcing of innovation inputs from distant individuals, firms, or universities (Piva, Grilli and Rossi-Lamastra 2011).<sup>2</sup> In addition, new prospective collaborators have emerged. Valuable innovation inputs are currently produced by communities of users and developers who interact through the Internet (Hargrave and Van de Ven 2006). In particular, intense and vibrant collaborations link the online community that develops Open Source software (“the OSS community” hereafter) and software entrepreneurial ventures. Existing evidence suggests that many entrepreneurial ventures in the software industry belong to the category of firms that Bonaccorsi, Giannangeli, and Rossi (2006) has labelled OSS firms, indicating that they offer OSS-based software solutions to their customers (Dahlander 2007; Dahlander and Magnusson 2008). In this paper, we refer to these entrepreneurial ventures as OSS entrepreneurial ventures.

OSS entrepreneurial ventures access and in-source innovation inputs produced and distributed through the Internet by the OSS community and use them to establish their offering. In other words, these firms download the OSS code available on the Internet and develop new software solutions based on that code. These OSS solutions are tailored to specific customers’ needs or are released to

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<sup>1</sup> We define *entrepreneurial ventures* as *new* and *independent* firms established to commercialise novel ideas developed by their founders.

<sup>2</sup> A long tradition in entrepreneurship research has recognised the importance of collaborations with firms and universities for entrepreneurial ventures’ innovation processes (for a recent review, see Hoskisson et al. 2011).

the mass market under an OSS license. Alternatively, OSS entrepreneurial ventures provide services (e.g., installation, system integration, or maintenance) for well-established OSS products, such as Linux or Apache. Moreover, OSS entrepreneurial ventures often participate in software development projects of the OSS community (Bonaccorsi and Rossi 2006), thereby actively contributing to the private provision of the OSS public good (Johnson 2002).

Collaborations between for-profit firms and the OSS community have been puzzling management and economic scholars since their inception. A lively research stream has examined the multifaceted aspects of these collaborations (for a review, see von Krogh, Rossi-Lamastra and Haefliger 2012). Many studies have elucidated the peculiarities of OSS-based business models (Hecker 1999). Likewise, numerous contributions have focused on firms' motivations to engage in the OSS movement (Rossi and Bonaccorsi 2006), on why and how firms usually mix the provision of proprietary and OSS solutions (see again Bonaccorsi, Giannangeli and Rossi 2006), on the advantages and disadvantages of firms' participation in OSS projects (Capra et al. 2011; Lerner, Pathak and Tirole 2006), and on the organisational challenges posed by firm-community collaborations (Alexy and Leitner 2011; Colombo, Piva and Rossi-Lamastra 2011; Dahlander and Wallin 2006). Two major gaps currently confront this literature. First, the real-world evidence documents that both large players in the software industry and small start-ups collaborate with the OSS community. Nevertheless, until now, few authors have taken into account the heterogeneity of OSS firms. Notable exceptions are Dahlander (2007) and Gruber and Henkel (2006). Both works have focused on new firms in the OSS domain. Dahlander (2007) has explored the different approaches to harness the OSS community adopted by *de novo entrants*, while Gruber and Henkel (2006) has investigated how the liabilities of newness and smallness of start-ups and market entry barriers affect new OSS firms. Despite these exceptions, entrepreneurship scholars have devoted scant attention to whether and how the distinctive characteristics of entrepreneurial ventures shape their collaborations with the OSS community. Second, the relationship between OSS and innovation has been poorly investigated. 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. Indeed, limited research efforts have been applied to explore the effects of collaborations with the OSS community on firms' innovation performance. An exception is Stam (2009), that has analyzed the effects of participation in OSS projects on firms' innovation performance. However, the author has not compared the innovation performance of collaborating and non-collaborating firms.

This paper contributes to filling these gaps by theoretically and empirically addressing the following research question: *Do entrepreneurial ventures that collaborate with the OSS community (i.e., OSS entrepreneurial ventures) exhibit superior innovation performance in comparison with their non-collaborating peers?*

Answering such a research question contributes to the general debate on the impact of collaborations with external third parties on firms' innovation performance, thus contributing to the academic discourse on open innovation. In addition, by focusing explicitly on entrepreneurial ventures, our analysis fits in the lively stream of the entrepreneurship literature that examines how entrepreneurial ventures network with third parties for innovation purposes. Accordingly, we feel confident that our work will stimulate discourse among scholars in the fields of open innovation and entrepreneurship.

Moreover, our analysis has great practical relevance. The allegedly positive effect that collaborations with the OSS community exert on the innovation performance of entrepreneurial ventures has strong echoes in the business and technical press and in conversations among practitioners. Survey data document the positive view that entrepreneurs seem to have regarding the relationship between collaborations with the OSS community and firm innovation performance. The ELISS I survey of Italian software firms (for details, see Bonaccorsi and Rossi 2004) analyses the motivations driving firms' collaborations with the OSS community. The top-ranking motive selected by the 146 respondents was that *collaborating with the OSS community allows even new*

*and small firms to be innovative* (Rossi and Bonaccorsi 2005). This result was confirmed by a second wave of the survey (ELISS II; for details, see Bonaccorsi, Rossi and Scateni 2005) of approximately 900 European software firms. In addition, case-study evidence has indicated that collaborations with the OSS community enhance the innovation performance of entrepreneurial ventures because resources that are freely available within the OSS community can be used as low-cost inputs for firms' innovation processes (Dahlander and Magnusson 2005; 2008). Nonetheless, to the best of our knowledge, it has never been tested whether collaborations with the OSS community promote innovation by entrepreneurial ventures.

In the empirical part of this paper, the impact of collaborations with the OSS community on the innovation performance of entrepreneurial ventures is rigorously analysed through the estimation of econometric models. The empirical analysis takes advantage of a unique dataset that contains detailed information on collaborations with the OSS community and the innovation activity of 199 Italian entrepreneurial ventures observed during the period 2005–2008.

The paper is organised as follows. In section 2, we extensively illustrate why one might expect collaborations with the OSS community to exert a positive effect on the innovation performance of entrepreneurial ventures. In section 3, we illustrate the dataset, describe the sample used in the empirical analysis, specify the econometric models and describe the variables included in the models. Section 4 summarises the results of the econometric estimates. Section 5 synthesises the main findings, acknowledges the limitations of the study, and indicates directions for further research.

## **2. Conceptual background**

Entrepreneurial ventures in the software industry (“software entrepreneurial ventures” hereafter) are usually at a disadvantage in the innovation race. Like most entrepreneurial ventures operating in high-tech industries (“high-tech entrepreneurial ventures” hereafter), software entrepreneurial

ventures generally lack financial resources (Carpenter and Petersen 2002a;b), internal competences (Colombo and Piva 2008), and complementary assets (Teece 1986).

Rooting on the high-tech entrepreneurship literature and the OSS research stream, we argue that collaborations with the OSS community render the above mentioned obstacles to innovation (as mentioned above) less severe. Accordingly, entrepreneurial ventures that collaborate with the OSS community (i.e., OSS entrepreneurial ventures) exhibit superior innovation performance in comparison with their non-collaborating peers.

### **2.1. Collaborations with the OSS community and software entrepreneurial ventures' financial constraints**

High-tech entrepreneurial ventures usually have limited internal finances (Carpenter and Petersen 2002a) and poor access to debt financing (Carpenter and Petersen 2002b). Moreover, empirical work has shown that there is a substantial wedge between the costs of internal and external equity financing (see, e.g., Asquith and Mullins 1986). This situation inhibits access to equity capital for most new high-tech ventures, especially in countries with a less developed and/or bank-based financial system (Berger and Udell 1998). Software entrepreneurial ventures are no exception. Existing evidence suggests that these ventures generally have few financial resources to invest in innovation activities (e.g., Romijn and Albaladejo 2002). Collaborations with the OSS community reduce the negative impact of these financial constraints of OSS entrepreneurial ventures. As a consequence, OSS entrepreneurial ventures enjoy an advantage in innovation over their non-collaborating peers.

By developing valuable OSS solutions, OSS entrepreneurial ventures may attract external capital more easily. The relationship between collaborations with the OSS community and a firm's ability to attract external financing has gone generally unnoticed in the academic literature (for two exceptions, see Alexy 2008; Feller and Fitzgerald 2002). However, the professional press notes that collaborations with the OSS community usually impress venture capitalists favourably, thereby making them more willing to sponsor the innovation projects of OSS entrepreneurial ventures (The

451 Group 2010). OSS has indeed been regarded as reliable and of high quality since the entrance of major players in the software industry, such as IBM and Sun, into the OSS arena. In addition, the openness of the OSS code allows anyone to inspect it to assess its value (Lerner and Tirole 2005), thereby signalling good quality for the OSS entrepreneurial ventures that have contributed to its development. It might be claimed that OSS entrepreneurial ventures also have a disadvantage regarding the attraction of external financing. Venture capitalists may indeed find it unattractive to invest in firms producing technological artefacts for which it is impossible to enforce intellectual property rights. Scholars have documented that venture capitalists attach a value to patent holding when deciding to finance a software firm (Mann and Sager 2007). Nevertheless, to the best of our knowledge, no study has shown that the possible *fear of openness* negatively counterbalances venture capitalists' positive assessment regarding OSS.

Two additional compelling reasons argue in favour of a positive impact of collaborations with the OSS community on OSS entrepreneurial ventures' financial constraints. First, and probably most important, collaborations with the OSS community substitute for internal R&D activities. The OSS community constitutes a common pool of software code and programming competences that OSS entrepreneurial ventures can access at a cost that, in most cases, is very low. OSS entrepreneurial ventures can then use these code and competences as inputs to develop new products and services (Bonaccorsi and Rossi 2003; 2004). Second, the free availability of inputs from the OSS community reduces the costs of OSS entrepreneurial ventures' daily operations. For example, no license fees are required to use an OSS compiler when developing software (Lerner and Tirole 2005). Likewise, user-to-user assistance with mailing lists maintained by OSS developers (Lakhani and von Hippel 2003) reduces the costs of OSS entrepreneurial ventures' customer care. To summarise, collaborations with the OSS community generate positive *pecuniary externalities* (Antonelli 1995). Therefore, OSS entrepreneurial ventures can invest the freed financial resources in their innovation processes.



## **2.2. Collaborations with the OSS community and software entrepreneurial ventures' lack of internal competences**

Initially, the competences of high-tech entrepreneurial ventures largely coincide with those of their founders (Cooper and Bruno 1977; Feeser and Willard 1990). However, these initial competences may be insufficient for the development of a sustained stream of innovations (McMuller and Shepard 2006). Therefore, high-tech entrepreneurial ventures soon experience a compelling need to enlarge their initial competence endowment. Competence enlargement might be achieved by hiring new talented individuals (Baron, 2010; Baron and Hannan 2002). However, scholars agree that high-tech entrepreneurial ventures usually have difficulties in recruiting (and subsequently retaining) talented individuals (for a review of the studies on this topic, see Colombo and Rossi-Lamastra 2011). Moreover, these firms rarely have the resources to make major investments in personnel (Bryant and Allen 2009). Therefore, high-tech entrepreneurial ventures usually expand their internal competence by partnering with other firms or collaborating with universities (for a recent review on this theme, see Hoskisson et al. 2011). In this framework, collaborations with the OSS community may be an alternative valuable competence-enlargement strategy for software entrepreneurial ventures for several reasons.

First, the OSS community is a large pool of talented individuals from which OSS entrepreneurial ventures can scout brilliant programmers, thereby complementing their internal competences with fresh individual skills (Eilhard 2008; Henkel 2009). OSS entrepreneurial ventures can access programmers' human capital through different employment modes, for example, by hiring programmers or by contracting them as freelancers (Lepak and Snell 1999). In both cases, the OSS framework attenuates the problems that high-tech entrepreneurial ventures usually experience in accessing human resources (Connelly et al. 2011).

However, it might be claimed that singling out the OSS programmers whose skills match the firm's requirements and linking these individuals to an OSS entrepreneurial venture is not so simple. Indeed, because anyone can enter the OSS community, OSS programmers have highly

variable skills and capabilities (Colombo, Piva and Rossi-Lamastra 2011). Nevertheless, the characteristics of OSS code might simplify this task. According to the OSS definition, OSS code must not only be open, but it must also contain a declaration of authorship.<sup>3</sup> Consequently, an OSS entrepreneurial venture that is searching for talented programmers has the opportunity to download the source code of a piece of Open Source software from the Web, inspect it to assess its quality, trace the programmer who wrote it and evaluate whether it is worthwhile to establish a collaboration with the programmer. We do not want to deny that this might be a complex and time-consuming procedure; what we intend to say is that OSS entrepreneurial ventures can rely on a potentially powerful and valuable instrument for scouting talented programmers that cannot be used by their non-collaborating peers.

Second, OSS entrepreneurial ventures can easily expand their internal competences by interacting with other OSS firms within the community. The OSS community is being increasingly populated by firms (Fitzgerald 2006), and evidence suggests that OSS firms are keen on interacting among each other and sharing their competences. OSS practitioners generally assert that OSS is more about collaboration than about competition. This *co-opetition* tendency (Van de Vrande et al. 2009) in the OSS realm is demonstrated by the numerous collaborative networks linking OSS firms that are developing software solutions based on the same OSS platform. The Japsportal network, which connects OSS firms working with the OSS platform Japs,<sup>4</sup> and the network of OSS firms basing their business on the Zope content management system<sup>5</sup> are prominent examples. In addition, academic research finds that OSS entrepreneurial ventures tend to inherit the values of knowledge sharing and collaboration of their funders, who frequently have served as OSS developers (Dahlander 2007).

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<sup>3</sup> <http://www.opensource.org/osd.html>.

<sup>4</sup> <http://www.japsportal.com/portal/>.

<sup>5</sup> <http://www.zope.com>.

To summarise, OSS entrepreneurial ventures enjoy an advantage in the innovation race over their non-collaborating peers in that they can access an alternative and, in many respects valuable, pool of external competences.

### **2.3. Collaborations with the OSS community and software entrepreneurial ventures' lack of complementary assets**

High-tech entrepreneurial ventures frequently lack the complementary assets that they need to profit from innovation (Teece 1986). In principle, these firms could develop such complementary assets internally or gain access to them by establishing alliances with third parties. However, both of these solutions are hardly feasible for high-tech entrepreneurial ventures. The well-known lack of internal resources restrains high-tech entrepreneurial ventures from internally developing complementary assets. Likewise, alliances often require high-tech entrepreneurial ventures to incur relevant transaction and management costs (Colombo, Grilli and Piva 2006). These costs usually have a hindering effect on alliance formation. OSS entrepreneurial ventures can overcome these obstacles by using the many external complementary assets available from the OSS community (Dahlander and Wallin 2006). Indeed, OSS entrepreneurial ventures can choose applications that complement their innovative focal solutions from the OSS common pool of software programmes and modules instead of developing them from scratch or licensing them from other firms. No licence fee is required when firms use these complementary applications, with the compliance that the OSS licenses under which these applications are released is the only restriction to their use (McGowan 2001). It is worth noting that being compliant with OSS licenses is crucial for OSS entrepreneurial ventures aiming at integrating OSS complementary applications into their offering. Indeed, achieving such compliance requires an awareness of the varied legal provisions associated with the diverse OSS licenses (Lerner and Tirole 2005). Gaining such knowledge may be particularly time consuming (Dahlander and Magnusson 2008), whereas failing to comply with the provisions of Open Source licenses can engender negative consequences on OSS entrepreneurial ventures. For example, if a complementary application is released under a copy-left license (e.g.,

the General Public License) and its integration with a software solution developed by an OSS entrepreneurial venture requires the modification of the source code of the two programmes, the OSS entrepreneurial venture has to release under a copy-left license the entire resulting software code (including the programme that it has produced internally). Indeed, copy-left licenses contain an *inheritance provision* that forbids the release under a proprietary license work that contains even one line of code taken from a copy-left programme (Rosen, 2001). The enforceability of OSS licenses has rarely being tested in the courts (Lerner and Tirole, 2002).<sup>6</sup> However, to establish effective collaboration with the OSS community, OSS entrepreneurial ventures must be trusted by community participants. If OSS developers envision that an OSS entrepreneurial venture may hijack OSS code and make it proprietary because it is not aware of the OSS license provision or, even worse, because it wants to make a profit on it, OSS programmers will be reluctant to provide feedback and contributions to the firm.

Finally, the OSS community is a low-cost channel for distributing and marketing software programmes (West and O'Mahony 2008). OSS entrepreneurial ventures can take advantage of the OSS distribution infrastructure based on online software repositories and dedicated Web sites, which enable OSS firms to reach a larger customer base at lower cost. To summarise, OSS entrepreneurial ventures enjoy an advantage in the innovation race over their non-collaborating peers because they can access the complementary assets made available to the OSS community.

### **3. Methods**

#### **3.1. The sample**

The sample used in this paper was extracted from an original database developed in 2009 by the general administration of the Emilia-Romagna region of Italy within the '*Emilia-Romagna Open Source Survey (EROSS survey) project*'.<sup>7</sup> The EROSS survey was intended to collect information

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<sup>6</sup> For a discussion of a litigation case for the violation of an OSS license, see Walsh (2011).

<sup>7</sup> See <http://www.regionedigitale.net/projects-piter/research-and-development> for further details.

about the collaborations between the OSS community and the software entrepreneurial ventures located in the region by administering a structured questionnaire to the owner-managers of these firms. The questions concerned information on firms' structural characteristics, sales and employee evolution, OSS offerings, strategies for external knowledge sourcing and IPR protection, and innovation processes. The data refer to the 2005–2008 period.

The design of the survey and the construction of the database underwent a careful preparation phase. At the beginning of 2009, in-depth face-to-face interviews were conducted with the owner-managers of three OSS entrepreneurial ventures. All of the informants were interviewed once and were asked about the main themes that the EROSS research group intended to include in the questionnaire. The interviews lasted for 45 to 60 minutes and were conducted by two people, with one researcher posing the questions and the other taking notes. The results of this preliminary analysis were used to design the questionnaire.

EROSS researchers intended to administer the questionnaire to a representative sample of software entrepreneurial ventures located in the Emilia-Romagna region. For this purpose, the regional population of software entrepreneurial ventures was identified by selecting the industry segments that include these firms from the Italian Classification of Economic Activities ATECO 2002. The resulting population included 7,355 entrepreneurial ventures. Next, a subset of 512 target firms was extracted. This subset was stratified according to the province (NUTS3 level) of firm location and industry segment. Between October and December 2009, the owner-managers of the 512 target entrepreneurial ventures were contacted, and 297 were available for a telephone interview (response rate: 58%) based on the questionnaire described above. Before conducting the telephone interviews, the questions that might be more subject to selective memory problems were sent by e-mail or fax to the respondents, who were asked to search for this information in advance. Therefore, even though there might be a recall bias in the data used in this paper, its extent is likely to be relatively limited. The fact that the data we use in our study are not subjective and can be verified by respondents also makes it unlikely that our results are driven by a common-method bias.

Because data regarding entrepreneurial ventures' innovation performance were collected during the 2005–2008 period, to avoid reverse causality problems, our sample does not include the entrepreneurial ventures established in 2005 or after or firms that began collaborating with the OSS community in 2005 or after. Therefore, the sample used in this paper includes 199 firms. This sample is representative of the regional population of the 7,355 software entrepreneurial ventures by province, industry segment, and firm age ( $\chi^2(7)=5.5$ ;  $\chi^2(3)=3.64$ ; and  $\chi^2(3)=4.17$ , respectively).

Of the 199 sample firms, 30.3% (i.e., 60 entrepreneurial ventures) collaborated with the OSS community and thus were considered OSS entrepreneurial ventures. This figure is in line with the results of other surveys (e.g., Bonaccorsi, Giannangeli and Rossi 2006).

[Table 1]

Table 1 reports some descriptive statistics for the 199 sample firms and distinguishes the 60 OSS entrepreneurial ventures from their 139 non-collaborating peers. Most sample firms were small; on December 31, 2005, 85.4% of them had a 10 or fewer employees. On the same date, 71.4% of the sample firms had been operating for more than 5 years. Interestingly, the figures in the table indicate that the OSS entrepreneurial ventures in the sample are smaller and newer than their non-collaborating peers. However,  $\chi^2$  tests show that there are statistically significant differences between the distribution of OSS entrepreneurial ventures across age categories and the corresponding distributions of non-collaborating sample firms ( $\chi^2(1)=3.95$ ), whereas there are no significant differences across size categories ( $\chi^2(1)=1.44$ ).

At the survey date, the sample firms offered products and services in different product and service categories. We considered the following four product categories: i) management applications, ii) office automation products, iii) web products (including content management systems, web sites, portals, hosting, and e-commerce solutions), and iv) other types of products. Regarding services, we considered six categories: i) installation, ii) maintenance and assistance, iii) training, iv) integration, v) software customisation, and vi) other types of services. The vast majority of the sample firms did not offer products in more than one category but offered services

in at least two categories. Most sample firms offered web products (81 firms; 40.7% of the sample), whereas few firms offered office automation products (51 firms; 25.6%). Regarding services, 73.9% of the sample firms offered maintenance and assistance services, whereas the least common service, with the exclusion of the residual category described as other types of services, was integration (60 firms; 30.2%). Interestingly, both the product portfolio and the service portfolio of the entrepreneurial ventures collaborating with the OSS community seem on average to be more diversified than those of their non-collaborating peers. Indeed, the percentage of OSS entrepreneurial ventures in each product (service) category is greater than the corresponding percentage for the entrepreneurial ventures not collaborating with the OSS community. In this study,  $\chi^2$  tests indicate that in all of the categories, the differences between the percentages of OSS entrepreneurial ventures and the corresponding percentages of non-collaborating firms are significant, the only exceptions being the product category management applications and the two service categories of software customisation and other types of services.

### **3.2. Innovation performance of the sample firms**

This section provides empirical evidence for the innovation performance of the sample entrepreneurial ventures. In this and the following sections, we focus only on innovation in terms of the introduction of new (or significantly improved) software solutions. To collect data on this type of innovation, the respondents of the EROSS survey were asked i) whether their firms introduced any new or significantly improved software solutions between 2005 and 2008, ii) how many new or significantly improved software solutions their firms introduced between 2005 and 2008, and iii) what share of their firms' total turnover between 2005 and 2008 was from new or significantly improved software solutions.

These questions are similar to typical questions included in innovation surveys in general and in the CIS Community Innovation Survey in particular (for a review on innovation surveys, see

Mairesse and Mohnen 2010). Therefore, we use these questions to draw three measures of entrepreneurial ventures' innovation performance.

Using the answers to the first question, we built *DInnovation*, a dummy variable equalling 1 if the focal entrepreneurial venture introduced any new software solutions during the 2005–2008 period. *DInnovation* is an indicator of the *probability* that an entrepreneurial venture innovates. The answers to the second question were used to build *NInnovation*, a count variable equal to the number of new software solutions introduced by the focal entrepreneurial venture during the 2005–2008 period winsorised at 95%. *NInnovation* quantifies the innovations introduced by an entrepreneurial venture. This measure is similar to those used in highly cited papers (e.g., Acs, Audretsch and Feldman 1992; Audretsch and Feldman 1996; for an application in the OSS realm, see Stam 2009). Using the third question, we built *ShareInnSales*, an ordered variable that takes a value of 0 if the share of the focal firm's turnover from new software solutions introduced during the 2005–2008 period equals 0%, 1 if it ranges between 0% and 20%, and 2 if it is higher than 20%. *ShareInnSales* captures the capacity of the innovations introduced by the focal entrepreneurial venture to *create value* in the medium term for the firm. In addition, the share of a firm's turnover from new products is an established measure of the firm's innovation (e.g., Laursen and Salter 2006).

[Table 2 and Figure 1]

Table 2 and Figure 1 report descriptive statistics for the three measures of innovation performance, distinguishing OSS from non-collaborating entrepreneurial ventures. The table and figure reveal that the sample OSS entrepreneurial ventures exhibited superior innovation performance during the 2005–2008 period compared with their non-collaborating peers. Specifically, Table 2 indicates that the OSS entrepreneurial ventures exhibited a greater probability of developing new software solutions; indeed, 56.7% of the OSS entrepreneurial ventures introduced new or significantly improved software solutions between 2005 and 2008 versus 29.5% of the non-collaborating entrepreneurial ventures ( $\chi^2(1)=13.17$ ). The table also shows that the OSS



entrepreneurial ventures achieved greater shares of turnover from new software solutions than did their non-collaborating peers. In the former group, the share of turnover from software solutions introduced during the 2005–2008 period was greater than 20% for most firms (50.9%), whereas in the latter group, the share was greater for only 23% of the firms. Moreover, the share was equal to 0% for 28.3% of the OSS entrepreneurial ventures, whereas it equalled 0% for most non-collaborating firms (52.4%). The distribution of the two groups of firms is clearly significantly different ( $\chi^2(2)=14.32$ ).

The histogram in Figure 1 shows the distribution of the number of new or significantly improved software solutions introduced between 2005 and 2008 for both OSS entrepreneurial ventures and their non-collaborating counterparts. For both groups of firms, the distribution is highly skewed, and the median number of new software solutions equals 0. However, the mean number is higher for the OSS entrepreneurial ventures (6.6 versus 2.2), and a Wilcoxon rank-sum test indicates that this difference is significant at a 1% level.

To determine whether these differences remain true once one controls for other factors that might influence the innovation performance of software entrepreneurial ventures, we performed the econometric analysis described in the following section.

### 3.3. Specification of the econometric models and description of the independent variables

We analysed the innovation impact of collaborations with the OSS community through the estimation of the following model:

$$Y_i = \alpha + \beta DOSSCollaboration_i + \gamma^T Z_i + \varepsilon_i, \quad (1)$$

where  $Y_i$  is one of the three measures of innovation performance presented in the previous section (i.e.,  $DInnovation$ ,  $NInnovation$ , and  $ShareInnSales$ ),  $DOSSCollaboration_i$  is the variable that identifies OSS entrepreneurial ventures,  $Z_i$  is a vector of firm-specific control variables, and  $\varepsilon_i$  is the error term.

Overall, five different econometric models were estimated, according to the dependent variable under consideration. We ran a logit model when the dependent variable was the dummy *DInnovation*, Poisson and negative binomial<sup>8</sup> models when we measured innovation through the count variable *NInnovation*<sup>9</sup>, and an ordered logit model when the dependent variable was the ordered variable *ShareInnSales*.

The independent variables of the models described above are as follows. The key explanatory variable is *DOSSCollaboration*, which is a dummy variable equalling 1 if the focal entrepreneurial venture started collaborating with the OSS community before 2005. If the coefficients of *DOSSCollaboration* were positive, we could conclude that entrepreneurial ventures collaborating with the OSS community exhibit innovation performance superior to that of their non-collaborating peers.

The models also included a series of control variables that might affect the innovation performance of software entrepreneurial ventures. Control variables refer to 2005, and they are therefore predetermined with respect to our dependent variables. First, we controlled for an entrepreneurial venture's human capital (*HumanCapital*). In line with the literature on labour and education economics (Heckman, Lochner and Todd 2003; Folloni and Vittadini 2010), we use a measure of human capital pertaining to off-the-job training. In particular, *HumanCapital* is equal to the percentage of the individuals employed by the focal firm that possessed at least a master's-level education.<sup>10</sup> Next, we included a proxy for firms' R&D investments: *DevelopersShare*. This variable is the number of software developers divided by the total number of employees of the focal

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<sup>8</sup> We adopted the negative binomial specification to control for departure from the assumption of equidispersion that is made when the model is of a Poisson type (i.e.,  $E[NInnovation] = Var[NInnovation]$ ).

<sup>9</sup> To ensure the reliability of our results regarding the impact of collaborations with the community on *NInnovation*, we adopted two alternative specifications. First, we used a weighted quasi-maximum likelihood (QML) Poisson model. Second, because *NInnovation* has a non-negligible number of zeros, we estimated both Zero-Inflated Poisson and Hurdle Poisson models (for a review of the solutions proposed in the econometric literature to have consistent estimates when a dependent variable is characterised by an excess of zero observations, see Cameron and Trivedi 2005). The results do not differ from those discussed below. These results are available from the authors upon request.

<sup>10</sup> As an alternative proxy for the human capital of the entrepreneurial venture, we built a continuous variable calculated as the total number of years of schooling of employees. When we replace *HumanCapital* with this new indicator, the sign and significance of the coefficients of *DOSSCollaboration* do not change. The results are available from the authors upon request.

firm. This measure is a widely used proxy for R&D investments in studies focusing on the software industry (see, e.g., Bessen and Hunt 2007) and proves to be especially suitable for entrepreneurial ventures for which it is difficult to collect data on R&D expenses. Moreover, because it is widely accepted that firm size is likely to affect firm innovation performance (for a thorough survey, see Becheikh, Landry and Amara 2006), we included *LnSize*, measured as the logarithm of the total number of employees (plus one), as a control.

To control for the sample firms' probability to introduce innovations other than new (improved) software solutions, we included a dummy equalling 1 if the focal entrepreneurial venture introduced any process or organisational innovation during the 2005–2008 period (*DOtherInnovation*). To control for the use of formal instruments for the protection of intellectual property, we inserted in the model *DIPR* a dummy variable that equals 1 if the firm had ever used patents and/or trademarks. Because recent studies have shown that access to external sources of information positively affects firms' innovation potential (see, e.g., Laursen and Salter 2006), we controlled for the total number of external sources of information to which the entrepreneurial venture had access and could thus exploit for innovation purposes (*NInfSources*). Six potential sources of information were considered: i) suppliers, ii) customers, iii) competitors, iv) public research organisations, v) professional associations and online communities, and vi) social networks. Therefore, *NInfSources* is a cardinal variable ranging from 0 to 6. To control for the effect of agglomeration economies, we included a geographical dummy variable equalling 1 for the entrepreneurial ventures located in the Province of Bologna, Italy. Indeed, of the nine provinces of the Emilia-Romagna region, Bologna is the area in which most software entrepreneurial ventures are located (more than 28% of the entire population). Finally, we controlled for firm age and for market-specific effects by including a series of age dummies<sup>11</sup> and industry segment dummies.<sup>12</sup>

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<sup>11</sup> We considered 4 age dummies that, respectively, equal 1 if the studied firm was founded (i) in 2004, (ii) in 2003, (iii) in 2002, and (iv) in 2001. The baseline is being founded before 2001.

<sup>12</sup> We considered four product market segments and six service types. The product market segments are the following: (i) management applications; (ii) software for office automation; (iii) content management systems, Web sites, portals, hosting, e-commerce solutions; and (iv) other products. The six service types are the following: (i)

Table 3 illustrates descriptive statistics for the independent variables and reports their correlation matrix. In general, the correlation across the independent variables is low, suggesting the absence of any relevant problems of multicollinearity.

[Table 3]

## 4. Results

### 4.1. The impact of collaborations with the OSS community on firm innovation performance

Table 4 presents the estimates of the econometric models. For each model, specification (a) includes only the controls, whereas specification (b) also includes the key explanatory variable *DOSSCollaboration*. The first two columns of the table report the results of the logit models, with *DInnovation* being the dependent variable (Models 1a,b). The next four columns report the results with *NInnovation* as the dependent variable differentiating between the Poisson model (Models 2a,b) and the negative binomial model (Models 3a,b). The last two columns report the results for the ordered logit models with the share of sales of new software solutions, *ShareInnSales*, as the dependent variable (Models 4a,b).

[Table 4]

Regarding the control variables (see Model specifications a), the coefficient of *DOtherInnovation* is positive and significant at conventional confidence levels in all of the specifications. Reasonably enough, a complementarity exists among the different innovation typologies (this result is in line with Cassiman and Veugelers 2006). Interestingly, all of the remaining determinants of the three measures of innovation performance are different. In Model 1a, none of the remaining controls is significant. Models 2a and 3a indicate that the number of new software solutions introduced by entrepreneurial ventures in the period under scrutiny was higher the larger the firm size was; *LnSize* indeed exhibits a positive coefficient, which is significant at a 1% level. Moreover, some differences exist between the Poisson and the negative binomial

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installation, (ii) maintenance and support, (iii) training, (iv) integration of different components, (v) software customisation, and (vi) other services.

specifications regarding the significance of the controls. In the Poisson Model 2a, *HumanCapital* exhibits a positive coefficient that is significant at a 1% level. This indicates that the entrepreneurial ventures having superior human capital introduced more new software solutions between 2005 and 2008. Conversely, in Model 3a, *DeveloperShare* exhibits a positive and significant (at 1%) coefficient. Reasonably enough, the entrepreneurial ventures employing a higher share of software developers introduced a higher number of new software solutions. Finally, in Model 4a, both *DeveloperShare* and *LnSize* exhibit positive and (weakly) significant coefficients.

When *DOSSCollaboration* is added to the set of regressors (see Models b), the signs and significance of the coefficients of the controls do not differ from those in Models a. The insertion of *DOSSCollaboration* improves the explanatory power of the models, as is documented by the increase of the McFadden's  $R^2$ .<sup>13</sup> More interestingly, the coefficient of *DOSSCollaboration* is positive and significant in all Models b. This finding indicates that during the period under consideration, OSS entrepreneurial ventures had a higher probability of generating innovations, introduced a higher number of innovative solutions, and had higher sales from new software solutions than their non-collaborating peers. Overall, we find evidence that OSS entrepreneurial ventures exhibit innovation performance superior to that of the other software entrepreneurial ventures.

To assess the magnitude of the effects of collaborations with the OSS community on the innovation performance of software entrepreneurial ventures, based on the estimates of Models b, we first computed the three innovation measures for a “benchmark” entrepreneurial venture (i.e., with all the dummy and cardinal control variables set at their median value and all the continuous control variables set at their mean value) with *DOSSCollaboration*=0. Then, we calculated the estimated values of the three innovation measures for the same benchmark firm with *DOSSCollaboration*=1. Regarding the benchmark entrepreneurial venture non-collaborating with

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<sup>13</sup> We also run likelihood-ratio tests for the exclusion of additional variables from the restricted logit model and Lagrange multiplier tests of the generalised logit model. Both types of test are strongly rejected at a 1% significance level. This means that Model 1b is more informative and that linearity in the parameters can be confidently assumed. The results of the tests are available from the authors upon request.

the OSS community, the OSS entrepreneurial venture was found to have a 23% higher probability to innovate, to introduce 2 additional new software solutions, and to have a 13% greater probability of being in a higher category of *ShareInnSales*.

It is worth noting that the estimates discussed above are unbiased and consistent, provided that the assumption of exogeneity of *DOSSCollaboration* is satisfied. However, some unobserved factors might render the observed relationship between *DOSSCollaboration* and the measures of innovation performance endogenous. For example, both the decision to engage in collaborations with the OSS community and entrepreneurial ventures' innovation performance may be positively correlated with the demographic characteristics of entrepreneurial ventures' owner-managers (Beckman and Burton 2011). Regarding the role played by owner-managers in shaping the innovation performance of high-tech entrepreneurial ventures, see also the recent contribution of Knockaert et al. 2011). Specifically, more experienced and educated owner-managers may be more likely to search for new knowledge sources and thus to initiate collaborations with the OSS community. At the same time, conventional wisdom in entrepreneurship suggests that owner-managers with superior human capital are likely to positively influence the innovation performance of their firms.

#### **4.2. Addressing the endogeneity problem**

Controlling for the potential endogeneity of *DOSSCollaboration* may be tricky because all of the models presented and discussed in the previous section are non-linear models, and *DOSSCollaboration* is a dummy variable. Indeed, for continuous outcome variables, two-stage regression strategies have been developed to tackle the problem, even when the endogenous variable is a dummy (Heckman 1978). However, in the presence of non-continuous outcomes with endogenous dummy variables, an approach via maximum likelihood is needed to obtain a consistent and efficient estimator.

For this purpose, we relied on a series of endogenous switching regression models (Miranda and Rabe-Hesketh 2006). In particular, we resorted to the following specification<sup>14</sup>:

$$Y_i = \alpha_1 + \beta_1 DOSSCollaboration_i + \gamma^T Z_i + \varepsilon_{1i} \quad (2)$$

$$DOSSCollaboration_i = \alpha_2 + \beta_2 DOpenStandard_i + \beta_3 DOpenValues_i + \gamma^T Z_i + \varepsilon_{2i} \quad (3)$$

where  $Y_i$  is one of the three measures of firm innovation performance (i.e., *DInnovation*, *NInnovation*, or *ShareInnSales*). Equation (2) contains the same explanatory variable and controls included in Equation (1) (see section 3.3). Equation (3) specifies a model for the endogenous switching dummy *DOSSCollaboration*. The model specifies two exclusion restrictions in the form of two dummies equalling 1 if the respondent for firm  $i$  rated as a highly important motive for collaborating with the OSS community sharing the OSS values (*DOpenValues*) and the possibility of exploiting the benefits on an open standard (*DOpenStandard*), respectively.<sup>15</sup> *DOpenValues* and *DOpenStandard* are good instruments because they are likely to explain the probability of collaborating with the OSS community but not the innovation performance of the entrepreneurial venture. The system of equations is fitted by maximum likelihood with Gauss-Hermite quadrature.

Moreover, to check for the presence of endogeneity, we tested the null hypothesis that the correlation between the error terms of the two equations ( $\varepsilon_{1i}$  and  $\varepsilon_{2i}$ ) does not significantly differ from zero. When the dependent variables are *DInnovation* and *ShareInnSales*, the likelihood-ratio test of the correlation of the residuals of Equations (2) and (3) is not rejected at conventional confidence levels ( $\chi^2(1)=0.21$  and  $\chi^2(1)=1.72$ , respectively). Conversely, when we measure innovation performance through the count variable *NInnovation*, the likelihood-ratio test is rejected at a 1% significance level. Therefore, in this case, *DOSSCollaboration* is likely to be endogenous.

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<sup>14</sup> Technical details on the econometric models as well as a hands-on tutorial on how to estimate them on Stata are provided in Miranda and Rabe-Hesketh (2006).

<sup>15</sup> We asked the respondents to rate on a 4-point Likert scale their level of agreement with the following statements: i) one of the key motives for collaborating with the OSS community is sharing the OSS values and ii) one of the key motives for collaborating with the OSS community is the possibility of exploiting the benefits of an open standard. The scale ranged from 1 (strongly agree) to 4 (strongly disagree). Next, we assigned a value of 1 to *DOpenValues<sub>i</sub>* and *DOpenStandard<sub>i</sub>* if the respondents rated their level of agreement with statements i) and ii), respectively, as 1 or 2.

Nevertheless, the sign and significance of the coefficient of *DOSSCollaboration* are still in line with the results presented in Table 4.

## 5. Discussion and conclusions

In this paper, we analyse the effects of collaborations with the OSS community on the innovation performance of software entrepreneurial ventures. By taking advantage of a unique dataset and through the application of rigorous econometric techniques, we show that OSS entrepreneurial ventures exhibit superior innovation performance in comparison with their non-collaborating peers. This finding is robust to the use of different innovation measures.

The paper contributes to the previous knowledge in three main respects. First, it adds to the extensive academic debate on open innovation. To date, the community of scholars studying open innovation has mainly focused on collaborations of established firms with other companies or universities (Laursen and Salter 2006). Entrepreneurial ventures being able to activate open innovation processes has been recognised only recently by the open innovation literature (van de Vrande et al. 2009). Moreover, the case of OSS is popular in the open innovation realm (van de Vrande et al. 2010), to the extent that the principles of OSS development have been used as a basis for understanding the functioning of open innovation (West and Gallagher 2006). However, how entrepreneurial ventures operate in this peculiar open innovation realm is still a poorly explored issue (for an exception, see Gruber and Henkel 2006).

Second, in the spirit of the present special issue, our work adds to the stream of the entrepreneurship literature that analyses the impact of collaborations with external third parties on the innovation performance of entrepreneurial ventures. A well-established tradition in the entrepreneurship field documents that entrepreneurial ventures intensively network with external third parties for innovation purposes (Stuart and Sorenson 2007). This literature has extensively studied the innovation impact of alliances with other firms and collaborations with public research organisations (e.g., Lee, Lee and Pennings 2001). Conversely, in general, no remarks have been



made on the impact of collaborations with communities of users and developers. By documenting that networking with the OSS community positively affects entrepreneurial ventures' innovation performance, this paper suggests that alternative third parties (i.e., *unconventional allies*, O'Mahony and Bechky 2008) can be sources of advantages in the innovation race for entrepreneurial ventures.

Third, the present paper contributes to the OSS literature. The business and technical press has often speculated on the links between OSS and innovation, asking whether OSS is about innovation or merely imitates successful proprietary solutions. However, few academic studies have explicitly addressed innovation in the OSS realm (for recent exceptions, see Rossi-Lamastra 2009; Katsamakos and Georgantzas 2010). In addition, no studies have addressed how collaborations with the OSS community affect the innovation performance of entrepreneurial ventures. Stam (2009) has analysed the effects of participation in OSS projects on firms' innovation performance. However, the author has neither explicitly considered the specificities of entrepreneurial ventures nor compared the innovation performance of collaborating and non-collaborating firms.

The paper has several limitations that suggest avenues for future research. First, we distinguish entrepreneurial ventures that collaborate with the OSS community (OSS entrepreneurial ventures) from their non-collaborating peers by introducing a dummy variable in our econometric specifications. However, an in-depth analysis of entrepreneurial ventures' collaborations with the OSS community would require more nuanced constructs and measures. OSS entrepreneurial ventures are heterogeneous in their collaboration modes. Frequently, they mix the offering of proprietary and OSS solutions, thus adopting a *hybrid business model* (Lerner and Schankerman, 2010; Bonaccorsi, Giannangeli and Rossi 2006). Moreover, different firms usually take advantage of the innovation inputs in-sourced from the OSS community in different ways, which range from selling pre-packaged OSS products to developing new OSS programmes from scratch. These diverse ways of relying on the OSS community for innovation purposes may differently affect OSS entrepreneurial ventures' innovation performances. In addition, OSS entrepreneurial ventures are possibly heterogeneous in their inner characteristics. These ventures probably have diverse internal

competences and resources, which are likely to moderate the impact of collaborations with the OSS community on their innovation performance. Specifically, the role of human capital in determining the innovation performance of high-tech entrepreneurial ventures is well established in the field of entrepreneurship (for a review, see Ungher et al. 2010). Therefore, it might be conjectured that the human capital of entrepreneurial ventures' owner-managers and employees affects the relationship between collaborations with the OSS community and innovation. Owner-managers and employees with advanced education in computer science or with extensive experience in the OSS field are probably more able to appropriate the innovation benefits stemming from collaborations with the OSS community. Specifically, experience in collaborating with the OSS community is likely to play a major role. Leveraging the OSS community for innovation purposes is far from simple for an OSS firm. Indeed, the OSS community is a varied common pool of resources and competences, the quality of which is highly variable (Colombo, Piva and Rossi-Lamastra 2011). In order to in-source valuable innovation inputs from such a common pool, an OSS entrepreneurial venture must learn to navigate it (Piva, Rentocchini and Rossi-Lamastra 2011). The firm must develop familiarity with which OSS projects develop high-quality code to be used as a basis for developing new software solutions and with who are the most talented OSS developers to become involved with in innovation activities. Likewise, the OSS literature has shown that OSS developers are sometimes suspicious of firms because they fear that firms' profit-oriented motives can drive them to hijack the open code, thereby removing it from the OSS common pool (O'Mahony 2003). Accordingly, OSS entrepreneurial ventures aiming at leveraging the OSS community for innovation must learn how to cope with the values of openness and knowledge sharing that inform the OSS community. Violation of these values can severely undermine fruitful collaborations with the OSS community.

Second, in line with a mainstream tradition in the innovation field, this paper focuses on product innovation. However, scholars explicitly recognise that collaborating with the OSS community is an important *organisational innovation* in firms' software production (Lerner and Tirole 2002). To exploit its full potential, such an organisational innovation should probably be

complemented by other organisational innovations, such as the introduction of new human resource management practices or new software production techniques. Therefore, exploring the impact of collaborations with the OSS community on the introduction of organisational innovations by entrepreneurial ventures would be a worthwhile addition to this work.

Third, we measure innovation performance through survey questions that resemble questions from the Community Innovation Survey. Such a method of data collection is well established in the innovation literature, but we are well aware that measuring innovation is a challenging task in the software realm (for a discussion of this issue, see, e.g., Rossi-Lamastra 2009). Therefore, future studies on the relationship between collaborations with the OSS community and firms' innovation performance would benefit from the introduction of alternative indicators of innovation performance (e.g., based on expert assessment and case-study evidence).

Despite its limitations, our paper has relevant practical implications. First, our data show that OSS deserves the confidence placed in it by entrepreneurs and managers. High-tech markets are currently globalised and highly competitive. Such hyper-competitive arenas not only magnify the traditional liabilities of relatively new ventures but also encourage them to engage deeply in the race for innovation. Our findings indicate that collaborating with the OSS community may be a winning strategy for software entrepreneurial ventures to compete in the market. Our results may also be of interest to policymakers aiming to stimulate innovation by entrepreneurial ventures. OSS has been attracting the attention of policymakers for years; however, to date, policy measures have largely been directed to support the adoption of OSS by public bodies (Rentocchini and Tartari 2010). The idea of incentivising entrepreneurial ventures' collaborations with the OSS community is still lagging. By offering evidence of the positive impact of collaborations with the OSS community on OSS entrepreneurial ventures' innovation performance, the present study can provide a rationale for policy interventions in this area.

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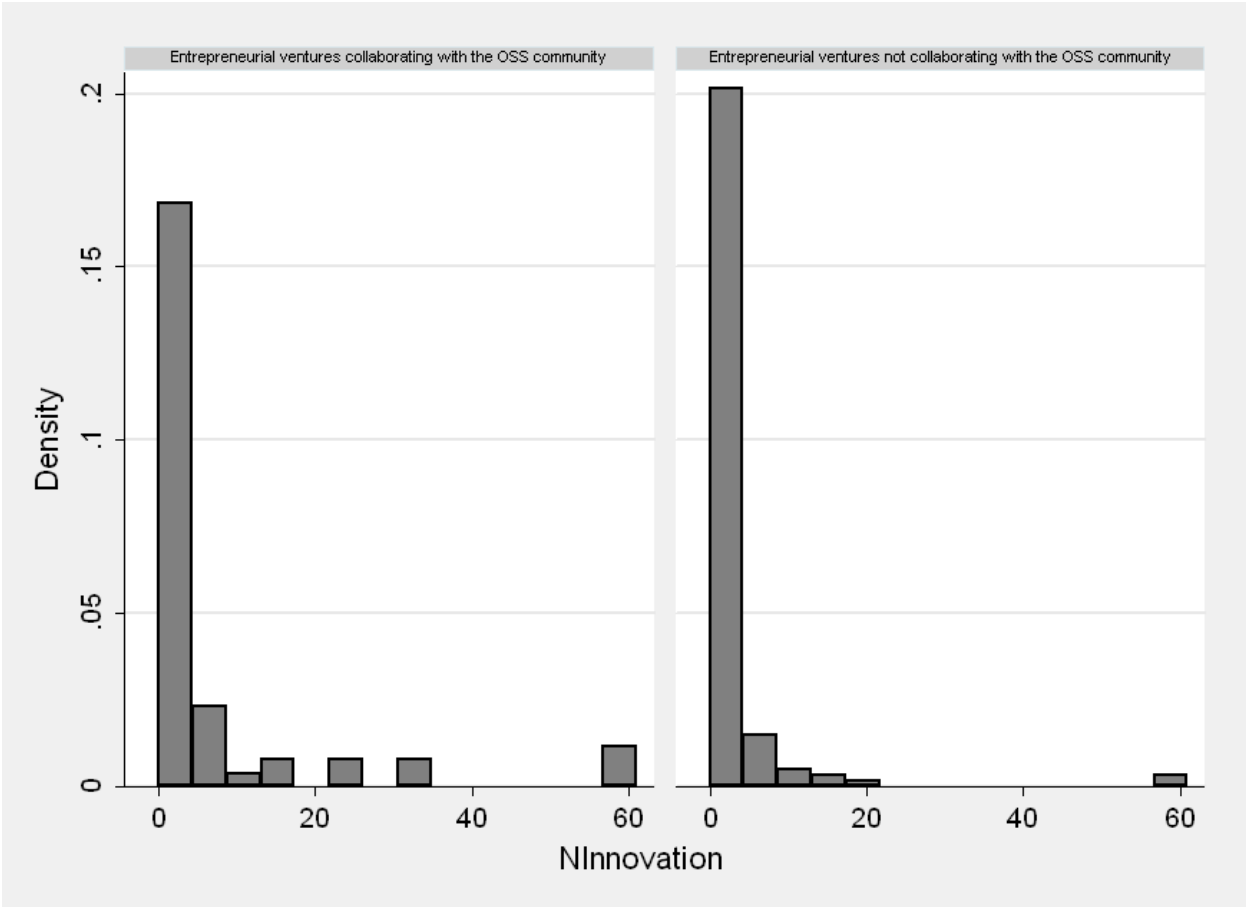
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**Figure 1 – Distribution of the number of new or significantly improved solutions introduced by sample firms between 2005 and 2008.**



**Table 1 – Descriptive statistics of the sample firms**

	Sample firms (N=199)		Entrepreneurial ventures collaborating with the OSS community (N=60)		Entrepreneurial ventures not collaborating with the OSS community (N=139)	
	No.	%	No.	%	No.	%
<b><i>Employees on December 31, 2005</i></b>						
≤10	170	85.4	54	90.0	116	83.4
>10	29	14.6	6	10.0	23	16.5
<i>Total</i>	<i>199</i>	<i>100.0</i>	<i>60</i>	<i>100.0</i>	<i>139</i>	<i>100.0</i>
<b><i>Age class on December 31, 2005</i></b>						
≤5 years	57	28.6	23	38.3	34	24.5
>5 years	142	71.4	37	61.7	105	75.5
<i>Total</i>	<i>199</i>	<i>100.0</i>	<i>60</i>	<i>100.0</i>	<i>139</i>	<i>100.0</i>
<b><i>Product categories</i></b>						
Management applications	74	37.2	27	45.0	47	33.8
Office automation products	51	25.6	23	38.3	28	20.1
Web products	81	40.7	38	63.3	43	30.9
Other types of products	57	28.6	26	43.3	31	22.3
<b><i>Service categories</i></b>						
Installation	101	50.8	38	63.3	63	45.3
Maintenance and assistance	147	73.9	51	85.0	96	69.1
Training	69	34.7	27	45.0	42	30.2
Integration	60	30.2	30	50.0	30	21.6
Software customisation	107	53.8	37	61.7	70	50.4
Other types of services	13	6.5	4	6.7	9	6.5

**Table 2 – Innovation performance of the sample firms between 2005 and 2008**

	<b>Entrepreneurial ventures collaborating with the OSS community (N=60)</b>		<b>Entrepreneurial ventures not collaborating with the OSS community (N=139)</b>	
	<i>No.</i>	<i>%</i>	<i>No.</i>	<i>%</i>
<b><i>DInnovation</i></b>				
=0	26	43.3	98	70.5
=1	34	56.7	41	29.5
<i>Total</i>	<i>60</i>	<i>100.0</i>	<i>139</i>	<i>100.0</i>
<b><i>ShareInnSales</i></b>				
=0 (i.e., 0%)	15	28.3	66	52.4
=1 (i.e., 1%-20%)	11	20.8	31	24.6
=2 (i.e., >20%)	27	50.9	29	23.0
<i>Total</i>	<i>53</i>	<i>100.0</i>	<i>126</i>	<i>100.0</i>

**Table 3 – Descriptive statistics and correlation matrix of the explanatory variables (N=199)**

<b>Variable</b>	<b>Mean</b>	<b>Std.</b>	<b>Min</b>	<b>Max</b>	<b>(1)</b>	<b>(2)</b>	<b>(3)</b>	<b>(4)</b>	<b>(5)</b>	<b>(6)</b>
(1) <i>DOSSCollaboration</i>	0.30	0.46	0.00	1.00	1.00					
(2) <i>HumanCapital</i>	4.41	14.31	0.00	100.00	0.15	1.00				
(3) <i>DevelopersShare</i>	66.90	36.03	0.00	100.00	0.13	0.08	1.00			
(4) <i>LnSize</i>	1.56	0.88	0.69	5.93	-0.04	0.1	-0.22	1.00		
(5) <i>DOtherInnovation</i>	0.30	0.46	0.00	1.00	0.12	-0.11	-0.04	0.12	1.00	
(6) <i>DIPR</i>	0.16	0.36	0.00	1.00	0.11	0.04	-0.12	0.19	0.15	1.00
(7) <i>NInfSources</i>	1.99	1.34	0.00	6.00	0.20	0.05	0.08	-0.01	0.30	0.14

**Table 4 – Results of the econometric estimates of the effect of collaborations with the OSS community on firm innovation performance**

		<i>DInnovation</i>		<i>NInnovation</i>			<i>ShareInnSales</i>		
		<b>Logit</b>		<b>Poisson</b>	<b>Negative binomial</b>		<b>Ordered logit</b>		
		<i>(Model 1a)</i>	<i>(Model 1b)</i>	<i>(Model 2a)</i>	<i>(Model 2b)</i>	<i>(Model 3a)</i>	<i>(Model 3b)</i>	<i>(Model 4a)</i>	<i>(Model 4b)</i>
<i>a</i> <sub>0</sub>	<i>Constant</i>	-3.24*** (1.00)	-3.45*** (1.06)	-4.14*** (0.97)	-3.77*** (0.97)	-5.72*** (0.99)	-5.58*** (1.02)	-	-
<i>a</i> <sub>1</sub>	<i>DOSSCollaboration</i>	-	0.99** (0.40)	-	0.84*** (0.29)	-	0.87** (0.43)	-	0.81** (0.40)
<i>a</i> <sub>2</sub>	<i>DeveloperShare</i>	0.01 (0.01)	0.01 (0.01)	0.01 (0.00)	0.00 (0.00)	0.02*** (0.01)	0.02*** (0.01)	0.01* (0.01)	0.01* (0.01)
<i>a</i> <sub>3</sub>	<i>HumanCapital</i>	0.01 (0.01)	0.00 (0.01)	0.03*** (0.01)	0.03*** (0.01)	0.02 (0.01)	0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)
<i>a</i> <sub>4</sub>	<i>LnSize</i>	0.34 (0.21)	0.34 (0.21)	0.87*** (0.18)	0.83*** (0.17)	1.07*** (0.23)	1.06*** (0.23)	0.37* (0.21)	0.38* (0.21)
<i>a</i> <sub>5</sub>	<i>DOtherInnovation</i>	0.82** (0.41)	0.75* (0.42)	0.88** (0.37)	0.82** (0.38)	1.22*** (0.41)	1.43*** (0.44)	0.87** (0.36)	0.85** (0.36)
<i>a</i> <sub>6</sub>	<i>DIPR</i>	0.06 (0.45)	0.02 (0.44)	0.27 (0.46)	0.23 (0.41)	0.10 (0.42)	-0.21 (0.46)	0.52 (0.52)	0.43 (0.50)
<i>a</i> <sub>7</sub>	<i>NInfSources</i>	-0.05 (0.16)	-0.08 (0.15)	0.11 (0.15)	0.06 (0.16)	0.02 (0.15)	-0.05 (0.15)	0.08 (0.15)	0.06 (0.14)
<i>Age dummies</i>		Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.
<i>Geographical dummies</i>		Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.
<i>Industry dummies</i>		Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.	Inc.
<i>Tests of proportionality of odds across response categories</i>									
<i>- Bran test</i>		-	-	-	-	-	-	-	-0.83(12)
<i>- Approximate likelihood ratio test</i>		-	-	-	-	-	-	-	28.98(21)
<i>McFadden's R<sup>2</sup></i>		0.16	0.18	0.48	0.51	0.08	0.09	0.16	0.17
<i>Observations</i>		199	199	199	199	199	199	179	179
<i>Wald <math>\chi^2</math></i>		34.57(21)**	36.66(22)**	135.11(21)***	149.53(22)***	127.15(21)***	120.58(22)***	64.08(21)***	63.02(22)***
<i>Log-likelihood</i>		-111.29	-108.29	-742.71	-708.52	-285.36	-284.23	-160.22	-158.02

Legend: \* p<0.10, \*\* p<0.05, \*\*\* p<0.01. Robust standard errors and degrees of freedom are in parentheses.