Network Formation via Contests: The Production Process of Open Source Software*

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Abstract

Why do both software developers and firms contribute to the production process of Open Source Software (OSS) despite not receiving direct monetary rewards for it? This papers extends results of the economic literature by modelling the OSS production process as an application contest to a "qualified network". The winners receive reputation and high investments. Investors searching for highly talented applicants profit from the selection mechanism of the OSS production process and finance it to receive inside information. We describe incentives for developers and firms and compare the mechanism with alternatives for its efficiency.

Keywords: Network, Network Formation, Open Source Software, Contest, Asymmetric Auctions, Career Concerns

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1 Introduction

Recent empirical studies have shown that the community of open source software (OSS) programmers has grown rapidly over the last decade.[1] Alike, more and more well-established companies invest into the development of software with open source code themselves, and closely interact with the OSS community.[2] Both phenomena require an economic explanation, since, on the one hand, by making use of OSS licences developers partly convey their rights of residual control and income to the OSS community.[3] As a consequence, there should be no incentives for software developers to spend time, effort, or money to take part in the OSS production process. On the other hand, firms that participate in this process primarily should be hurt, since it costs them human and financial resources without—because of positive externalities—the potential of ever receiving direct satisfactory returns for it. If accepting "viral" OSS licensing requirements,[4] competitors of a software company have direct access to the very core of this company's OSS products, thereby not only being legally allowed to copy the programme (again under an OSS license) or to imitate it (possibly for distribution as closed source software (CSS), as long as the OSS code is not copied one-to-one), but also learning a lot on the way the company structures its programmes and development processes.

We can explain both phenomena by understanding the OSS production process as an application contest of developers to the network of *prominent* developers or OSS project *leaders*, whose winners directly receive reputation which, in turn, is equivalent to medium-term and long-term economic gains. Thus a "qualified network" is formed. On the other side, we should take into account that firms very often

[1]See Ghosh et.al. (2002) or Lerner and Tirole (2002a).

[2]See Wichmann (2002) or Baake and Wichmann (2003).

[3]See Lerner and Tirole (2002b) for a discussion of the various OSS license schemes.

[4]Some OSS licenses are "viral" because it is sufficient to include only one line of source code that was published under an OSS license before into a piece of software for prohibiting any programme containing this line to be distributed as proprietary closed source software.

face uncertainty concerning the quality of the projects they consider to invest in or concerning the talent of employees they hire for highly specific and complicated to oversee tasks such as software development. We argue that a contest among OSS developers—which is implicit in the structure of the OSS production process—can reduce this high degree of uncertainty; in particular, if the firm can integrate itself in the process of OSS production thereby supporting it with human and financial resources.

The central feature of open source programming is that the code the developer originally entered can be viewed by anybody (given a bit of technical expertise). With CSS, which the vast majority of programmes consists of, even experts only can deduct parts of the source code while seeing just binary code. In general, the more information on a developer's (high) talent and effort a piece of software transmits and the more people use it and view its code, the higher the probability that this developer will be offered collaboration - for cash - in other projects (open and closed source ones) or that an investor will invest in her firm. Therefore, it is clear that OS software reduces more hidden information than closed source programmes.

The main goal of this article is to find a mechanism that resolves the hidden information problem, if there are investors—e.g. software firms—searching for new projects or employees, and applicants— e.g. OSS developers—with publicly unknown talents looking for investors to hire them or to invest in their projects.[5]

It is shown that, if the ex ante share of highly talented applicants is sufficiently large, there are mixed equilibrium strategies that can solve the winner's curse the outsider originally faces in a sealed-bid first price auction. It is profitable for an investor to

[5] The same mechanism can be used to explain seemingly different phenomena: For example, if we regard venture capital firms as "investors" and start-up companies as "applicants", we can reason the existence of business plan competitions. If employers are "investors" and graduate students are the "applicants", we can proof that it makes sense for both parties to form a network of high potentials. Finally, certain types of cooperatives could also be regarded as qualified networks where e.g. vintagers are "applicants" and wine wholesalers or consumers play the part of our "investors".

become an insider, if the screening costs of the jury, which the insider has to pay, are sufficiently low. As long as the marginal cost of effort are reasonably high for lowly talented applicants, and reasonably low for highly talented applicants, there is an infinite set of equilibrium effort levels, applicants can exert, that clearly separate low and high potentials. This leads to a reduction in the degree of information asymmetry the investors face concerning the applicants' talents. Since highly talented applicants profit from this reduction, they are motivated to apply for network membership. Potential applicants with low talents though have no interest in revealing it and refrain from applying—as long as they know their talent ex ante already, which is not clear in reality (see Krähmer, 2003). Finally, it is suggested that contests for applicants to networks are more efficient than alternative screening mechanisms, if the reputation gains of newly accepted network members are sufficiently large.

During the last years an entire strand of the literature on OSS has developed trying to explain motivations of individuals and firms to contribute to the OSS production process. Lerner and Tirole (2002a) explain that contributions to OSS projects reduce developers' short-term income, but enhance long-term prospects. Johnson (2002) supports this approach and points on the importance of career concerns for mostly young developers. Baake and Wichmann (2003) focus on the motivations of firms and organisations while Bonaccorsi and Rossi (2003) and Lakhani and Wolf (2003) employ broader, interdisciplinary explanations and overviews on the literature. Powell (1990) and Baker et.al. (2002) explain that networks are of particular suitability, if transactions between two parties are based upon relational contracts or informal relationships, i.e. if they are not verifiable and enforcable by a third outside party such as a court. However, Schmidt and Schnitzer (2003, p.9) in their study of open source communities doubt the importance of relational networking in larger organisations: "while it is widely acknowledged that reciprocity does play an important role for the interaction of people in small groups it is very unlikely that altruism and/or reciprocity provide sufficient incentives to explain the enormous contributions in time and effort to open source software." Therefore, although we accept its importance, we do not focus on the relational aspects of network formation, but on another mechanism that distinguishes them both from markets and hierarchies: selection.

Our model has the following form. Investors can choose between supporting the qualified network of OSS project leaders and becoming an insider, or to refrain from that and staying an outsider, thus restricting themselves to the development of closed source software. Applicants, having private information on their own talent, can exert effort with their application, i.e. they can spend a lot of time programming for OSS projects and producing lots of code that might be accepted by a project leader as part of the latest version of the software whose development that leader manages. The entire OSS community in general, and the qualified network of current OSS project leaders in particular, serve as the jury of the contest judging the amount of sophisticated code of each developer.

Since for investors it is prohibitively expensive to screen the entire amount of OS software published, they require support in determining the potential value of applicants. Jury members, who have to screen the work of applicants anyway to do their job of managing software projects properly, know about high quality developers who have not been promoted as project (sub-)leaders yet, and can convey this information to the insider.[6]

In line with it, in our set-up the jury randomly chooses the winners of the contest (i.e. assigning positions as project leaders) among the applicants with high effort leading to reputation gains of the winners. The outsider gets no individual advice and only sees who has won the tournament and is accepted as a new network member, i.e. the outsider can only assemble a mere list of all OSS projects' heads at a low

[6] If one prefers specific incentives for such a behaviour, parts of the insider's expenses could be used to reward jury members with a premium for pointing on highly talented developers currently without a prominent role. Jury members would not scientifically exaggerate the talent of applicants to receive higher premiums, if threatened by a loss of own reputation in case of revealed false advice, i.e. a trigger strategy of the insider.

cost, and knows that these leaders were awarded with leadership by their fellows.[7] Therefore, they should fulfill certain quality criteria or embody a high talent respectively. But the outsider does not get the extra information which applicants besides the new project leaders embody a high talent. Using the set-up of a sealed-bid first price auction with asymmetric information, we model the final stage of the game, when the inside and the outside investors bid for every applicant according to the knowledge they have.

Because of these elaborations this paper not only relates to the literature on OSS, but also to network formation. A string of the literature focusing on theoretical models that explain, just as this paper, the formation of network forms of organisation is comprehensively covered by the compendium of Dutta and Jackson (2003). However, besides the formation of networks these articles mostly research the dynamics and stability of certain network forms or their welfare effects. This paper, in contrast, focuses on the application mechanism *before* the network exists thereby taking the stability of the network itself as exogenous.

The paper is organised as follows. Section 2 describes the model. Also, bidding equilibria of the investors, effort equilibria of the applicants, and resulting motivations for both groups to participate in a network form of organisation are given. Section 3 briefly discusses, without a formal model, under which circumstances networks could be an efficient organisational form to select applicants. Section 4 concludes.

2 The model

There are two investors and, to keep algebra simple, $n = 3$ applicants. Investors are looking for applicants, for instance to employ them or to invest in their start-up projects, and have to decide whether to support the qualified network of OSS

[7] Raymond (1998) confirms: "The free-software community's internal market in reputation exerts subtle pressure on people not to launch development efforts they're not competent to follow through on."

project leaders with financial and human resources. Potential applicants (software developers) are searching for an employer or investor and consider to apply for network membership, i.e. they consider whether to contribute to the OSS production process at all.

2.1 The game

The timing of the game is as follows:

1. Nature determines a level of talent $\eta \in \{L, H\}$ for each applicant. Thus every applicant either belongs to the less talented group L or to the highly talented group H, and carries a value $y(\eta)$ for investors.

2. One investor is defined not to finance the network in any case thereby playing an *outsider* strategy. The second one may either participate in the network playing an *insider* strategy, or become an outsider, too. An insider has to pay the screening costs of the application contest amounting to $nk = 3k$.

3. Applicants choose an effort level $e \in \{0, e^*\}$. Because of monetary expenses for the contest and an individual level of effort disutility, they incur costs of $c_\eta = a_\eta e$ each, where $a_H < a_L$. That is, applicants with high talents have relatively lower marginal costs when exerting effort than applicants with low talents.

4. The independent jury recognizes the effort levels, and randomly draws the winner from the applicants with high effort levels.[8] The winner is accepted

[8]The jury can be regarded to be independent, i.e. not having any private interest in the acceptance or non-acceptance of a specific developer to the qualified network, since we defined it to be very large. There might be single jury members who prefer to exclude certain applicants from a prominent position, for instance because they work on a similar project. But this is not problematic for the model, since "the jury" can be regarded as a multitude of juries, and there could be another group of OSS programmers who like the output of this one developer and invite her to a more prominent position within their project.

as a new network member and receives reputation r. The insider obtains a perfect signal on the effort level provided by each applicant from the jury. The outsider only gets to know which applicant has won the contest (weaker signal).

Both investors bid the price p according to their respective signals for each applicant. The higher bid wins and is paid from the bidder to the applicant.

2.2 Investors' bidding equilibrium

The game is resolved as usual starting with the 4th stage. We are looking for a Bayesian equilibrium of the sealed-bid first-price auction. Here, the information asymmetry among the investors is relevant for their bidding strategies: Insiders are perfectly informed by the jury which applicants provided a high effort level, and which did not.[9] Outsiders, in contrast, only know which applicant was declared the winner and accepted as new member of the network.

$y(\eta)$ equals the net value of the investment project an applicant stands for. We assume that both possible values are common knowledge, but the specific one of each applicant is her private information.

We still need to elaborate on the relation between high talented applicants and the number of winners: As will be explained in more detail on the third stage of the game, we assume that two out of the three applicants embody high talent. But there can be only one victor who becomes the new network member.[10] This one,

[9]The jury has to be independent from the insider's intervention when determining the winner. Otherwise, it would not be credible to choose "the best" applicant. As a result, the winner, and the network as a whole, would obtain no reputation, and applicants with high talent would have no higher a priori probability to receive a high bid p than low talented folk. The contest mechanism would break down.

[10]It is a crucial assumption for the model that there are more applicants with high talent than winners of the contest (or positions for project leaders). As long as this assumption is fulfilled the inside investor has an advantage over the outsider, since she is in steady contact with the jury, or parts of it (via conferences, common projects, or the like). Because of the high total amount

therefore, is always of high talent.[11] All this is common knowledge. Therefore, there is no information asymmetry among the investors when bidding for the winner. Both face perfect Bertrand competition and will bid exactly the value of a high quality investment project, $y(H)$, and receive zero profits. The winner, on the other side, on top of the reputation will obtain this price of $y(H)$.

The remaining case of the contest losers is more interesting, since, by definition, this group is mixed and consists of one applicant with high and one with low talent. Both investors have the same a priori beliefs with a share of q losers with high talents and a share of $(1 - q)$ lowly talented ones. The equilibrium solution *only for the losers of the contest* provides

> *Result 1: (i) There is no equilibrium in pure strategies. (ii) In mixed strategies, an equilibrium exists, if* $q \geq \frac{y(H)-y(L)}{2y(H)-y(L)}$. *(a) The outsider has a mixed strategy which is independent of the applicant's type. She will bid* $y(L)$ *with probability* $\phi = (1-q)$. *She will bid* $(1-q+uq)y(H)$, *where* u *is uniformly distributed between 0 and 1, with probability* $(1 - \phi) = q$. *She makes zero expected profits. (b) The insider always bids* $y(L)$ *for a loser with low talent. For a loser with high talent she bids* $\frac{(1-q)y(L)+uqy(H)}{1-q+uq}$. *In expectation, she makes positive profits of*
>
> $$\frac{2(1-q)(y(H)-y(L))}{2-q}. \qquad (1)$$

of OSS developers and the dynamic market environment, where new developers enter and leave the production process frequently, it should take a while until applicants with high talent could be promoted as new project leaders. Moreover, the amount of projects enjoying a certain degree of public interest should be restricted because of high search cost of the public. Hence, at a given point of time, there should be less leaders than highly talented applicants in the OSS community.

[11]We assume that the independent jury randomly assigns the winner's title to an applicant who has exerted a high effort level. This resembles applicants with high talent as we will see below. The remaining high talent will be among the losers of the contest, but only the insider will get to know, via the jury, who she is. This relation is a central feature of the mechanism described.

Proof: See appendix.[12]

The case is tricky, since the outsider cannot play a pure strategy. If she did that, the insider would always bid slightly more for applicants with high talent. For low quality applicants, the insider would bid only $y(L)$, hence the outsider would be able to invest. But her bid would have always been too high in relation to the low value she bought leading to structural overinvestment of the outsider. This is called the *winner's curse* problem and requires the outsider to play a mixed strategy. Such a mixed strategy of the outsider forces the insider to play a mixed strategy in equilibrium, too, for technical reasons.

2.3 Applicants' effort equilibrium

2.3.1 The trade-off of the applicants

We have assumed so far that the jury's decision is based upon the effort levels exerted by the applicants. To make sure that effort levels can be used to separate high from low talent precisely, we need to derive separating effort equilibria.[13] We found these, if the effort level e^* the jury requires to see to regard an applicant as having a high talent (i.e. via assessing an applicant developer's programming output) is only exerted by highly skilled applicants, whereas ones with low talent invest less effort. This is necessary to make the signal, that is seen by the jury and told the insider on the fourth stage of the game, valuable motivating her to invest in the network at all.

The winner of the contest is accepted as new network member and receives (independent of her real, publicly unknown talent) reputation r, which is created by the

[12]The structure of the proof follows Rajan (1992) and Engelbrecht-Wiggans et.al. (1983). For our case with one loser with high and one loser with low talent, the result can easily be boiled down as $q = 1/2$.

[13]The following kind of modelling – dichotomous talent and dichotomous effort – is, thereby, different from Spence (1973) – dichotomous talent and continuous effort – and Holmström (1999), who adds white noise ϵ to continuous talent and continuous effort.

selection mechanism. r is a variable to express the long-term opportunities to obtain high investment bids p.[14] It is positively dependent on the number of applicants n and general, exogenous, industry specific factors $\alpha > 0$.[15] Therefore, with the values used in this model the utility derived from reputation is $r = \alpha n = 3\alpha$.

Let Q be the share of applicants of the total population $n = 3$ who exert an effort level of $e^* > 0$. If we can prove that e^* is a separating effort equilibrium, then Q also stands for the share of highly talented applicants in all applicants. Consequently, the share of low talent is $(1 - Q)$.[16]

We further assume that the population of applicants consists of two highly talented agents and one lowly talented one, i.e. $Q = 2/3$.[17] For the investors have surveyed the market of applicants in the past, Q is common knowledge among them, but not necessarily among the applicants. The investors know that the jury randomly draws the winner from the applicants with high talent; therefore they can deduct that, if $Q = 2/3$, the share of high potentials in the group of losers used in the fourth stage of the game is $q = 1/2$.

According to result 1, the outsider just bids $y(L)$ in $\phi = (1 - q) = 1/2$ of the auctions. Then the insider will bid the highest price p with a mean of $\frac{2(1-q)y(L)+qy(H)}{2-q} = \frac{2y(L)+y(H)}{3}$, given the applicant has a high talent. For low quality projects she

[14]By that, reputation equals the net present value of the total utility accumulated after the auction of stage four, that is connected to winning the contest in the present.

[15]α could also be regarded as the degree of relevance of relationship networking, i.e. making contacts, exchanging industry internal information, etc.

[16]Please, note that, in contrast to this, q stands for the share of high talents in the losers only.

[17]This simple case is sufficient to show the mechanism of the model, since the group of losers is mixed. Other values of Q are less interesting, because insider and outsider are not subject to information asymmetry and face perfect Bertrand competition. They either always bid $y(H)$ for winners and $y(L)$ for losers (if $Q = 1/3$) or the mechanism breaks down anyway as there is perfect and complete information (for $Q = 0$ or $Q = 1$). Larger numbers of applicants just make algebra more complicated but do not reveal new insights. The general requirement that has to be fulfilled is that $Qn > m$, i.e. there have to be more applicants with high talent than the ex ante number of winners.

also bids $y(L)$. In $(1-\phi) = q = 1/2$ of the cases the outsider bids a mean of $(1-\frac{q}{2})y(H) = \frac{3}{4}y(H)$, which is higher than the insider's mean as long as $y(H) > \frac{8}{5}y(L)$, since that is $y(L)$ for a lowly talented applicant or $\frac{2y(L)+y(H)}{3}$ for a high quality project.[18] If $y(H) < \frac{8}{5}y(L)$, the insider's mean of bids for highly talented applicants is higher than the outsider's.

Thus, an applicant choosing $e = e^*$ expects:

$$\begin{cases} \frac{1}{2}(y(H)+r) + \frac{1}{2}\left(\frac{1}{2}(\frac{2y(L)+y(H)}{3}) + \frac{1}{2}(\frac{3}{4})y(H)\right) - a_\eta e^* & \text{if} \quad y(H) > \frac{8}{5}y(L) \\ \frac{1}{2}(y(H)+r) + \frac{1}{2}(\frac{2y(L)+y(H)}{3}) - a_\eta e^* & \text{if} \quad y(H) < \frac{8}{5}y(L). \end{cases} \tag{2}$$

An applicant setting $e = 0$ knows that she can never win the contest, as in case of a separating equilibrium, there is, by definition, at least one other applicant exerting high effort. Hence she expects:

$$\frac{1}{2}y(L) + \frac{1}{2}(\frac{3}{4})y(H). \tag{3}$$

2.3.2 Separating effort equilibrium

Given a specific realisation of e^*, we obtain a separating effort level, if (2) $\geq$ (3) for all applicants with high talents and (3) $\geq$ (2) for all applicants with low talent. A lowly talented applicant will not exert any effort for the application (i.e. set $e = 0$) if and only if

$$\frac{1}{2}y(L) + \frac{3}{8}y(H) \geq \frac{37}{48}y(H) + \frac{1}{6}y(L) + \frac{1}{2}r - a_L e^* \quad \text{if} \quad y(H) > \frac{8}{5}y(L) \tag{4}$$

$$\frac{1}{2}y(L) + \frac{3}{8}y(H) \geq \frac{2}{3}y(H) + \frac{1}{3}y(L) + \frac{1}{2}r - a_L e^* \quad \text{if} \quad y(H) < \frac{8}{5}y(L). \tag{5}$$

Alike, a highly talented applicant will exert effort (i.e. choose $e = e^*$) if and only if

$$\frac{1}{2}y(L) + \frac{3}{8}y(H) \leq \frac{37}{48}y(H) + \frac{1}{6}y(L) + \frac{1}{2}r - a_H e^* \quad \text{if} \quad y(H) > \frac{8}{5}y(L) \tag{6}$$

$$\frac{1}{2}y(L) + \frac{3}{8}y(H) \leq \frac{2}{3}y(H) + \frac{1}{3}y(L) + \frac{1}{2}r - a_H e^* \quad \text{if} \quad y(H) < \frac{8}{5}y(L). \tag{7}$$

[18] If $y(H) = \frac{8}{5}y(L)$, there is a chance of 0.5 for each investor to be declared the highest bidder. For simplicity we include this case only implicitly.

Therefore, e^* has to fulfil the following conditions:

$$\frac{19y(H) - 16y(L) + 24r}{48a_L} \leq e^* \leq \frac{19y(H) - 16y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) > \frac{8}{5}y(L) \tag{8}$$

$$\frac{14y(H) - 8y(L) + 24r}{48a_L} \leq e^* \leq \frac{14y(H) - 8y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) < \frac{8}{5}y(L). \tag{9}$$

To qualify these ranges as stable separating equilibria, a lowly talented applicant must not have any incentive to mimic high potentials by setting $e = e^*$. Also, a highly talented applicant must have no incentive to save the disutility created by exerting effort and set $e = 0$.

Therefore, given that (8) and (9) are fulfilled, to make sure the lowly talented applicant has no incentive to play $e = e^*$, in addition it is required that[19]

$$e^* \geq \frac{21y(H) - 12y(L) + 24r}{72a_L}. \tag{10}$$

To make sure the high quality project leaders have no incentive to set $e = 0$, on top of (8) and (9) it is required that

$$e^* \leq \frac{13y(H) - 16y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) > \frac{8}{5}y(L) \tag{11}$$

$$e^* \leq \frac{8y(H) - 8y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) < \frac{8}{5}y(L). \tag{12}$$

> *Result 2: (i) As long as equations (8) to (12) are fulfilled, there exists an infinite set of separating equilibrium effort levels* e^**. (ii) This is possible only, if the marginal cost of effort for applicants with low talent* a_L *are sufficiently high, and the marginal cost of applicants with high talent* a_H *are sufficiently low. (iii) For each of these equilibrium effort levels both highly talented applicants will exert an effort of* e^**, whereas the lowly talented applicant will refuse any effort.*

Proof: See appendix.

The signal demanded by the jury from high talents, to play $e = e^*$ and thereby to

[19] For a derivation see appendix.

spend sunk costs of $c_H = a_H e^*$, does not increase the insider's profit besides the working signaling mechanism itself. The highly talented applicants, however, are affected negatively, since their net payoff is reduced. Therefore, it would be efficient – if not necessary to keep the mechanism work though – to minimize the sunk costs and set e^* to the lowest parameter realisation that is within the boundaries of result 2.

2.4 Why does the OSS community exist?

It remains to be inspected whether the investor, who has the option to choose an insider strategy on stage two of the game, should make use of it. In line with it, we shall question whether applicants do have any incentives at all to apply for network membership.

Without the option of becoming the financier of a network both investors are outsiders. They just know Q and bid for each applicant according to the expectation

$$p = E(y(\eta)) = Qy(H) + (1-Q)y(L) = \frac{2}{3}y(H) + \frac{1}{3}y(L). \tag{13}$$

Since this is exactly the mean value of the applicants for the investors, the outsiders expect profits of $E(\pi) = 0$. In case one investor decides to become an insider, according to result 1, it affects the other investor's bidding strategy, but not her expected profits. For the insider herself, however, the situation changes: As she knows exactly which of the two losers of the contest is of high talent, she gets an informational advantage. Because of this she expects profits according to result 1:

$$E(\pi) = \frac{2(1-q)(y(H) - y(L))}{2-q} = \frac{2}{3}(y(H) - y(L)). \tag{14}$$

The price for this advantage is that the insider has to pay for the jury's screening costs, i.e. the transaction costs of the network, which accumulate to $nk = 3k$. Let $\theta(Q = 2/3)$, where $\theta \in [0, 1]$, be the a priori probability known to all investors that

$Q = 2/3$ (given the values we have used so far, of course $\theta(Q = 2/3) = 1)^{20}$. Then we get

Result 3: Investors do have a motivation to invest in a network organisation, if the costs to screen applicants are sufficiently low, i.e. if $\frac{2}{3}\theta(Q = 2/3))(y(H) - y(L)) \geq 3k$.

If investors have no possibility to obtain more information on applicants' talents by asking them to apply for a network the investors are financing (or a similar revelation mechanism), according to (13) all applicants expect $p = \frac{2}{3}y(H) + \frac{1}{3}y(L)$, which is independent of their real talents.
On the contrary, applicants with low talents or bad quality projects, who set $e = 0$ as we know from result 2, according to (3) expect net payoffs of $p = \frac{1}{2}y(L) + \frac{3}{8}y(H)$, if they apply for network membership.

Result 4: Lowly talented applicants do not have any incentive to apply for network membership – given they know their realisations of the talent parameter η *already at the point of time they have to decide about applications.*

Proof: Applying makes sense for lowly talented folk, if $\frac{1}{2}y(L) + \frac{3}{8}y(H) - \frac{2}{3}y(H) - \frac{1}{3}y(L) \geq 0$. This equals $y(H) \leq \frac{4}{7}y(L)$, which is impossible for all supported values, since we assumed $y(H) > y(L)$. $\square$

High flyers, who set $e = e^*$ as we know from result 2, according to (2) expect $p = \frac{37}{48}y(H) + \frac{1}{6}y(L) + \frac{1}{2}r - a_H e^*$.

Result 5: Highly talented applicants, who are informed about their relative degrees of talent at the point of time they have to decide about

[20] The relation $Q = 2/3$ is depicted in our case, since it is the only value where there are more highly talented applicants than possible winners of the contest (i.e. $Q \neq \{0, 1/3\}$) so there are losers with high talent, and we have asymmetric information (i.e. $Q \neq \{0, 1\}$) so the contest carries a positive value for the insider at all.

applications, do have incentives to participate in a contest to become a network member, if $e^* \leq \frac{1}{a_H}(\frac{5}{48}y(H) - \frac{1}{6}y(L) + \frac{1}{2}r)$.

Proof: Applying is attractive for highly talented applicants, if $\frac{37}{48}y(H) + \frac{1}{6}y(L) + \frac{1}{2}r - a_H e^* - \frac{2}{3}y(H) - \frac{1}{3}y(L)) \geq 0$. Rearranging yields result 5. It is possible within supported ranges of the parameters and depends on their specific realisations. □

Summarizing, if screening costs are sufficiently low, investors always are motivated to finance a network organisation, i.e. software companies have incentives to collaborate with the OSS community, if the sum of human and financial resources they have to commit to this task, is not prohibitively high. Applicants with high talents will apply depending on specific parameter realisations. Hence, gifted software developers will spend time and effort on OSS, if their marginal cost of effort is low or if the difference in values for investors between them and lowly talented developers is high or if the reputation to gain by contributing to an OSS project is large. Low quality projects, in contrast, who suffer from diminishing information asymmetry concerning talent or quality, have no incentives to get involved in contests. However, the latter result fundamentally depends on the assumption that applicants know the degree of their own talents relative to other potential applicants at the point of time they have to decide whether to apply, or not. But this is not clear at all in reality (e.g. see Krähmer (2003)).
If developers ex ante do not know their own talents but only the probability to be of high talent, building on result 5 and combining the weighted expectation of highly and lowly talented candidates' payoffs, we could easily derive incentives to apply for all applicants given certain parameter realisations.

3 Efficiency of application contests to networks

We will examine the efficiency of the application contest to a qualified network inherent in the OSS production process by comparing the mechanism described above with two likely alternatives.

We explained that in our model the insider bears costs of $3k$, the outsider pays nothing, and all applicants together invest $2a_He^*$. The insider yields a perfect signal, i.e. she knows exactly who is of high talent, and the outsider yields a weak one: she learns who has won the contest (and has a high talent, for sure). Furthermore, the victor gets reputation r.

Alternative 1: In case just one investor surveys the applicants privately without telling her findings to the public, she still bears costs of $3k$. The other investor still pays nothing, and the (two highly talented) applicants have to spend $2a_He^*$ together. In exchange, the surveying investor still gets a perfect signal, but her competitor gets none. Since the public is not informed, reputation gets lost.

Alternative 2: If both investors each test all applicants privately, both obtain perfect signals, but also total costs double to $6k + 4a_He^*$.

The investors cannot be keen on alternative 2, since they had to bear high costs but would not get any informational advantage over the other leading to Bertrand results and zero profits. Via alternative 1 information asymmetry among the investors is larger than in the network case. According to result 1, the inactive investor would yield zero profits, the surveying one would expect gross payoffs of $\frac{1}{2}(y(H) - y(L))$ for each highly talented applicant, i.e. a total gross payoff of $y(H) - y(L)$.[21] This is larger than the insider's gross payoff in the network case (compare (14)). As screening costs amount to $3k$ in both cases, the investing investor should prefer alternative 1 over the network.

However, even without a formal model it seems plain to assume that the network form of organisation is the most attractive mechanism to apply for highly talented applicants: on the one hand they do not have to incur higher cost through effort than when applying individually to one investor (alternative 1), on the other hand they have the chance to gain reputation and a higher price being bid for them by investors because of decreased information asymmetry. This is why the average ab-

[21] This can be calculated easily by setting $q = Q = 2/3$ in (1).

solute quality of applicants should be higher in contests to networks than in the alternative screening forms, as long as applicants may choose only one channel of application because of budget constraints. Thereby, the insider, who finally is interested in bidding for the very best applicants, also benefits from financing the qualified network of OSS project leaders.

4 Concluding remarks

The main objective of this paper has been to investigate the approach to model the OSS production process as an application contest to a qualified network, to explain its use, and to compare it with alternative screening forms. We showed that investor firms who finance the OSS community (insiders) do have an informational advantage over outsiders in the final asymmetric sealed-bid first-price auction, which is reflected positively in their profit expectations because they just better know than outsiders which developers to employ or which start-up firms of developers to invest in. As long as the share of highly talented applicants exceeds a certain threshold, we can solve the winner's curse originating for outside investors by introducing mixed bidding strategies in the Bayesian equilibrium.

Given marginal cost of effort are sufficiently high for lowly talented applicants, and sufficiently low for highly talented ones, we found equilibrium effort levels that applicants have to invest for being labelled as of high talent. Thereby, we derived an infinite number of separating effort equilibria where high talents exert the demanded amount of effort, and low talents do not. Because of that the effort level forms a perfect signal for the jury (and the insider) to detect applicants with high and low talent respectively.

Transferring this result to the world of software development, there should be a certain amount of code produced by a developer that is sophisticated enough to be regarded worthwhile to be included in the next version of a programme by several fellow developers or project leaders. Only after reaching this threshold a developer has the potential of making a name for herself in the OSS community and gaining reputation to be of outstanding ingenuity (i.e. winning the contest). But even if, for "bad luck", the high talent cannot reach the position of a project leader well known to the rest of the community, a current prominent project leader might point on her when being approached by software firms in search of talented staff.

This informational advantage leads to incentives for investors to support the OSS production process, if screening costs are sufficiently low, despite the fact that there is a positive externality: just because the insider invested, the outsider can detect one high talent, too (the winner of the contest). With certain parameter realisations, highly talented applicants also have incentives to reveal their talents by applying for network membership. On the contrary, this is exactly why applicants with low talents have no incentives to apply, given they already know their own talents relative to other potential applicants when they have to decide about application.

Comparing the OSS production process with alternative screening mechanisms, we concluded that it is the efficient (and preferred) organisational form, if the reputation the victor of the contest gains is sufficiently large. Because of that the application contest to a qualified network not only is of great value in software production, but in general in industries where ex ante unknown talent or quality of individuals and reputation are very important, for instance, in all human capital intensive spheres (see Powell (1990, p.324)).

A straightforward extension of our approach would be the analysis of the role of active marketing of the current project leaders and other OSS community members for the victor's reputation and, thereby, for the attractivity of the qualified network per se. Alike, one could survey, if investors can increase expected profits by accepting more than one new member to the network or charging a (monetary) application fee, that is no sunk cost. A natural extension would be to connect this model of a contest reasoning for network formation with the literature researching the dynamics and stability of networks after the contest.

A Appendix

A.1 Proof of result 1

Annotations: The proof draws on a very general model of Engelbrecht-Wiggans et.al. (1983) and an application of it to a discrete distribution of types introduced by Rajan (1992), which is extended and adjusted here.

An applicant has private information on the realisation of the random variable $\mathbf{V}$ of the value of her talent or project for investors. $\mathbf{V}$ takes values in $\mathbf{R}_+$ and has finite expectation. The two investors are the informed insider and the uninformed outsider. The random variable $\mathbf{X}$ represents the insider's private information about the value of the project. Both the insider and the outsider know the joint distribution of $(\mathbf{V}, \mathbf{X})$.

Both investors simultaneously bid a price p, which is the fraction of the value of an applicant with high talent, $y(H)$. The applicant accepts the highest bid which exceeds her reservation bid 0. Thereby, investors face the risk to meet a low talented type, since they bid a fraction of the value of a high quality project anyway, but may get only low quality for it.

The insider's problem, after observing $\mathbf{X} = x$, is to choose p to maximize Prob(Bid p wins)$(E[\mathbf{V}|\mathbf{X} = x] - py(H))$. Her private information $\mathbf{X}$ enters her decision problem only through $\mathbf{F} = E[\mathbf{V}|\mathbf{X}]$. Without loss of generality we assume that the insider observes the random variable $\mathbf{F}$ which has the same support as the value of the applicant $\mathbf{V}$, unlike $\mathbf{X}$ which describes the applicant's type. After observing the private information, the insider can be characterized by her information-induced *type* $\mathbf{f}$.

The solution method requires a one-to-one mapping of the insider's information induced type to her equilibrium bid. Since $\mathbf{F}$ does not have a continuous but a discrete (Bernoulli) distribution, we have to transform the (two) discrete types of the insider into a continuous distribution. This happens by allowing her to play mixed strategies. To enter a random factor to the insider's bidding strategy, she makes use of the random variable $\mathbf{U}$, that is independent of $(\mathbf{V}, \mathbf{X})$ and has an atomless distribution on $[0,1]$. A mixed strategy β for the insider is a function from $\mathbf{R}_+ \times [0,1] \to [0,1]$, where $\beta(f,u)$ is the bid when $\mathbf{F} = f$ and $\mathbf{U} = u$. We assume without loss of generality that $\beta(f,u)$ be nondecreasing in u for fixed values of $\mathbf{f}$.

We derive a continuous type $\mathbf{t}$ from the joint distribution of $\mathbf{f}$ and $\mathbf{u}$. Let $\{(\mathbf{F}, \mathbf{U}) < (f,u)\}$ denote the event $\{(\mathbf{F} < f)$ or $(\mathbf{F} = f$ and $\mathbf{U} < u)\}$. Let $T(f,u)$ be the probability of that event and define $\mathbf{T} = T(\mathbf{F}, \mathbf{U})$. $\mathbf{T}$ is the insider's *distributional type*, which is uniformly distributed on $[0,1]$. Thereby, $\mathbf{T}$ carries the same information that $\mathbf{F}$ does, but has the advantage of being a continuous distribution.

To summarize, we started with the private information of the insider $\mathbf{X}$, received the conditional $\mathbf{F}$, and transformed it to the continuous distributional type $\mathbf{T}$ by making use of the random variable $\mathbf{U}$. Therefore, the equilibrium strategy β is a function from the space of the insider's types $t \in [0,1]$ to the space of her bids $\beta \in [0,1]$ and is assumed to be nondecreasing in t.

For the outsider gets no signal – none that supports her decision making process, at least – her bidding strategy can be described by a distribution G over $[0,1]$ representing her random choice of bids.

We shall point on the fact that the insider employs a mixed strategy because of technical reasons: necessarily, she has to transform her discrete information-induced type $\mathbf{f}$ to a continuous distributional type $\mathbf{t}$. The outsider, in contrary, plays a mixed strategy, for the insider knows everything the outsider does leading to the outsiders *winner's curse*: if the outsider played a pure strategy, whenever the insider detected a high quality applicant, she would bid slightly more than the outsider's pure strategy told. For all applicants with low talent, however, the insider would only bid the lowest possible realisation of $\mathbf{V}$ letting the outsider overinvest in the project.

Proof: To obtain Bayesian equilibrium strategies each bidder has to maximize her own expected payoff, according to the information available to her, given that the other bidder does so, too. The proof consists of the following four steps:

1. We have to show that equilibrium bids have identical supports.
2. This may be used to show that the outsider's expected payoff in equilibrium is zero.
3. We shall set the outsider's payoff to zero to receive the optimal strategy of the insider.
4. The bidding strategy of the outsider can be derived by making use of the insider's optimizing behaviour.

Since steps 1 and 2 are identical to Engelbrecht-Wiggans et.al. (1983), they are omitted here.[22]

Step 3: The expected profit of the outsider conditional on winning with a bid p (where t is the corresponding informed type such that $\beta(t) = p$) is $E[F(\mathbf{T}) - py(H)|\mathbf{T} \leq t]$. Setting this equal to zero and rearranging yields

$$p = \beta(t) = \frac{E[F(\mathbf{T})|\mathbf{T} \leq t]}{y(H)}. \tag{A.1}$$

This expression holds when $t \geq t_0$, where t_0 is the insider's type that bids the lowest reasonable amount, $\frac{y(L)}{y(H)}$.[23] All types $t < t_0$ also bid $\frac{y(L)}{y(H)}$.

Step 4: We know about the strategy of the outsider that the insider in optimum reacts with playing $\beta(t)$ to it. After seeing her own distributional type t the insider maximizes $G(p)[F(t) - py(H)]$, where $p = \beta(t)$. Differentiating this with respect to p yields

$$\frac{dG(p)}{dp}[F(t) - py(H)] - G(p)y(H) = 0. \tag{A.2}$$

[22] In particular, we point on theorem 2 of Engelbrecht-Wiggans et.al. (1983) which proves that the outsider makes zero profits in expectation.

[23] It cannot be an equilibrium to bid less than $\frac{y(L)}{y(H)}$, for, if one investor did it, the other one could bid slightly more and obtain a positive payoff even when the applicant had a low talent. The first investor would react correspondingly, and bid slightly more than she expects the second one to bid, and so on. Therefore, the Bertrand solution with both investors bidding $\frac{y(L)}{y(H)}$ for applicants with (expectedly) low talent, is stable.

Using $dG(p) = G'(p)$ and rearranging gives

$$\frac{G'(p)}{G(p)} = \frac{y(H)dp}{F(t) - py(H)}. \tag{A.3}$$

Also, because of (A.1), for the insider's strategy it is valid in general[24]

$$p = \beta(t) = \frac{\int_0^t F(s)ds}{ty(H)}, \tag{A.4}$$

leading to

$$dp = \beta'(t)dt = \frac{tF(t) - \int_0^t F(s)ds}{t^2 y(H)} dt. \tag{A.5}$$

Substituting in (A.3) from (A.4) and (A.5),

$$\frac{G'(p)}{G(p)} = \frac{1}{t} dt. \tag{A.6}$$

Integrating between t and 1 (for $t \geq t_0$) and applying the boundary condition that $G(\beta(1)) = 1$, it is valid for the outsider's strategy in general[25]

$$G(\beta(t)) = t. \tag{A.7}$$

For any bid by the outsider corresponding to an informed type $t < t_0$ of the insider, the outsider expects losses. Therefore, $G(\beta(t_0)) = G(\frac{y(L)}{y(H)})$, i.e. with a certain probability the outsider does not bid more than $\frac{y(L)}{y(H)}$.[26] This probability is $\phi = G(\frac{y(L)}{y(H)})$.

Now consider the model in the text: With probability q an applicant is worth $y(H)$ for investors, with probability $(1 - q)$ her value is $y(L)$. The insider exactly knows the realisation. Hence, $\mathbf{F} = y(H)$ or $y(L)$. The outsider knows the distribution of

[24]See Engelbrecht-Wiggans et.al. (1983), p.164.

[25]Hereby, the numerator of (A.6), dt, is transformed to its primary function and the denominator is "filled up" from t to 1.

[26]As mentioned above, she also does not bid less, though.

the (two) realisations. Assume without loss of generality that $\mathbf{U}$ is uniform on $[0,1]$.

$$t(f,u) = prob\{(\mathbf{F} < f) \quad \text{or} \quad (\mathbf{F} = f \quad \text{and} \quad \mathbf{U} < u)\},$$
$$t(f = y(L), u) = u(1-q)$$
$$\text{and} \quad t(f = y(H), u) = (1-q) + uq.$$
$$F(t) = y(L) \quad \text{for} \quad t \leq 1-q$$
$$\text{and} \quad F(t) = y(H) \quad \text{for} \quad t > 1-q.$$

Substituting these values in (A.4) and (A.7), yields

$$\beta(t) = \frac{(1-q)y(L) + uqy(H)}{(1-q+uq)y(H)} \quad \text{if} \quad t > t_0, \tag{A.8}$$

$$G(\beta(t)) = 1-q+uq \quad \text{if} \quad t > t_0, \tag{A.9}$$

$$G(\beta(t)) = 1-q \quad \text{if} \quad t \leq t_0. \tag{A.10}$$

We obtain $G(\beta(t_0))(=\phi)$ by substituting $\beta(t_0) = \frac{y(L)}{y(H)}$ in (A.8), i.e. the value of t at which the optimal bid of the insider is $\frac{y(L)}{y(H)}$.
Through applicants with low talent the insider expects a payoff of zero because of the Bertrand competition mentioned above. However, she expects profits of $\frac{(1-q)(y(H)-y(L))}{1-q+uq}$ for each high quality applicant. Since $\mathbf{U}$ is uniformly distributed, its expectation is $E(u) = 0.5$. Substituting, this leads to a
Profit of the insider conditional on highly talented applicants:

$$\frac{2(1-q)(y(H)-y(L))}{2-q}. \tag{A.11}$$

The profit of the outsider is zero on average. As with a probability of $\phi = (1-q)$ she bids the riskless price $\frac{y(L)}{y(H)}$, with probability q she bids higher also for applicants with low talent. The insider, though, only bids $\beta(t_0) = \frac{y(L)}{y(H)}$ in these cases, and the outsider makes losses and suffers from a *winner's curse*. The zero profit condition of the outsider implies that these losses are equal in expectation to the profit she makes in the good state: $(1-\phi)(1-q)((1-q+uq)y(H) - y(L))$. By substituting

$\phi = (1-q)$ and $E(u) = 0,5$ we get the

Loss of the outsider from bidding for applicants with low talent:

$$q(1-q)\left(\frac{2-q}{2}y(H) - y(L)\right). \tag{A.12}$$

Finally, according to theorem 2 of Engelbrecht-Wiggans et.al. (1983), the profit of the outside investor is zero in expectation. This holds for

$$q \geq \frac{y(H) - y(L)}{2y(H) - y(L)}. \tag{A.13}$$

If the share of high quality applicants q is smaller, a Bayesian equilibrium cannot be obtained in the investors' bidding strategies.[27] □

A.2 Derivation of equations (10) to (12)

A.2.1 Ad (10)

In case a lowly talented applicant sets $e = e^*$, jury and insider get three e^*-signals and know that they are no help in decision making.[28] If this was possible, the outsider, knowing the specific effort level e^* demanded by the jury, would know that it does not produce a separating equilibrium and also would not trust in her own signal (getting informed about the contest's winner). As a consequence, the bidding equilibrium was that both investors bid the applicant values' expectation, $E(y(\eta)) = \frac{2}{3}y(H) + \frac{1}{3}y(L)$, for each of them and expect zero profits. Logically, the lowly talented applicant expects[29]

$$\frac{2}{3}y(H) + \frac{1}{3}y(L) + \frac{1}{3}r - a_L e^*. \tag{A.14}$$

[27] Please, note that the bidding strategies in result 1 were multiplied by $y(H)$ to receive total values, and not fractions of $y(H)$ as in this proof.

[28] Each of the applicants would have a chance of 1/3 to win the contest.

[29] Since applicants with high talent would have the same gross payoff, but less cost for exerting effort, it cannot be an option for high potentials to play $e = 0$, if it is profitable even for a lowly talented applicant to set $e = e*$.

According to (3), with no exertion of effort she expects $\frac{1}{2}y(L) + \frac{3}{8}y(H)$. After rearranging, we see that there is no incentive for the applicant with low talent to fake her type, if and only if

$$e^* \geq \frac{21y(H) - 12y(L) + 24r}{72a_L}. \tag{A.15}$$

A.2.2 (11) and (12)

If a highly talented applicant sets $e = 0$, the jury declares the remaining applicant, who set $e = e^*$, as the winner of the contest, being sure that she is of high talent.[30] The outsider would know that the specific level of e^* does not produce a separating equilibrium and would not trust her own signal. Alike, both investors would know that there is one highly talented and one lowly talented loser, but nobody knew who is who. As a consequence, the bidding equilibrium was that both investors bid $y(H)$ for the winner and the losers' expectation, $\frac{1}{2}(y(H) + y(L))$, for each of the losers. In contrast, if the highly talented applicant chose $e = e^*$, according to (2), she would expect $\frac{37}{48}y(H) + \frac{1}{6}y(L) + \frac{1}{2}r - a_H e^*$, if $y(H) > \frac{8}{5}y(L)$ and $\frac{2}{3}y(H) + \frac{1}{3}y(L) + \frac{1}{2}r - a_H e^*$, if $y(H) < \frac{8}{5}y(L)$. After rearranging, we see that there is no incentive for an applicant with high talent to fake her type, if and only if

$$e^* \leq \frac{13y(H) - 16y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) > \frac{8}{5}y(L) \tag{A.16}$$

$$e^* \leq \frac{8y(H) - 8y(L) + 24r}{48a_H} \quad \text{if} \quad y(H) < \frac{8}{5}y(L). \tag{A.17}$$

A.3 Proof of result 2

We have to prove that there exist effort levels e^* that fulfill equations (8) through (12) at the same time. To do that, we have to differentiate between two ranges within the relation of $y(H)$ and $y(L)$.

[30]This is obvious, since if the lowly talented applicant had an incentive to exert effort, the same would be true (stronger) for high talents, because of their cost advantage. If there is anyone uniquely setting $e = e^*$, it must be someone with high talent.

A.3.1 Equilibrium range if $\mathbf{y(H) > 8/5y(L)}$

If $y(H) > \frac{8}{5}y(L)$, equations (8), (10) and (11) have to hold. The right-hand side (RHS) of (8) is always larger than the RHS of (11). Hence, the RHS of (11) is the upper boundary of e^*. The left-hand side (LHS) of (8) is not smaller than the LHS of (10), if $r \geq y(L) - 0.625y(H)$. In this case, the LHS of (8) is the lower boundary of separating e^*. We found a defined range of realisations of e^*, if the LHS of (8) is smaller than the RHS of (11). This is given for

$$\frac{a_H}{a_L} \leq \frac{13y(H) - 16y(L) + 24r}{19y(H) - 16y(L) + 24r}. \tag{A.18}$$

If $r \leq y(L) - 0.625y(H)$, the LHS of (10) forms the lower boundary of e^*. This is smaller than the RHS of (11) for

$$\frac{a_H}{a_L} \leq \frac{13y(H) - 16y(L) + 24r}{14y(H) - 8y(L) + 16r}. \tag{A.19}$$

There are supported solutions for both (A.18) and (A.19).

A.3.2 Equilibrium range if $\mathbf{y(H) < 8/5y(L)}$

If $y(H) < \frac{8}{5}y(L)$, equations (9), (10) and (12) have to hold. The RHS of (9) is always larger than the RHS of (12). Hence, the RHS of (12) is the upper boundary of e^*. The LHS of (9) is never smaller than the LHS of (10). Thus, the LHS of (9) is the lower boundary of separating e^*. We found a defined range of realisations of e^*, if the LHS of (9) is smaller than the RHS of (12). This is given for

$$\frac{a_H}{a_L} \leq \frac{4y(H) - 4y(L) + 12r}{7y(H) - 4y(L) + 12r}. \tag{A.20}$$

There is an infinite set of supported solutions for (A.20). □

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