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The Effect of Project Types and Technologies on Software Developers' Efforts

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Abstract

Considering intrinsic valuation of software developers as the main motive for participating in open source projects, we examine the (Nash) equilibrium effort levels of the software developers in implementing projects that follow one of the three different technologies: the summation, the weakest-link, and the best-shot. Under the summation technology, developers having higher intrinsic valuation exert more effort in open source projects but all developers in commercial projects expend the same effort. Under the weakest-link technology, regardless of the types of the projects, all developers exert the same effort at equilibrium. In open source projects, the developer with the lowest intrinsic valuation has a crucial role in determining the equilibrium effort level while, in case of commercial projects, the equilibrium effort level is bounded by the net wage. Finally, under the best-shot technology, only one developer makes serious effort and the others free ride in both open source and commercial projects.

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1 Introduction

The phenomenal growth of open source software market has brought attention to the economics of open source software. Understanding issues around open source software (OSS) becomes important to both academics and practitioners. Especially, identifying motivations for software developers' participation in OSS projects has been exclusively studied by researchers from different fields including economics, information systems, management and psychology. Shah (2006) summarizes various motivations for OSS participation in the literature, including free software ideology (Stallman 2001), software users' desire to meet their own needs (Franke and von Hippel 2003, Lakhani and von Hippel 2003), career concerns (Learner and Tirole 2002), reputation within the community(Raymond 1999) and enjoyment (Ghosh 1998). A major implication from the aforementioned studies is that participation in OSS projects is driven by both intrinsic and extrinsic motivations unlike commercial software projects which are fueled by extrinsic motivations only.

The literature on intrinsic motivation of economic agents is growing in economics. Besley and Ghatak (2005) study job seeking behavior of motivated agents with different intrinsic benefits. Benabou and Tirole (2003) examine the relationship between extrinsic and intrinsic motivations of an agent in a setting where an informed principal selects a policy (extrinsic incentives) which reveals information about the agent's ability or his task (intrinsic incentives). Benabou and Tirole (2006) consider the three components of an agent's motivation: altruistic motivation, material self-interest, and self-image concerns. Lerner and Tirole (2002) argue that the motivations for OSS project participation can be explained by the existing economic theory.

With a motivation to understand the economics of OSS, we examine two issues: (1) impact of intrinsic valuation on software developers' project choice between commercial software and OSS and (2) software developers' optimal effort levels in different types of software projects with different technologies. Grounded in a principle-agent theory, we first investigate the project choice behavior of software developers and characterize the conditions for each project to be selected. Then, we analyze the optimal levels of efforts that the developers in each project exert to make the project successful. We consider three different technologies following Hirshleifer (1983): (1) summation technology, (2) weakest-link technology, and (3) best-shot technology.

This article is organized as follows: Section 2 presents the model and examines the project choice behavior of individual software developers. Section 3 analyzes the optimal levels of efforts in different types of projects with different technologies. Concluding remarks are provided in Section 4.

2 Endogenous Project Choice of Individual Developers

We consider the individual developers' choice between commercial and OSS projects. Participation in OSS projects is driven by developers' *intrinsic* motivation, which is inherent satisfaction for contributing to success of the project. That is, the developers in OSS projects get intrinsic benefits in case of the success of the projects. Instead, the developers in commercial software projects have *extrinsic* motivation such as external rewards (i.e., monetary incentives) in return for their efforts. Economists call the workers pursuing intrinsic benefits such as OSS developers *motivated agents*.

We assume that each developer's intrinsic valuation θ is uniformly distributed across the population of developers on an interval $[0, 1]$. The success of a project depends on the developer's unobservable effort. If the developer chooses his effort level $e \in [0, 1]$, he incurs cost $c(e) = \frac{1}{2}e^2$ and the project succeeds with probability $p(e) = e$. We assume that all the developers are risk-neutral and the reservation utility of them is 0.

Now we consider the individual developer's decision problem on which project to participate in between an OSS project and a commercial software project. First, consider the case of participating in the OSS project. If a developer with intrinsic valuation θ_i participates in the OSS project, he chooses the optimal effort level e_i which maximizes his expected utility

$$U_i = \theta_i e_i - \frac{1}{2}e_i^2.$$

$*$ in the superscript denotes the optimum in OSS project. Solving the maximization problem leads to the optimal effort level and expected payoff from the OSS project as follows:

$$e_i^* = \theta_i \quad \text{and} \quad U_i^* = \frac{1}{2}\theta_i^2.$$

Next, consider the commercial software project. In this case, the developer exerts his effort for external rewards offered by the software company. The company designs an incentive scheme $w = (w_s, w_f)$ that is contingent on success and failure of the commercial software project in order to induce the developer's effort. If the project succeeds, the company pays the developer the wage w_s. Otherwise, the company pays him the wage w_f. We assume that the individual developer has limited liability, that is, he cannot be paid a negative wage in any case. Let π be the benefit of the company when the project succeeds. The company gets nothing in case of the failure of the project. Then, the company solves the optimal contracting problem under moral hazard as follows:

$$\max_{\{w_s, w_f\}} U_C = e_i(\pi - w_s) - (1 - e_i)w_f$$

subject to:

- The limited-liability constraint: $w_s \geq 0$, $w_f \geq 0$;
- The participation constraint:

$$U_i = w_s e_i + w_f(1 - e_i) - \frac{1}{2}e_i^2 \geq 0;$$

- The incentive-compatibility constraint, which stipulates that the developer's effort level maximizes his expected payoff given an incentive scheme $w = (w_s, w_f)$:

$$e_i = \arg\max_{e_i \in [0,1]} U_i = w_s e_i + w_f(1 - e_i) - \frac{1}{2}e_i^2.$$

The incentive-compatibility constraint can be simplified to $e_i(w_s, w_f) = w_s - w_f$. $**$ in the superscript denotes the optimum in commercial software project. Substituting $e_i(w_s, w_f)$ into the expected payoff of the commercial company and solving its optimal contracting problem, we obtain the following incentive scheme the company offers to the developer:

$$w_s^{**} = \frac{1}{2}\pi \quad \text{and} \quad w_f^{**} = 0.$$

Given the optimal wage levels w_s^{**} and w_f^{**}, we obtain the equilibrium effort level and expected payoff of the developer participating in the commercial software project:

$$e_i^{**} = \frac{1}{2}\pi \quad \text{and} \quad U_i^{**} = \frac{1}{8}\pi^2.$$

Comparing the expected payoffs of the developers in the OSS project (U_i^*) and the commercial software project (U_i^{**}) leads to the following proposition.

Proposition 1 *The individual developer with low intrinsic motivation ($\theta_i \in [0, \frac{1}{2}\pi)$) participates in the commercial project. The individual developer with high intrinsic valuation ($\theta_i \in [\frac{1}{2}\pi, 1]$) chooses the OSS project.*

Proposition 1 indicates that the population of developers on an interval $[0, 1]$ is dichotomized by the critical value of intrinsic benefit from the OSS project, $\frac{1}{2}\pi$. This implies that an individual developer makes his project choice by comparing his intrinsic valuation (θ_i) with his monetary incentive ($\frac{1}{2}\pi$). Hence, the number of developers participating in the commercial project increases as the extrinsic benefit (π) increases.

3 Optimal Effort Level with Different Technologies

The success of software projects depends on the effort of individual developers. In this section, we investigate how much effort an individual developer, who belongs to either the commercial project or the OSS project, exerts to make the project successful. The effort level of each individual will depend on his own intrinsic and extrinsic benefits, costs, the efforts exerted by the other developers in his group, and the technology that transforms the efforts of the group into outcomes. We examine the effort levels of the individual developers in each project under the following three different technologies used in Hirshleifer (1983):

- **The summation technology:** The success of the project depends on the sum of the efforts exerted by the individual developers.
- **The weakest-link technology:** The success of the project depends on the minimum effort exerted by the individual developers.
- **The best-shot technology:** The success of the project depends on the maximum effort exerted by the individual developers.

Varian (2002) distinguishes these three prototypical cases in the context of software development. Focusing on computer system reliability and security, he examines the optimal effort levels of individual developers and free riding problem in each case. In this section, we study how different technology (i.e., summation, weakest-link and best-shot) affects the optimal effort levels of individual developers in different projects (i.e., commercial and OSS).

Let m and n be the numbers of developers who are participating in an OSS project and a commercial project, respectively. An individual developer i in the OSS project has his own intrinsic valuation θ_i. Without loss of generality, we assume that $\theta_1 \geq \theta_2 \geq \ldots \geq \theta_m$. Let e_i represent the effort level expended by the individual developer i in each group, and let $p(e_1, e_2, \ldots, e_{m(n)})$ be the probability of success of the project. We assume that the probability function $p(\cdot)$ is twice-differentiable, increasing, and concave, i.e. $p' > 0$ and $p'' < 0$.

3.1 The Summation Technology

The probability function can be defined as $p(\sum_{j=1}^{m(n)} e_j)$. We first consider the OSS developers' optimal effort levels. Let U_i be the expected payoff of developer i. Then developer i chooses e_i to maximize his expected payoff, given other developers' effort levels,

$$U_i = p\left(\sum_{j=1}^{m} e_j\right)\theta_i - \frac{1}{2}e_i^2.$$

By getting the best response of developer i from the first-order condition for maximizing U_i with respect to e_i, we obtain the following Nash equilibrium condition of the OSS project group:

$$e_i^* = p'\left(\sum_{j=1}^{m} e_j^*\right)\theta_i,$$

which implies that the developer with higher intrinsic valuation for the project exerts more effort in the equilibrium.

Now we investigate how much effort developer i exerts in the commercial project. Given monetary incentive scheme (w_s, w_f) and the effort levels of the other developers in his group, developer i chooses e_i which maximizes his expected payoff

$$U_i = p\left(\sum_{j=1}^{n} e_j\right) w_s + (1 - p\left(\sum_{j=1}^{n} e_j\right))w_f - \frac{1}{2}e_i^2.$$

The Nash equilibrium condition in the commercial project group is as follows:

$$e_i^{**} = p'\left(\sum_{j=1}^{n} e_j^{**}\right)(w_s - w_f).$$

The result implies that all the individual developers in the commercial project exert the same effort level in the equilibrium unlike the OSS project where the developers' optimal effort levels vary according to their intrinsic valuation.

3.2 The Weakest-Link Technology

In the weakest-link case, the probability function can be defined as $p(\min\left\{e_1, \cdots, e_{m(n)}\right\})$. We examine the OSS project first. Given the effort levels of the other developers in his group, developer i maximizes his expected payoff

$$U_i = p(\min\{e_1, \cdots, e_m\})\theta_i - \frac{1}{2}e_i^2$$

with respect to e_i.

Considering the characteristics of min function, we can see that each developer will match his effort level to the minimum effort level of the other developers if his effort is greater than the minimum of the other developers. From this intuition, we obtain the following best response of developer i in the OSS project:

$$e_i^B(e_{-i}) = \min\left\{e_i^b, e_{-i}\right\},$$

where $e_{-i} = (e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_m)$ and $e_i^b = \{e_i | p'(e_i)\theta_i = e_i\}$. From the best responses of developers in the OSS, we get the following Nash equilibria:

$$(e_1^*, \ldots, e_m^*) = (e^*, \ldots, e^*),$$

where $e^* \in [0, e_m^b]$. That is, there exist multiple pure-strategy Nash equilibria. Among these equilibria, the equilibrium $(e_m^b, \ldots, e_m^b)$ is the Pareto dominant equilibrium. Note that e_m^b is the effort level which maximizes the expected payoff of developer m who has the lowest intrinsic valuation in the group. That is, the lowest-intrinsic-valuation developer has a crucial role in determining the equilibrium in the OSS project.

Now we consider how much effort an individual developer in the commercial project exerts. Given (w_s, w_f) and the effort levels of the other developers, developer i chooses e_i that maximizes his expected payoff

$$U_i = p(\min\{e_1, \cdots, e_n\})w_s + (1 - p(\min\{e_1, \cdots, e_n\}))w_f - \frac{1}{2}e_i^2.$$

Since all the developers in the commercial project face the same monetary incentive scheme, we have symmetric Nash equilibria at which all the developers exert the same effort level as follows:

$$(e_1^{**}, \ldots, e_n^{**}) = (e^{**}, \ldots, e^{**}),$$

where $e^{**} \in [0, \bar{e}]$ and $\bar{e} = \{e | p'(e)(w_s - w_f) = e\}$. Similar to the OSS case, there exist multiple pure-strategy Nash equilibria, among which $(\bar{e}, \ldots, \bar{e})$ is the Pareto dominant equilibrium.

3.3 The Best-Shot Technology

In the best-shot technology, the probability function is $p(\max\{e_1, \cdots, e_{m(n)}\})$. We first examine the OSS developers' optimal effort levels. Developer i seeks to maximize his expected payoff

$$U_i = p(\max\{e_1, \cdots, e_m\})\theta_i - \frac{1}{2}e_i^2$$

with respect to e_i.

Under this best-shot technology, only one developer exerts all the effort and the others free ride on him in equilibrium. From this intuition, we can also know that there may exist the multiple Nash equilibria of the game and the number of the equilibria depends on the intrinsic valuation of the developers. For instance, at one of the equilibria, only the developer with i-th highest-intrinsic valuation exerts effort and the others do nothing. Hence, at maximum, there could be m number of Nash equilibria in the game. Among them, the following vector of efforts always constitutes one of the Nash equilibria of the game:

$$(e_1^*, \ldots, e_m^*) = (e^*, 0, \ldots, 0),$$

where $e^* = \{e | p'(e)\theta_1 = e\}$. Note that e^* is the effort level which maximizes the expected payoff of developer 1 who has the highest intrinsic valuation in the group. That is, at this equilibrium, only the developer with the highest intrinsic motivation in the OSS project, expends his effort while others do not make any contribution.

Now we examine the commercial project case. Given the monetary incentive scheme (w_s, w_f) and the effort levels of the other developers, developer i maximizes his expected payoff

$$U_i = p(\max\{e_1, \cdots, e_n\})w_s + (1 - p(\max\{e_1, \cdots, e_n\}))w_f - \frac{1}{2}e_i^2$$

with respect to e_i.

In the commercial project case, there exist n number of Nash equilibria at which only one of the developers exerts all the effort while others exert zero effort. One possible equilibrium is as follows:

$$(e_1^{**}, \ldots, e_n^{**}) = (e^{**}, 0, 0, \ldots, 0, 0),$$

where $e^{**} = \{e | p'(e)(w_s - w_f) = e\}$.

4 Conclusion

We examine two issues surrounding open source software from an economic perspective: (1) impact of intrinsic valuation on software developers' project choice between commercial software and OSS and (2) software developers' optimal effort levels in different types of software projects with different technologies. We find that the intrinsic motivation leads to participation in the OSS project. With summation technology, developers with higher intrinsic valuation exert more effort in the OSS project while all developers make the same effort in the commercial project. In the weakest-link case, there exist multiple Nash equilibria where all developers exert the same level of effort in both OSS and commercial projects. At the Pareto dominant equilibrium, the optimal effort level is bounded by the effort level of the developer with lowest intrinsic valuation in the OSS project while the net wage plays a significant role in the commercial project. In the best-shot technology, there exist multiple equilbria at which only one developer makes effort while the others free ride regardless of project type. Our findings give managerial implications to software companies and developers who face their choice problems between commercial and OSS projects.

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