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Skills, division of labor and performance in collective inventions: Evidence from open source software

Paola Giuri [a], Matteo Ploner [b], Francesco Rullani [c], Salvatore Torrisi [a,d,*]

[a] Department of Management, University of Bologna, Via Capo di Lucca, 34, 40126 Bologna, Italy
[b] Department of Economics, University of Trento, Via Inama, 5, 38100 Trento, Italy
[c] Department of Innovation and Organizational Economics, Copenhagen Business School, Kilevej 14A, 2000 Frederiksberg, Denmark
[d] CESPRI-KITES, University L. Bocconi, Milano, Italy

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This paper investigates the skills and the division of labor among participants in collective inventions. Our analysis draws on a large sample of projects registered at Sourceforge.net, the world's largest incubator of open source software activity. We test the hypothesis that skill variety of participants is associated with project performance. We also explore whether the level of modularization of project activities is correlated with performance. Our econometric estimations show that skill heterogeneity is associated with project survival and performance. However, the relationship between skill diversity and performance is non-monotonic. Design modularity is also positively associated with the performance of the project. Finally, the interaction between skill heterogeneity and modularity is negatively associated with performance.

1. Introduction

Collective inventions among profit-seeking individuals and organizations have become popular in the economics literature since the seminal paper of Robert Allen (1983) on the iron district of Cleveland in the nineteenth century. More recently, collective inventions have come to the forefront of economists' attention because of the diffusion of open source software (OSS hereafter). OSS can be viewed as a 'virtual' community of practice made up of inventors who voluntarily contribute to multiple collective inventions. OSS offers expert developers the opportunity to participate in innovation networks which are, to some extent, reminiscent of the communities of users in the early age of computing (Steinmueller, 1996; Torrisi, 1998) or other user-centered innovation processes such as those analyzed by von Hippel (1988).

Most studies have attempted to explain why a growing number of independent developers ('hackers') voluntarily disclose their inventions. Several theoretical works seek to understand not only the motivations for disclosure of the source code, but also the social norms and the patterns of collaboration among distributed developers, and the implications for efficiency and social welfare (e.g. Raymond, 1999; von Hippel, 2001; Lerner and Tirole, 2002; Johnson, 2002; Harhoff et al., 2003; Dalle and David, 2005).

Empirical studies (e.g. Lakhani and von Hippel, 2003; Hertel et al., 2003; Lakhani and Wolf, 2005) also ask why hackers freely reveal information and what is the contribution of single participants to the productivity of specific OSS projects. However, little is known about the determinants of OSS projects' performance on a larger scale.

Our paper uses a large sample of OSS teams to study the association between a project's performance (measured by bugs and patches fixed, new feature requests completed, new file releases and changes made to the project's source code) and two important dimensions of team production — skill composition and the level of modularity of project activities.

Our analysis draws on two streams of the literature. The first one is rooted into team production theory. Team production requires collaborative skills, i.e. communication ability (people skills), leadership, and the ability to carry out multiple tasks. These skills add to specialized technical skills, thereby expanding production possibilities. Collaborative skills also favor the "discovery of ways to assign, organize, and perhaps alter tasks to produce more efficiently" (Hamilton et al., 2003: p. 470). Moreover, most importantly for this paper, heterogeneity among team members favors mutual learning and intra-team bargaining, creating opportunities for nonmonetary benefits such as a stimulating working environment, peer recognition and decisional authority (Hamilton et al., 2003).

* Corresponding author. Department of Management, University of Bologna, Via Capo di Lucca, 34 40126 Bologna, Italy. Tel.: +39 051 2098061; fax: +39 051 246411.
E-mail address: torrisi@unibo.it (S. Torrisi).

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In this setting we analyze the association between project performance and skill heterogeneity of its members. We expect that skill heterogeneity is positively associated with project performance in teams of open source software developers (Galunic and Riordan, 1998; Sutton and Hargadon, 1997). We focus on two dimensions of skill heterogeneity. First, individual participants must be prepared to carry out multiple tasks whose fulfillment requires a variety of skills. Second, open source participants may have different levels of commitment to single projects. In particular, we can distinguish core developers, who are highly committed and presumably highly experienced people, from the varied community of contributors, who occasionally participate in problem solving by supplying patches, reporting bugs or asking for assistance. Then, it is likely that the level and composition of skills vary across different categories of participants.

The second research line is associated with a key characteristic of the modern organization design that is modularity (Milgrom and Roberts, 1990, 1995). Modularity in design and production has been defined as a strategy for "building a complex product or process from smaller subsystems that can be designed independently" (Baldwin and Clark, 1997, p. 84). In modular production, the value generated by each module can be separated from the total outcome. Moreover, modularity allows for experimentation and innovation, increases the efficiency of design activities, favors mutual learning between team members, and stimulates innovation (Baldwin and Clark, 1997; Langlois, 2002; Pil and Cohen, 2006). Thus, we posit that the level of design modularization or division of tasks at the project level is correlated with observable differences in performance across open source software projects.

This paper provides a novel empirical contribution to the literature on the economics of collective inventions. Our contribution is twofold. First, unlike many previous works that have focused on one or a few open source software projects, we provide an empirical investigation based on a large sample of OSS projects hosted by the SourceForge.net website, one of the largest repositories of OSS activity. To our knowledge, this is one of the few attempts to provide a systematic empirical analysis of multiple dimensions of OSS projects. Second, we focus on a crucial economic issue and examine open source projects with the aim of understanding the association between performance and key project characteristics — team members' skill composition and design modularity.

This paper is organized as follows. Section 2 discusses the theoretical background. Section 3 presents the data. Section 4 illustrates the methodology for estimating the relationship between skills and modularity and project performance. Section 5 analyzes the empirical results. Section 6 concludes.

2. Theoretical background

Our paper focuses on two dimensions of collective inventions: (i) the diversity of skills of team members and (ii) modularity.

2.1. Diversity of skills

The economics literature has analyzed the association between skills and innovation. Human capital is found to be an important input to innovative activity in several empirical studies (e.g. Leiponen, 2005; Mohen and Roller, 2005). Skills are not only important for creating new ideas, but also for using new technologies and absorbing knowledge generated elsewhere. A vast body of the literature on productivity growth has demonstrated the complementarity between skills and investments in new technologies (e.g. Bresnahan et al., 2002).

The implications of skill heterogeneity for productivity and innovation have been less explored in the literature. First, skill heterogeneity implies that firms can experiment with complex combinations of skills that are difficult to imitate (Lippman and Rumelt, 1982). Second, skill diversity allows a more flexible strategic adaptation to changing external environments (Galunic and Riordan, 1998). Skill heterogeneity provides firms with more comprehensive problem-solving ability and creative conflict resolution (Sutton and Hargadon, 1997; Galunic and Riordan, 1998). The cognitive diversity resulting from interaction among people with different perspectives makes it possible to identify and formulate a wider array of problems and to find a larger set of alternative solutions (Bantel and Jackson, 1989).

Finally, skill heterogeneity has a positive effect on team productivity because of mutual learning (higher-skilled team members can transfer their knowledge to lower-skilled partners) and intra-team bargaining. Even if the participation decision is beyond the scope of our paper, we should recall briefly the reasons why heterogeneous individuals decide to participate in the same team. This is important to our purposes because, as Hamilton et al. (2003) have noted, "the productivity level achieved by the team is limited by the productivity of the highest-ability worker on the team, and this worker will not join a team without an additional source of surplus from team production" (p. 472). While it is quite obvious why a low-ability individual joins a team, the participation incentives of high-ability individuals are much less clear. Higher-skilled workers have a higher outside option and a greater bargaining power; therefore, they can affect the work norm and induce a higher level of team productivity. Moreover, highest-ability workers in team production systems may sacrifice some income in exchange for non-pecuniary benefits, such as socialization, a higher social status, greater decisional authority among peers, and a more challenging working environment (Hamilton et al., 2003).

Various empirical papers examine the benefits of heterogeneous workforce using firm-level and worker-level data. For example, Bantel and Jackson (1989) have analyzed the top management teams of a sample of U.S. banks and showed that more innovative banks have a more diversified set of top manager expertise. Similarly, Hamilton et al. (2003) have analyzed individual and team productivity in a U.S. garment firm over a three-year period, during which the workers could voluntarily switch from traditional production lines to flexible work teams based on a modular production system, U-shaped workplace, and multitasking. They found that skill heterogeneity of workers has a positive effect on team productivity. Laursen et al. (2005) have examined the performance of engineering consulting firms in Denmark and found less clear-cut results. More precisely, they report a non-monotonic relationship between skill diversity and performance in large firms, whereas small firms do not seem to benefit from skill diversity at all. Laursen et al. (2005) claim that these results reflect the cost of skill diversity. Communication costs and misunderstandings lead to negative productivity outcomes that counterbalance the productivity gains arising from the creativity and flexibility advantages discussed above. The negative productivity effects of communication costs have also been noted by Lazear (1999), who has made the point that without a common language, intercultural, global teams cannot gain from diversity. To take advantage of their complementary skills, team members have to reduce communication costs by sharing a common language. This line of reasoning can be extended to OSS teams where coordination costs are primarily due to the spatial dispersion of contributors. Although these costs are moderated by shared beliefs and visions among participants, Lazear's theory of multi-cultural teams suggests that the members of OSS teams should have some overlapping skills to communicate and coordinate their efforts.[1]

The discussion above leads to the following hypotheses. First, we expect a positive relationship between diversity in the skill level and profile of team members and project performance, controlling for the average level of skills. Second, when diversity increases beyond some

[1] We thank an anonymous referee for raising the point of overlapping skills and knowledge as a moderator of communication costs.