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Intrinsic Motivation versus Signaling in Open Source Software Development

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Intrinsic Motivation versus Signaling in Open Source Software Development**

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Abstract

This papers sheds light on the puzzling fact that even though open source software (OSS) is a public good, it is developed for free by highly qualified, young, motivated individuals, and evolves at a rapid pace. We show that when OSS development is understood as the private provision of a public good, these features emerge quite naturally. We adapt a dynamic private-provision-of-public-goods model to reflect key aspects of the OSS phenomenon. Apart from extrinsic motives (namely signaling), the present model also contains intrinsic motives of OSS programmers, such as play value or *homo ludens* payoff, user-programmers' and gift culture benefits. Such intrinsic motives feature extensively in the wider OSS literature and contribute new insights to the economic analysis.

Keywords: open source software, public goods, homo ludens, war of attrition.
JEL classification: L86, H41, L31

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1 Introduction

With the success of famous open source software (OSS) products like the operating system 'Linux', the 'Apache Web Server' or the web browser 'Firefox', the open source movement has attracted the interest of economists; e.g. Johnson (2002), Lerner and Tirole (2002), Myatt and Wallace (2002), Mustonen (2003), Bitzer (2004), and Von Krogh and von Hippel (2003); see Rossi (2006) for a recent literature review. What puzzles economists dealing with this topic is the fact that OSS – a public good[1] – is developed for free by highly educated volunteer programmers and at a speed of innovation that in some respects outpaces commercial software development. Yet, in general, economic theory would predict that privately provided public goods suffer from problems of under-provision, delays in supply, and inferior quality.

In the attempt to answer the question of why someone might contribute to OSS projects, economists have proposed a broad range of programmer motives. Some studies emphasize the importance of job signaling as a motivation for participation in OSS projects, e.g. Lerner and Tirole (2002). Others point to the private benefits for the participating programmers in so far as software they need themselves is developed – user-programmers, e.g. Johnson (2002). Recent empirical studies again show that strong drivers for OSS programmers can be found in intrinsic motives such as the fun of programming, e.g. Hertel et al. (2003), Lakhani and Wolf (2005), and the gift culture surrounding OSS, e.g. Raymond (2000a, 2000b), Zeitlyn (2003). Thus, the motivation of OSS developers is a mixture of extrinsic motives like signaling and future wages, and intrinsic motives like their own need for software, fun / play and gift culture. Obviously, the benefits of all of these types of payoffs / motives could compensate a potential provider of the public good OSS for his private costs of programming. Thus, an analysis of OSS provision is well advised to acknowledge the existence of multiple motives, because the motive mix and the structure of the gain and cost streams may differ over time, the identification of the skills of a programmer via the signal set by programming OSS might be blurred by the existence of intrinsic motives, and the distribution of motives in programmer communities may differ between OSS projects.

[1]OSS is a public good since it features non-rivalry in consumption (a characteristic of most non-material goods) and non-excludability, see Appendix C. The latter feature is ensured by distribution of OSS under licenses of the Free Software Foundation (FSF) such as GNU GPL, or GNU LGPL, which stipulate that the source code of software can be copied, modified, distributed freely and that – most importantly – all derived work is covered by the same open source license (FSF (2004)). See Bitzer and Schröder (2006), and Lerner and Tirole (2005) for a detailed discussion of OSS licensing schemes.

Theoretical research on OSS has incorporated several programmer motives into private-provision-of-public-goods frameworks – e.g. Johnson (2002), Myatt and Wallace (2002) and Bitzer and Schröder (2005) – although none has incorporated all of the motives discussed above simultaneously. Johnson (2002), in particular, models user-developers and thus also features an intrinsic motive. In contrast to the model of the present paper, he uses a static model with incomplete information and studies the effects of population size on the probability that an OSS product will be provided. Myatt and Wallace (2002) consider, in a binary-action public good provision game, issues of free riding and coordination, including the classic motives of user-programmer benefits and cost of provision. Their focus is on the existence and selection of equilibria. Bitzer and Schröder (2005) start with the same model as the present paper but introduce repeated contribution to the OSS, which enables them to examine joining and exiting dynamics of OSS communities. They include signaling as a private payoff, but do not distinguish separating and pooling equilibria and they ignore further intrinsic motives.

This is the point of departure for the present paper, which, by incorporating a range of intrinsic and extrinsic motives into the analysis, attempts to arrive at a richer characterization of the contributors and initiators of OSS projects. The model of the present paper examines the OSS phenomenon as a private-provision-of-public-goods model. In particular we follow the tradition of Bliss and Nalebuff (1984), Hendricks et al. (1988) and Bilodeau and Slivinski (1996). Apart from the usual benefits and private costs connected to the provision of the public good, we augment the model to capture the following motives. First, we include signaling in the way that agents are employed by firms and where being the provider of OSS can serve as a signal potentially triggering higher future earnings. Furthermore, we include additional private payoffs capturing *homo ludens* payoff, and a gift benefit. We use this framework to study some key characteristics of OSS providers that would prevail under separating and pooling equilibria, whereas in the latter case, the private provision of OSS becomes a continuous time n player *war of attrition*. We arrive at the following findings: within the model, *ceteris paribus* an OSS-programming individual is characterized by a larger value attached to the gift benefit, a longer time horizon (i.e. a younger individual), more patience, higher efficiency (lower development cost), and a high *homo ludens* payoff, i.e. the value derived from playing with the software and mastering the challenge. Moreover, a higher gain from using the OSS software solution (user-programmer benefit) matters in a pooling equilibrium but has no influence on defining the group of potential providers in a separating equilibrium.

The central limitation of the present framework is that we establish neither full characterizations nor existence of equilibria, since such an analysis would require additional assumptions and explicit structure on the distribution of parameters in the community of programmers. However, to reach the aim of our paper – namely, to determine key characteristics of OSS providers – it is sufficient to examine some central characteristics of fairly broad classes of equilibria, namely separating and pooling equilibria of the game. A drawback of this approach is that the present model has little to say about the actual provider in situations where separation occurs and more than one agent wants to develop the OSS in question simultaneously, and if – or under what conditions – the one or the other type of equilibria occurs. Furthermore, it must be noted that our model can only endeavor to capture part of the many aspects surrounding OSS. For example, the dynamics within OSS programmer communities, or what type of software products and organization structures are conducive to this production method are not addressed within the present work.

The paper is structured as follows. Section 2 reviews the motives of OSS contributors discussed in the literature and relates our model to this context. Section 3 introduces the formal model. In Section 4, we discuss the results of our model. Section 5 concludes the paper.

2 Motives to program OSS

There have been a number of papers dealing with the motivation of programmers and examining why they are willing to program OSS. Raymond (2000a, 2000b), Lerner and Tirole (2002), Torvalds and Diamond (2001) carried out case-study-based analysis, focussing on famous OSS projects like the Apache Web Server, Perl, and sendmail. Empirical studies based on the analysis of web archives are those of Hertel et al. (2003), who dealt with Linux, and Lakhani and Wolf (2005), Krishnamurthy (2002), and Hars and Ou (2002) who were concerned with a broad range of different OSS projects.

In the studies mentioned, two general groups of motives are identified: intrinsic and extrinsic motives. While *intrinsic motivation* describes the situation in which somebody is doing something because it is inherently interesting, enjoyable or challenging, in the case of *extrinsic motivation*, someone expects a separable outcome (Deci and Ryan, 1985, Ryan and Deci 2000).

A central aim of the present paper is to capture within a formal framework a broad range of motives and to characterize those agents who are willing to provide the *initial* public good OSS. The motivation of a programmer for starting an OSS project is of course a mixture of intrinsic motives on the one hand, and of classic extrinsic motives on the other. Reviewing the rapidly emerging literature on OSS, we identify three crucial themes which regularly appear when analyzing the intrinsic motivation of OSS programmers and in particular of initiators: (a) the need for a particular software solution, i.e. the phenomenon of user-programmers, (b) the fun of play, i.e. some form of *homo ludens* payoff, and (c) the desire to give a present to the programmer community, i.e. a gift benefit.

In particular the latter two motives are greatly underrated in economics – with some notable exceptions (Frey and Osterloh, 2002, Lindenberg, 2001) – yet are frequently discussed in other branches of the social sciences. Motives such as gift benefit and *homo ludens* payoff are included in the OSS accounts of e.g. Zeitlyn (2003), Torvalds and Diamond (2001), Raymond (2000a, 2000b).[2]

A crucial prerequisite for starting an OSS project is the need for a particular software. Founders usually start a project because they are not satisfied with existing software or simply because the required software does not exist. Linus Torvalds, for example, needed a Unix for his PC, and the result was Linux (Torvalds and Diamond, 2001), Eric Allman needed a more efficient email server resulting in 'Sendmail', Larry Wall needed a tool to automatically generate web pages resulting in 'Perl', and finally Don Knuth needed a convenient tool for type-setting documents resulting in 'TeX' (Knuth, 1979). Thus, the programmer benefits directly from developing the software. However, this is insufficient for explaining why someone does the programming himself – instead of hiring an outsider – and more importantly why an agent would make the programming result publicly available and for free. Accordingly, other intrinsic motives may play a crucial role for the initiator of an OSS project.

Apart from the substantial contracting problems that outsourcing of the programming activity would cause, it is striking to note that important OSS contributors insist that they are doing the programming 'just for fun' (Torvalds and Diamond, 2001). Programming is regarded as a leisure-time activity, i.e. playing around with the possibilities of software or mastering the challenge as a pastime. This idea – that the fun of play is an important motivation for humans – is not new and can be traced back to Plato; the *locus classicus* is Johan Huizinga (1938). Huizinga's *homo ludens*, the playful human, means in our setting that the programmer receives some form of benefit simply from carrying out the programming or from mastering a software problem. Raymond even goes one step further and argues that the

[2]Lerner and Tirole (2002) also acknowledge such motivational drivers, e.g. "A 'cool' open source project may be more fun than a routine task" (Lerner and Tirole, 2002, p. 213).

intrinsic interest in the software leads to better-quality programming:

> "It may well turn out that one of the most important effects of open source's success will be to teach us that play is the most economically efficient mode of creative work."
>
> (Raymond, 2000b, chapter 11)

Thus, the fun of playing appears to be another important factor for starting an OSS project, but like the motive 'need for a new software', it is not sufficient on its own. There are thousands of programmers who program new software because they need it and have fun programming it, but these programmers decide to earn money with the final product or refuse to publish the source code and instead keep it as a private software solution. Thus, what is the motive to turn one's efforts into a public good, namely publish the source code of one's programm and have it licensed under, for example, the GPL?

There are a host of candidate motives and the literature is far from settled on the issue. Although the various explanations differ, all of them carry the common theme of 'giving one's program as a gift to the community'. We summarize such motives under the term 'gift culture' (Berking, 1996; Zeitlyn, 2003). One of the motives falling into this category is the desire to gain a reputation within the hacker community. The names of the 'patrons' are distributed with the source code of their piece of software, which includes a list (e.g. the update log) of all contributors to the project. In this way, the individual's acceptance within the community is boosted and thus its reputation and social status. The 'gift' that the programmer gives to the community thus determines his 'social status' within it (Raymond 2000a, chapters 6-8).[3] Another motive is what Hars and Ou (2002) call 'community identification'. By this they mean that programmers see the open source community as a family striving towards convergence of their individual goals and the goals of the community. Members see the community as 'kin' and are therefore willing to do something that might be beneficial to the community, although not necessarily to themselves. Of course, 'membership' in the OSS community entails some kind of obligation for the individual programmer to follow the rules of the community, i.e. to publish the source code of his software.[4] Although this is not obvious, Lindenberg (2001) shows

[3]Closely connected to the 'social status' of a programmer is his ability to attract support (e.g. bug reports, feature requests) from the community.

[4]Of course another explanation might be that it is simply fun to discuss one's work with like-minded people. We owe this point to an anonymous referee.

that obligations can be considered as intrinsic motives, arguing that if people act based on a principle, they do not pursue external rewards. Another branch of the obligation hypothesis can be regarded as 'reciprocal altruism' in the sense that the volunteers who invest their efforts carry a belief that other programmers investing efforts in related problems will also make the resulting solution publicly available. Finally, pure altruism must also be mentioned as an important motive for publishing the source code of one's software. For example, Richard Stallman (1999) regards OSS, with its promotion of computer users' right to use, study, copy, modify, and redistribute computer programs, as a social movement based on fundamental democratic principles.[5] Publishing the source code of one's software may thus often be based on the wish to support this movement.

It is important to note that such explanations of gift culture are only feasible due to the freely available information within the community of developers. The close-to-costless information flow within the community is a crucial characteristic of the open source development process. Information about new or ongoing projects, feature requests, bug reports and bug fixes is compiled on websites and in news groups receiving wide circulation. Information about contributors is embedded in the source code itself. Most importantly, the source code is not only the product itself, it is also a complete blueprint of the product, and in fact a log of which members of an OSS community created which elements of the software, and not least, how they did it.

Finally, a similar argument can be made for the signal embedded in the provision of OSS (e.g. Lerner and Tirole, 2002). While the programming of a well-functioning piece of closed source software may generate a valuable intra-firm signal that could lead to promotions or higher wages, an OSS signal is much more transparent and, more importantly, reveals more information on the performance of the programmer, precisely because a large amount of information is contained in the source code itself. Even for experts, it is difficult to assess the effort required to write a piece of software without the information incorporated in the source code. Accordingly, community members have an immense interest in revealing as much information as possible on their project to either display the value of their 'gift' and/or to signal their abilities to potential employers.

To sum up, the value of the public good OSS in combination with the various private benefits captured by the above mentioned extrinsic and intrinsic motives compensate the contributor of the OSS for his private costs of programming.

[5]Cf. www.fsf.org for more information.

3 The Model

Consider a population of n finitely lived individuals i, who are software programmers employed continuously throughout their lifetime. Let T_i denote individual i's finite time horizon. Apart from his day job, each individual has the ability to develop one discrete unit of OSS, which is identical for all individuals, and consumption of which is characterized by non-rivalry and non-excludability.[6] Thus, the software is a public good and, once developed, it exists forever. Time is continuous and individuals discount the future at rate r_i. Utility flows from software are as follows: Without the OSS, individuals have to live with a commercial proprietary software alternative and receive each an identical utility flow normalized to zero. From the time of introduction of the OSS, all individuals obtain the flow utility $z_i \geq 0$ for all $i = 1, ..., n$, i.e., the flow value of the OSS becoming available.

Individuals can produce the OSS software at a cost. If individual i is the actual developer of the software, he suffers – depending on his programming skills – a one-time development cost $c_i \geq 0$, but receives a one-time play value $p_i \geq 0$ (*homo ludens* payoff) and a net utility flow $g_i \geq 0$, denoting the gift benefit incurred until the end of the agent's life. Each individual receives the independently distributed z_i, c_i, g_i and p_i drawn from distributions S^k, where $k = z, c, g, p$.[7] It is assumed that within the group n (the community) the individual costs and benefits realizations are common knowledge, but that employers (firms) only know the distributions S^k, yet not the realized values of individuals.

The total net cost for agent i of voluntarily developing the software at time t can thus be written as: $c_i e^{-r_i t} - p_i e^{-r_i t} - \frac{g_i}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right)$. We assume that p_i and g_i do not outweigh the development cost c_i (i.e. providing the OSS still implies a net cost) but that all individuals find it worthwhile to

[6]This modelling of a one-off complete piece of software captures the situation of a project initiator. The actual OSS programming process of ongoing projects consists instead of multiple contributions by various programmers to the pool of OSS, say programming enhancement or a new module to an ongoing OSS project. This issue is examined – based on a model related to the present framework – in Bitzer and Schröder (2005). Also note that the present set-up could also be re-interpreted to capture a situation where all programmers continuously engage in various ongoing OSS projects alongside their day job, but that the start of a new and promising project or module requires an extraordinary effort by one agent – the leader. On the role of such leaders in the start-up of OSS see also Lerner and Tirole (2002).

[7]Notice that we thus permit situations where several of the cost and benefit parameters do take value zero for several or all agents.

develop the OSS rather than to live without it forever, namely

$$\frac{z_i}{r_i}(1-e^{-r_iT_i}) > (c_i - p_i) - \frac{g_i}{r_i}\left(1-e^{-r_iT_i}\right) > 0 \;\; \forall \;\; i = 1, ..., n \; . \qquad (1)$$

Thus, by (1) we define who is a computer programmer and part of the OSS community, namely people with relatively low net costs of development and those with much to gain from the OSS. In the normal-form version of this game, a pure strategy of the individuals in community n is a time $t_i \in [0, T_i)$ where i will develop if no one else already has done so, and it will depend on his benefit from the existence of the OSS, the cost of developing the software himself, his time preference, and the wage.[8]

Next consider the labor market. Assume that a number of identical commercial software firms each employ $m < n$ computer programmers and compete for the labor force represented by community n. The software production process is such that firm profits, π, depend, inter alia, on the average programming costs, $\frac{1}{m}\sum_{i=1}^{m} c_i$, of their employees, such that $\frac{\partial \pi}{\partial \frac{1}{m}\sum_{i=1}^{m} c_i} < 0$. The individual c_i (and z_i, p_i, and g_i) realizations, however, are unobservable to employers, but the distributions S^k are known to firms. Absent a signal, all firms have ex-ante the same expected programming cost $E(\frac{1}{m}\sum_{i=1}^{m} c_i) = \frac{1}{n}\sum_{i=1}^{n} c_i = \bar{c}$. The provider of the OSS, however, is identified; thus being the provider of the public good can serve as a signal. Since the OSS, and hence the signal, comes as a discrete event, all separating equilibria feature only two types of wage contracts, namely high and low wages, denoted w^H and w^L. Furthermore, we can simplify the problem by assuming that $\frac{1}{n-1}\sum_{i=1;i\neq j}^{n} c_i = \bar{c}$, for large n and where agent j is the provider of the OSS.[9] This implies that the lower wage offer, w^L, of the separating equilibrium can be approximated by the zero-profit wage offer, w^P, of a pooling equilibrium. Because programming for pay has neither play value, nor – since the source code is closed – gift benefit, the zero-profit wage offer for all individuals prior to OSS provision must be $w^L = w^P = \pi(\bar{c})$.

We can state the following payoffs: if the OSS is developed by individual $j \neq i$ at time $t \leq T_i$, i's payoff – independent of whether we are in a pooling

[8] As discussed in the introduction, in what follows we do not establish the actual equilibria of this game. Rather, we exploit some characteristics of two broad classes of equilibria, namely separating and pooling equilibria of the signaling game, based on simple necessary conditions alone.

[9] Put differently, we assume that removing one certain agent from the pool of programmers via the signal does not change the ex-ante productivity of all firms. Yet adding this one agent to a specific firm may alter the ex-post profits of that firm such that the wage w^H is justified. The more precise specification would of course read $w^L < w^P$, but only expand the notation without changing the qualitative results of what follows.

or separating equilibrium – is:

$$F_i(t) = \frac{\pi(\bar{c})}{r_i}\left(1 - e^{-r_i T_i}\right) + \frac{z_i}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right) \ . \tag{2}$$

If individual i develops the software at time t, his payoff is

$$D_i^P(t) = F_i(t) + \frac{g_i}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right) - (c_i - p_i)e^{-r_i t} \tag{3}$$

in a pooling equilibrium, and

$$D_i^S(t) = D_i^P(t) + \frac{w^H - \pi(\bar{c})}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right) \tag{4}$$

in a separating equilibrium. Finally, if no one ever develops the software, individual i has payoff $R_i = \frac{\pi(\bar{c})}{r_i}\left(1 - e^{-r_i T_i}\right) = lim_{t \to T_i} F_i(t)$.

For any separating equilibrium, we have to examine not only the zero-profit condition of firms, but also the self-selection constraints of agents. In particular, the self-selection constraint of the OSS provider demands $D_i^S(t) > F_i(t + \tau)$, where τ is the expected delay until some other agent provides. Noticing that $F_i(t)$ is monotonously falling in t, a stronger condition for an agent to fulfill the self-selection constraint (or self-selection if $\tau = 0$) becomes $D_i^S(t) > F_i(t)$, which after inserting from (2), (3) and (4) becomes:

$$\frac{w^H - \pi(\bar{c}) + g_i}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right) - (c_i - p_i)e^{-r_i t} > 0 \ . \tag{5}$$

In other words, inequality (5) states that to ensure self-selection of the OSS provider – if a separating equilibrium exists – requires that the high-wage contract must more than compensate for the net cost of being the provider. Any individual for whom (5) is fulfilled, since $D_i^S(t)$ is monotonous and falling in t, maximizes utility at $D_i^S(0)$. Namely, any such individual i will develop voluntarily and immediately at time $t = 0$. As stated above, we assume throughout the paper that the individual costs and benefits are common knowledge within the community of programmers but unobservable to employers – hence the value of a signal. Accordingly, under these – arguably strong – assumptions, the eventual provider is known within the group of potential providers, and agents know that provision will take place at time $t = 0$.[10] However, multiple agents may be willing to provide. From the above

[10]Thus $\tau = 0$ and furthermore, this assumption allows us to set aside the effect that the timing of provision – and thus the signal and identification of the providing agent – has on firm profits and hence w^H.

we are unable, without imposing further structure onto the model, to identify the actual provider of the OSS in such separating equilibria – or in fact if such equilibria exist at all. Yet, we are able to discern some key characteristics about agents that are part of this group of potential providers.

In particular, given the presence of the gift and the play value, the actual provider (receiving w^H) may not be the individual with the highest programming ability (lowest c_i). Thus, there is uncertainty if agents with low programming ability may display the signal in equilibrium. Depending on the functional form of π and the distributions S^k one, many or no agent may fulfill (5). Obviously, in the 'no agent' case, separation does not occur, leaving pooling situations as candidate equilibria. Yet, if separating equilibria exist, we can determine the characteristics that will make an individual more likely to be in the group of potential OSS providers. Formally,

Proposition 1. ***(Separating Equilibria)*** *If there exist separating equilibria, ceteris paribus a higher separating wage w^H attracts more potential OSS providers; an individual with a*

i) lower cost of software development, c_i
ii) larger gift benefit, g_i
iii) longer time horizon, T_i (younger)
iv) lower discount rate, r_i (more patient)
or
v) higher value of play, p_i
is more likely to be in the group of potential OSS providers.

Proposition 1 follows from the derivatives of (5).[11]

Next we turn to OSS provision in pooling equilibria. Even though all agents receive the same wage in such situations, we are still able to deduce some important characteristics of the likely OSS provider. From (2), (3) and (1) it follows that $F_i(t) > D_i^P(t)$ for all t, and hence this situation constitutes an n player complete information war of attrition.[12] By allowing individuals to postpone their decision for some time, for example to wait and see if someone else is developing the OSS software, important dynamics emerge. Obviously the length of time a member of the community n is willing to wait depends on his benefit from the existence of the OSS, the cost of developing the software himself, and his time preference. Following Hendricks et al. (1988) and Bilodeau and Slivinski (1996), one can characterize the following

[11] The derivatives are provided in Appendix A at the end of the manuscript.

[12] See e.g. Hendricks et al. (1988) or Bilodeau and Slivinski (1996). The one-shot intra-community game of OSS provision features a host of pure and mixed-strategy Nash equilibria in which anyone might be the developer of the software. The war of attrition emerges once individuals are allowed to out-wait each other.

equilibria for this type of game: for every individual i there is a subgame perfect equilibrium outcome in which only i will develop immediately. Or more intuitively, if no one other than i develops, then i's best strategy is to develop immediately, and if i develops immediately, everyone else's best strategy is to wait.

Thus, the game permits – as is usual for this type of game – many subgame perfect equilibria in which anyone might volunteer. However, the set of subgame perfect equilibria here is radically reduced because time horizons are finite (see Bilodeau and Slivinski, 1996). Based on this assumption, we are able to characterize the individual that will actually provide the public good in a pooling equilibrium when a war of attrition takes place. The effect of a finite time horizon is that the game becomes non-stationary. Thus, from an agent's perspective, there is a point in time $\bar{t}$ where he will no longer choose to develop the OSS.[13] Beyond that point in time, even when the software is not provided, a dominant strategy is to *not develop* at all, i.e. $D_i^P(t) < R_i \; \forall \; t > \bar{t}_i$. Solving for $D_i^P(\bar{t}) = R_i$ defines this point in time. In particular, individual i will not develop the OSS after time

$$\bar{t}_i = T_i - \frac{1}{r_i} \ln \left(\frac{z_i + g_i}{z_i + g_i + r_i(p_i - c_i)} \right). \tag{6}$$

Bilodeau and Slivinski (1996, p. 304) show that for this situation, there exists a unique subgame perfect equilibrium in which the individual with the highest $\bar{t}_i$ volunteers at time $t = 0$. The intuition for this result is straightforward. If you know that you are the one with the highest benefit/cost ratio of developing the OSS, and if you know that everyone else knows this as well, then you might as well give in right away. Thus, even though we allow individuals to wait, the war of attrition with full information features *no* rational delay. Software is developed sooner rather than later. The individual actually developing the software is characterized by the highest $\bar{t}$.[14] This enables us to characterize the likely OSS programmer. Formally,

Proposition 2. ***(Pooling Equilibria - War of Attrition)*** *If there exist pooling equilibria where individuals play a war of attrition, ceteris paribus an individual with a*

i) higher gain from the software, z_i

ii) larger gift benefit, g_i

[13]Another interpretation of $\bar{t}_i$ is: "Suppose it is time t. What is my benefit if I contribute now, versus not contributing at all?"

[14]Notice that existence of a pooling equilibrium requires the information that an agent has the highest $\bar{t}_i$ to provide no statistical information for firms on c_i. There might be conditions where this is not the case, implying the possibility of separation.

iii) longer time horizon, T_i (younger)
iv) lower discount rate, r_i (more patient)
v) lower cost of software development, c_i
or
vi) higher value of play, p_i
is more likely to provide the OSS.

Proposition 2 follows from the derivatives of $\bar{t}_i$.[15]

4 Discussion of the model results

Comparing the provider characterizations given in Proposition 1 and Proposition 2 to empirical accounts and our discussion in Section 2, we find that several of the model predictions match well with the stylized facts on OSS programmer characteristics. Empirical work finds that the 'average' OSS contributor is young, well-educated, enjoys programming, and values gift-culture type rewards. Hars and Ou (2002), for example, find 54 percent of the contributors in their sample to be less than 29 years of age and 72 percent to have a bachelor's, master's or Ph.D. degree. Similar results are found by Hertel et al. (2003), Lakhani and Wolf (2005), Krishnamurthy (2002). Furthermore, Luthiger (2005) and Lakhani and Wolf (2006) conclude from their empirical studies that the fun of programming is a major motivational driver. The role of community identification and other gift culture related values are pointed out in the surveys of Hertel et al. (2003) and Lakhani and Wolf (2006).

Thus, by introducing the possibility of such unconventional motives into a private-provision-of-public-goods framework with signaling, we found that – fully in line with the evidence available – provision of OSS will be swift, and that programmers will be young and efficient (talented/well-educated/low-cost), will have a high play value associated with programming (*homo ludens* payoff), and will value the gift culture surrounding OSS.

Furthermore, a comparison of Proposition 1 and Proposition 2 shows that the derived characteristics of OSS programmers are largely identical. This is notable, given that very different solution techniques are invoked. It implies that, driven by the public good characteristic of OSS, the pure observation that signals are possible and that individuals value signals need not imply that the situation results in a separating equilibrium. Put differently, the formal model establishes the non-obvious result that the signaling motive

[15] The derivatives of $\bar{t}_i$ are provided in appendix B at the end of the manuscript.

cannot be distinguished from intrinsic motives by simply mapping out individual valuations for either of them.[16] Furthermore, what is surprising in the formal results is that user-programmer gains, z_i, turn out to impact differently in a pooling compared to a separating situation. The agent's own benefit from the public good he is producing, z_i, drives providers to develop the OSS in a pooling situation, but it does not contribute as a force putting an agent into the group of potential providers in separating situations. We think that this finding is of some interest because much of the literature emphasizes user-programmer benefits as central to the OSS issue. Our framework hints that there might in fact be a clash when evoking signaling arguments simultaneously with user-programmer arguments. Yet, this conclusion should not be pushed too far since our results for the separating case do not establish the actual provider and are only based on the self-selection constraint. It is quite clear that after refining the equilibrium and adding sufficient structure onto the problem, there will most likely be an impact of z_i on selecting the actual provider in the separating case. Finally, our framework displays the feature that wage increases for the agent displaying the signal only play a role in separating equilibria, while the size of wages of course has no effect in situations of pooling equilibria.

The above results hint at a number of empirical avenues for future research. The clearest empirically testable hypothesis implied by the model apparatus concerns of course the question whether or not there are observable wage differentials between computer programmers that do or do not have a prior history of OSS programming. If one found that no significant wage differentials exist, this would indicate a pooling equilibrium; but if a wage premium turns out to be associated with OSS programming, this would be consistent with the signaling hypothesis. To the best of our knowledge, no empirical studies exist addressing the issue of wage premia for OSS programmers. Furthermore, the above framework implies certain dynamics of programmer motives. For example, if one accepts the notion that early, immature project phases command lower signaling values than mature and successful OSS projects, then the role of direct user-programmer benefits should become less relevant over the life cycle of projects. Finally, and most importantly, future empirical research should address the issue of motive interaction and overlap that is implied by the presence of multiple motives as drivers for OSS contributors.

[16] Furthermore, as noted above, the gift and play value might overcompensate cost disadvantages in providing the OSS. This has far reaching effects on the identification of the most efficient individual by the firms looking for employees. Put differently, intrinsic motives can distort signals, such that the separating outcome may not be viable.

5 Conclusion

This paper attempts to shed light on the puzzling fact that even though OSS is a privately provided public good and should accordingly suffer from under-provision or low quality, it evolves quite to the contrary at a rapid pace, is developed for free by highly qualified, young, motivated individuals, and in fact poses a viable alternative to commercial software products. Based on a review of the OSS phenomenon and the motives behind it, we adapt a private-provision-of-public-goods model in the tradition of Bliss and Nalebuff (1984), Hendricks et al. (1988) and Bilodeau and Slivinski (1996) to address this puzzle and to characterize those agents who find it worthwhile to develop OSS.

Existing economic accounts of the OSS phenomena emphasize various extrinsic and intrinsic motives. The main contribution of our paper is that extrinsic motives such as signaling and intrinsic motives such as need for a particular software solution, the fun of play, and gift culture are incorporated simultaneously. In particular the latter two motives, although widely acknowledged in the social sciences in general, are often ignored in economics, yet carry important insights for the case at hand.

Our paper incorporates these motives into a private-provision-of-public-goods model. Given the extrinsic motive of signaling, we examine some key characteristics of classes of separating and pooling equilibria, where agents in the latter case play out a war of attrition. We find that both types of equilibria feature similar characteristics for the likely OSS provider. *Ceteris paribus* the provider extracts a higher gain from using the software (pooling equilibria) or is attracted by a higher separating wage (separating equilibria); furthermore the provider obtains a larger gift benefit, has a longer time horizon (i.e. is a younger individual), has higher programming skills (lower costs of development), and is deriving a high value from play (homo ludens payoff). These results compare well with empirical accounts of the OSS phenomenon.

Our model also raises several new questions. First, to answer the question if job-signaling plays a significant role in motivating OSS programmers it has to be tested empirically if a wage premium for programmers contributing to OSS projects exists. Second, for modelling dynamics in the motive-mix of OSS programmers, empirical work has to analyse the movements between the single motives during the life cycle of an OSS project as well as during the "programming career" of an OSS developer. Finally, the motives discussed are likely to interact in complex ways, an issue that so far has not been examined formally since solid empirical evidence on these issues is lacking.

A Appendix: Proposition 1

From (5) define

$$\phi = \frac{w^H - \pi(\bar{c}) + g_i}{r_i}\left(e^{-r_i t} - e^{-r_i T_i}\right) - (c_i - p_i)e^{-r_i t}\ . \tag{A.1}$$

Inspection of (A.1) gives immediately that $\frac{\partial \phi}{\partial w_H} = \frac{\partial \phi}{\partial g_i} = \frac{e^{-r_i t} - e^{-r_i T_i}}{r_i} > 0$ and that $\frac{\partial \phi}{\partial c_i} = -\frac{\partial \phi}{\partial p_i} = -e^{-r_i t} < 0$. Finally, evaluating the derivative of (A.1) wrt r_i at the time of provision, namely $t = 0$, gives:

$$\frac{\partial \phi}{\partial r_i} = \frac{\left(e^{r_i\,T_i} - 1 - r_i\,T_i\right)\,\left(\pi(\bar{c}) - w^H - g_i\right)}{e^{r_i\,T_i}\,r_i^2}\ . \tag{A.2}$$

Since $\pi(\bar{c}) < w^H$ in a separating equilibrium, we have that A.2 is negative if $(e^{r_i\,T_i} - 1 - r_i\,T_i) > 0$. Rearranging and taking logs gives $r_i\,T_i > \log(r_i\,T_i)$ which is true $\forall\ r_i T_i > 0$, and hence we have $\frac{\partial \phi}{\partial r_i} < 0$.

B Appendix: Proposition 2 – derivatives of $\bar{t}_i$

In the limit when T_i approaches infinity, inequality (1) can be stated as:

$$z_i + g_i + r_i(p_i - c_i) > 0 \quad \forall\ i \in [1, n] \tag{B.1}$$

And the war of attrition (pooling equilibrium) condition, becomes:

$$c_i - p_i > \frac{g_i}{r_i} \quad \forall\ i \in [1, n] \tag{B.2}$$

Own value of OSS and gift benefit: The derivatives of (6) with respect to z_i and g_i are identical:

$$\frac{\partial \bar{t}_i}{\partial z_i} = \frac{\partial \bar{t}_i}{\partial g_i} = -\frac{(z_i + g_i + r_i(p_i - c_i))\left(\frac{1}{z_i + g_i + r_i(p_i - c_i)} - \frac{z_i + g_i}{(z_i + g_i + r_i(p_i - c_i))^2}\right)}{r_i(z_i + g_i)} \tag{B.3}$$

which simplifies into

$$\frac{\partial \bar{t}_i}{\partial z_i} = \frac{\partial \bar{t}_i}{\partial g_i} = \frac{c_i - p_i}{(z_i + g_i)(z_i + g_i + r_i(p_i - c_i))} \tag{B.4}$$

By (B.2) and (B.1) both the numerator and the denominator in (B.4) are positive. Hence, $\frac{\partial \bar{t}_i}{\partial z_i} = \frac{\partial \bar{t}_i}{\partial g_i} > 0$.

Programming cost and *homo ludens* payoff: The derivatives of (6) with respect to c_i and p_i are identical in absolute value but with opposing signs:

$$\frac{\partial \bar{t}_i}{\partial c_i} = -\frac{\partial \bar{t}_i}{\partial p_i} = -\frac{1}{z_i + g_i + r_i(p_i - c_i)} \tag{B.5}$$

By (B.1) the denominator in (B.5) is positive. Hence, $\frac{\partial \bar{t}_i}{\partial c_i} < 0$ and $\frac{\partial \bar{t}_i}{\partial p_i} > 0$.

Discount rate: The derivative of (6) with respect to r_i is:

$$\frac{\partial \bar{t}_i}{\partial r_i} = \frac{p_i - c_i}{r_i(z_i + g_i + r_i(p_i - c_i))} + \frac{\log\left(\frac{z_i+g_i}{z_i+g_i+r_i(p_i-c_i)}\right)}{r^2} \tag{B.6}$$

Which is the sum of a negative and a positive term. We want to show that $\frac{\partial \bar{t}_i}{\partial r_i} < 0$. Using (B.6) we can state our problem as:

$$\log\left(\frac{z_i + g_i}{z_i + g_i + r_i(p_i - c_i)}\right) < \frac{r_i(c_i - p_i)}{z_i + g_i + r_i(p_i - c_i)} \tag{B.7}$$

Adding and subtracting $\frac{z_i+g_i}{z_i+g_i-r_i(c_i-p_i)}$ on the right-hand side (B.7) can be restated as:

$$\log\left(\frac{z_i + g_i}{z_i + g_i + r_i(p_i - c_i)}\right) < \frac{z_i + g_i}{z_i + g_i + r_i(p_i - c_i)} - 1 \tag{B.8}$$

Define $a = \frac{z_i+g_i}{z_i+g_i+r_i(p_i-c_i)}$. By (B.1) and (B.2) we have $a > 1$. Inequality (B.8) can now be stated as:

$$a - \log(a) > 1 \tag{B.9}$$

which is true for all $a \in R^+ |\, a \neq 1$. Hence, $\frac{\partial \bar{t}_i}{\partial r_i} < 0$.

C Appendix: Why is OSS a public good?

A crucial prerequisite for our examination of the OSS phenomenon is the assumption that such software is indeed a public good. A closer look at the requirements for its classification as a public good shows that the license terms differentiate between open source and commercial proprietary software. Due to the fact that software is an immaterial good, the use of the program code by one individual does not affect its use by another individual. Therefore software is non-rival in its consumption (Houghton, 1992, p.5; Quintas, 1994). Thus, the first characteristic of a public good is fulfilled by *all* software programs (Atkinson and Stiglitz, 1980). As to the second characteristic – non-excludability – it is important to note that development of OSS goes back to the late seventies, when the free exchange of software source codes was common (Stallman, 1999). Only since the emergence of proprietary software at the beginning of the eighties have commercial enterprises started to exclude users from the use of their software via copyright licenses and by distribution of compiled software, etc. Since then, the public good character of some software programs has become a distinguishing feature. It is obvious that those programmers who wanted their software to remain open to anyone interested and who wanted to prevent a commercial 'hijacking' of the software had to make sure that their software remained non-excludable. As a reaction to this challenge, the Free Software Foundation (FSF) was founded to guarantee the free access to the software of this group by developing corresponding licenses. Different licenses, e.g. GNU GPL, GNU LGPL[17], were introduced which ensure that the source code of software can be copied, modified, distributed freely and – most importantly – that all further developments fall under the same open source license (FSF (2004)). Taking the non-rivalry of software together with the FSF software licenses, which guarantee non-excludability, OSS qualifies as a public good.

[17]GNU is a recursive acronym for 'GNU's not Unix', further, GNU General Public License (GNU GPL), GNU Lesser General Public License (GNU LGPL).

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