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# Voluntary Provision of Public Knowledge Goods: Group-Based Social Preferences and Coalition Formation

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# Voluntary provision of public knowledge goods: Group-based social preferences and coalition formation\*

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## Abstract

In this paper we develop a private-collective model of voluntary public knowledge production, where group-based social preferences have an impact on coalition formation. Our theoretical model builds on the large empirical literature on voluntary production of pooled public knowledge goods, including source code in communities of software developers or data provided to open access data repositories. Our analysis shows under which conditions social preferences such as ‘group belonging’ or ‘peer approval’ influence stable coalition size, as such rationalising several stylized facts emerging from large scale surveys of Free/Libre/Open-Source software developers (David and Shapiro, 2008), previously unaccounted for. Furthermore, heterogeneity of social preferences is added to the model to study the formation of stable, but mixed coalitions.

**JEL Classification:** C70, D71, H40, L17.

**Keywords:** Public knowledge goods, Coalition formation, Private-collective model, Group belonging, Peer approval, Open source software.

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# 1 Introduction

A vast body of empirical research has shown the effectiveness of voluntary mechanisms for the production of public knowledge goods.<sup>1</sup> From the point of view of public good theory, two important features of successful economic and institutional arrangements are highlighted in this literature: first, the importance of reaching an adequate group size for the knowledge generation process to proceed and, second, the effect of private benefits on the willingness of agents to participate to the public knowledge production through coalitions.

The first feature has been widely analyzed in empirical surveys of open source software communities. For example in a recent large-scale survey, Schweik and English (2012) have shown that reaching a certain group size is a condition for developers to effectively pool their efforts and contributions. In other words, only if the aggregate level of the produced public good is high enough -through attracting a sufficient number of contributors with appropriate expertise for selected tasks at hand- will agents be motivated to voluntarily contribute to the development of a project. Indeed, in a simulation model of large-scale open source software projects, Dalle and David (2008) emphasize the importance of such sub-group diversity when characterising the dynamics of actual projects.<sup>2</sup>

Further, when the minimal coalition size is reached, this size will theoretically also be the equilibrium size. Since other agents can free ride on the public good once it is produced, there is no economic incentive for them to join the contributors' group. This duality between the core group of user-developers on the one hand and the broader user group on the other, is a well-known pattern that is observed in open source development projects as well (Raymond, 1999). Indeed, in these projects, the group of users-developers grows until the group-size is sufficient for the task at hand, while the broader group of software users continues to grow beyond that size. The latter however does not imply that the core group of developers remains invariably composed of the exact *same* people over time (Dalle and David, 2008).<sup>3</sup>

The second feature related to public good theory, which can also be illustrated by examples from the empirical literature on open source development, is that voluntarily provided knowledge goods have a joint public/private character (Hippel and Krogh, 2003). These goods generate both aggregate public and personal private benefits to the contributors, such as private problem solving, learning and enjoyment, higher citations for researchers through increased visibility, or access to new personal competencies by joining a group with high-level expertise. As a consequence, agents

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<sup>1</sup>See e.g. Lessig (2001), Benkler (2006), Hess et al. (2008), or David (2008).

<sup>2</sup>Different sub-groups, with different motivations, are then attracted to different sub-branches of the "tree-like" process driving open source software development.

<sup>3</sup>Because of this 'turnover' of developers, the core group is more accurately described as a 'quasi-stable' community of agents, which nonetheless always has the appropriate size to intervene in the accessible parts of the code-base requiring further development.

contributing to public knowledge pools are both driven by the public good benefits and the private benefits generated by the production of that good. Evidence for this mixed public/private character is given in many studies of public knowledge goods in fields beyond the case of the software developers communities. One can think for example of open access databases with tailor made data management tools that benefit specific communities and individuals (David, 2005), or hybrid funding arrangements -including both market and non-market tools- for openly available culture products on the internet (Lessig, 2008).

As has been shown elsewhere, this joint public/private character can have different effects on contributions.<sup>4</sup> One major issue however is not addressed in the existing theoretical models: what is the role of private benefits when *group-related* social preferences affect the willingness to join a coalition producing public knowledge goods? Indeed, as shown by Dalle and David (2008) in the particular case of open source development, reaching a ‘quasi-stable’ stage of a community of contributors generating an evolving code-base, is best explained by the joint involvement of several classes of participants with different mixes of privately and socially motivated agents. In three of these classes social preferences play an explicit role, where developers are either driven by peer esteem (so-called ‘kudos’ seekers), group related learning opportunities (so-called social interaction seekers), or both. In other words, when *group approval* or *group belonging* are important to agents, private benefits of knowledge production transcend the purely individual or altruistic divide studied in earlier work,<sup>5</sup> and also have a group-based dimension.

To study the role of such preferences in this context, we develop a theoretical model of *voluntary* public knowledge production. To the best of our knowledge, we are first to investigate the effect of group-based social preferences on the kind of bargaining processes set to overcome social dilemmas. Our approach draws on the private-collective incentive theory of Hippel and Krogh (2003), developed within the wider context of ‘user based innovation’. We then complement this perspective by building on the theory of group-related internal motivations, as well as the social psychology literature analyzing social preferences, extra-role behaviour and organizational citizenship behavior (LePine et al., 2002).

Our main finding is that the private benefits of public knowledge production can have *contrasting* effects on coalition formation. First, and in line with earlier work, private benefits bring about smaller coalitions since the public benefits of knowledge are needed less to overcome its production costs. However, and especially

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<sup>4</sup>If the private benefit has a market substitute, the joint character can undermine the willingness to contribute to the public good in situations where the market price of the substitute is sufficiently low (Cornes and Sandler, 1984). See also Andreoni (1988), Kotchen (2006, 2009) and Vicary (1997, 2000) for opposite effects in the absence of market substitutes.

<sup>5</sup>See for example Gächter et al. (2010) and Garriga et al. (2012) for a discussion on the effects of inequality aversion, fairness and reciprocity in the private-collective context.

when group approval is more important to developers than group belonging, larger individual benefits can lead to bigger coalitions as well. Because cooperation is perceived as being based more on self-interest than on altruistic motives in this case, knowledge production is considered less of an achievement by peers. Consequently, larger public benefits produced by a bigger coalition are needed to compensate for these ‘reputational’ losses.

In short, whether a coalition is made up out of developers deriving large direct gains from knowledge production -such as the ‘hackers’ discussed further on- or exhibit social preferences for contributing to the group’s social identity -such as the ‘social learners’ introduced below- makes a difference in terms of stable coalition size. Also, as the group-based social preferences become more pronounced across the board, joining the coalition simply becomes too alluring for non-members. Developers then rally around ever higher group-induced welfare levels, up to the point that the grand coalition is the only stable coalition.

Lastly, we study a population composed of multiple developer types, each with different social preferences. We show that, in line with earlier findings by Dalle and David (2008), smaller groups with homogeneous social preferences can overcome the social dilemma by broadening their base. This results in larger, more heterogeneously composed coalitions, made up out of diverse sub-groups.

The paper is organized as follows. Section 2 provides the basic motivation of our analysis and elaborates on the supporting literature. Section 3 theoretically analyses how social dilemmas can be overcome through coalition formation in a private-collective model, allowing for social preferences. In Section 4 we present an application of the model assuming heterogeneous social preferences. Section 5 concludes.

## 2 Motivation

To fully grasp the scope of our theoretical model introduced below, we first look at the personal attributes and behavioral patterns of real-life software developers. This to illustrate how the interplay of social preferences and private benefits can influence coalition formation.

### 2.1 The case of FLOSS developers

The FLOSS-US 2003 survey (David and Shapiro, 2008) is a web-based survey, generating a wealth of data on motivations and reasons for developers to begin to work on Free/Libre, Open Source Software (FLOSS) projects. Using this data, David and Shapiro (2008) classify the respondents according to their distinct motivational profiles by hierarchical cluster analysis (see figure 1 in appendix C). In addition, whenever possible, the respondents in each cluster are also matched to projects of

known membership sizes, revealing that the fractions of respondents from each motivational cluster for the large and the very small project ranges are different (see figure 2 in appendix C). Now, two major outcomes from this study cannot readily be explained in a model without social preferences.

The first point is related to the contrasting effects of social preferences on coalition formation, specifically in the case of low versus high direct *private* returns for the members of the coalition. As can be seen from the study of David and Shapiro (see figure 2 in appendix C), the three clusters where group-based social preferences are at work - the ‘social learners’, ‘social programmers’ and ‘user/innovators’- are present both in the small and large ranges of the project sizes. Stable coalitions of the smaller and larger kind are thus equally spread, and this compared to other clusters which are only present in the large ranges. This is consistent with the intuition that group belonging and peer approval foster cooperation in situations of social dilemma. In contrast, the cluster of ‘aspiring hackers’, which is composed of *[...] individualist, materially motivated programmers, which take part to FLOSS in the interest of a future career*’ (David and Shapiro, 2008), is more present in the large-size groups than in the small-size groups. In such cases the willingness to join a coalition arguably depends more on the purely individual, rather than the group-based benefits from knowledge production. The question remains why these aspiring hackers participate more in the *larger* projects, whilst deriving sizeable career benefits from contributing. Indeed, the literature on coalition formation would in this case predict the exact opposite outcome. Our model provides some intuition here.

The second point concerns the formation of heterogeneous coalitions to overcome social dilemmas, when homogeneous groups are too small to form viable coalitions. Figure 3 in appendix C gives the matrix for developers’ movements among projects of different membership size. In reading these data, it is reasonable to assume that on average developers in their first project derive higher personal learning and problem solving benefits, i.e. higher *direct* private benefits, compared to the involvement of these same persons in their second and/or most recent project (David and Shapiro, 2008). As a result, and on average, developers in second stage projects show a higher probability to go to larger FLOSS projects, where the individual marginal return on the aggregate public good is likely to be higher.

In particular, this result is valid both for agents that were involved in the first stage in small groups, which are likely to be homogeneous, or in medium groups, which include both homogeneous and heterogeneous cases. The first case corresponds to homogeneous groups that extend to heterogeneous groups to reach the stable coalition size. The second case corresponds to the increase in optimum group size for heterogeneous coalitions, where the private return component of the contribution to the public good is also decreasing. So far, this interpretation coincides well with the literature on coalition formation: smaller private benefits imply larger coalitions.

Nevertheless, a certain amount of developers continues to work on projects of equal, or even smaller size as well. Also here, our model offers an explanation, rationalising the process of mixed coalition formation.

In short, our model will frame most of these -often seemingly contrasting- dynamics and pinpoint where the private benefits of knowledge production and social preferences interact. This to provide a fresh perspective on how coalitions take shape in a private-collective setting.

## 2.2 Supporting literature

Whilst a large theoretical literature has studied endogenous coalition formation among countries grappling with global environmental problems,<sup>6</sup> we zoom in on voluntary contribution to *public goods* production.<sup>7</sup> As pointed out earlier, and adding to this latter perspective on coalition formation, we focus on a specific sub-category of public goods: public knowledge goods. We consider a situation where software developers face a social dilemma so that, as is the standard initial position in any public good game, their dominant strategy will be non-contribution to the production of the knowledge good. The aim of the model is then to investigate how *social preferences* influence the bargaining process, taking place to overcome this social dilemma.

To allow for social preferences, we draw on the private-collective incentive theory developed by Hippel and Krogh (2003). In line with their extensive case study research, we assume that *‘[...] contributors to a public good can inherently obtain private benefits that are tied to the development of that good. These benefits are available only to project contributors and not to free riders and represent a form of selective incentives for project participation that need not be managed by collective action project personnel’* (Hippel and Krogh, 2003).

This approach chimes well with the general theory of joint products proposed by (Cornes and Sandler, 1984, 1994), and further developed by Kotchen (2006, 2009) and Vicary (1997, 2000). One of the main contributions here, is that free-riding over other agents’ contribution to public goods decreases when these same goods also provide contributors with private benefits.<sup>8</sup> Now, by introducing evidence from social psychology on the role of group behavior, we extend the scope of these private benefits beyond the purely self-interested, materially tinged frontier. What is more, since these benefits are group-related, they will be *conditional* on coalition-membership.

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<sup>6</sup>Hoel (1992), Carraro and Siniscalco (1993) or Barrett (1994) laid the groundworks here, followed by e.g. Barrett (2003), Ulph (2004) or Kolstad (2007). Finus (2008) provides a survey of this large body of literature.

<sup>7</sup>See e.g. Kosfeld et al. (2009) or McEvoy (2010).

<sup>8</sup>In Sandler and Arce (2007), such impure public good production is set in the context of international development cooperation. Here, donor countries can also derive private benefits -e.g. through the sale of technology- in addition to the global public good benefits related to the increase in economic development and poverty alleviation. Finus and Rübhelke (2013) go on to study such ‘ancillary benefits’ of public good provision in a setting of international environmental agreements.

The literature in social psychology highlights two key dimensions of social preferences that play a prominent role in group behavior: *group identity* related to the collective goals realized by a group or community, and *peer approval* of pro-social attitudes. First, studies provide compelling evidence that the longing for a positive social group identity is a key determinant of engagement in group behavior. Social psychological experiments have shown that social group identity is even in many cases the most important explanatory factor to account for various types of group related motivations such as procedural justice, fairness and supervisor ratings (Blader and Tyler, 2009; Wit and Kerr, 2002). The second type of social preference that plays an important role in group engagement is the social approval for individual pro-social attitudes and behavior (LePine et al., 2002). These individual pro-social reputational effects have also been studied extensively in the context of overcoming social dilemmas (Suurmond et al., 2004; Bolton et al., 2005).

Especially the latter dimension is reminiscent of the social exchange approach modelled by Holländer (1990), where voluntary cooperative behavior is assumed to be motivated by social approval. This approval is conceptualized as an emotional activity: emotions, feelings, but also verbal expressions are modelled as having a stimulus power  $s(b)$ , prompting emotional reactions that measure the subjective value of cooperative behavior  $b$ . We will follow a similar approach in what follows, using linear relationships for simplicity.

### 3 The model

Consider a community of  $n$  developers interacting in a common environment, potentially pooling their efforts to produce public knowledge goods  $q_j$ . To model the decision-making driving this process, we follow the approach pioneered by Hoel (1992), Carraro and Siniscalco (1993) or Barrett (1994), which comes down to modelling two games under perfect and complete information. A ‘contribution’ public good game, where each developer decides how much to contribute to the public knowledge good, is then preceded by a ‘metagame’, defining actual cooperation. Indeed, by taking into account the behaviour of others, a developer may decide to team up with colleagues in a coalition, or to go at it alone. Working backwards, we start out with the contribution game, *given* these alternative strategic combinations of cooperation.

### 3.1 Contribution game

Depending on whether a coalition of  $s$  members ( $s = |S|$ ) is formed in the ‘metagame’, and whether developer  $i$  is a member of this coalition, his utility is defined by

$$u_i = \begin{cases} b \sum_j^N q_j - cq_i + abq_i & \text{if } i \notin S \text{ or if } S = \emptyset \\ b \sum_j^N q_j - cq_i + abq_i + q_i(\beta + (b-a)\theta) & \text{if } i \in S \end{cases} \quad (1)$$

where the public good character of the benefits to knowledge production  $b \sum_j^N q_j$  depends on total production  $\sum_j^N q_j$ , and the cost of production is given by  $c$ . The purely individual, ‘ancillary’ benefits derived from knowledge production -such as private problem solving, learning, increased visibility or access to expertise- are denoted by  $a$ . We assume these are outweighed by the marginal public benefit of producing the knowledge good, such that  $b > a$ , and that they are enjoyed by all contributors. In other words, so far utility was the same for coalition members as well as non-members.

Conversely, the group-related social benefits we mentioned above, accrue only to developers working together in a coalition. The sense of ‘belonging’ to a larger group striving to achieve the same goals, which we defined above as contributing to the *group identity*, is given by  $\beta$ . The degree to which fellow developers appreciate individual contributions to this larger group, what we called *pro-social reputation* building above, is marked by  $\theta$ . The larger the divide between the public ‘social’ benefit of production  $b$  and the purely individual benefit  $a$ , the more an individual contribution is perceived as an achievement by peers.

We are now ready to go over the possible outcomes of the game, given every possible strategic combination decided on in the ‘metagame’ a priori. Assume first that all developers play simultaneously and non-cooperatively. The Nash equilibrium is then derived by computing the fixed point of developer’s reaction functions, yielding a payoff vector  $\vec{u}_o$ . Instead, when developers decide to produce the knowledge good by forming a coalition, we assume a *bargaining* process works towards the Pareto optimal outcome. This process may result in a coalition of  $s$  members, where  $s$  goes from 2 to  $n$ , in which case the grand coalition forms. The cooperative outcome of this game is given by the Nash bargaining solution,<sup>9</sup> with the non-cooperative pay-off vector  $\vec{u}_o$  as the threat point.

Now, to model a social dilemma, we assume the social optimum where everyone works together is different from the non-cooperative equilibrium. Also, following Finus and Rübbelke (2013), we normalize the strategy space to  $q_i \in (0, 1)$  so that there are essentially only two possible equilibrium strategies: ‘produce knowledge’ ( $q_i = 1$ ) or not ( $q_i = 0$ ). A sufficient condition for production to be an equilibrium choice in

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<sup>9</sup>This assumption is not essential, any bargaining solution in the literature would deliver similar results.

the social optimum is then given by

$$\frac{\partial \sum_j^n u_j}{\partial q_i} = nb + ab - c + (\beta + (b - a)\theta) > 0 \quad (2)$$

whilst for programmers to desist ( $q_i = 0$ ) in the non-cooperative Nash-equilibrium we need

$$\frac{\partial u_i}{\partial q_i} = b + ab - c < 0 \quad (3)$$

arriving at the typical prisoner's dilemma outcome: production pays from a global, social perspective but not from an individual one. The question then becomes whether developers will choose to cooperate to overcome this social dilemma. We investigate the stability of such a coalition in the next section.

### 3.2 Stability and profitability of coalitions: the 'metagame'

Each individual developer considers the possible choices (cooperative or non-cooperative) of his counterparts, and his subsequent outcomes defined in the contribution game. A coalition of  $s$  members can then only form if production pays off, i.e. if the benefits of each contributing member  $u_i^M$  outmatch the payoffs under the non-cooperative outcome given by  $\vec{u}_o$ . This kind of *profitability* is guaranteed by

$$u_i^M = sb + ab - c + (\beta + (b - a)\theta) \geq u_o = 0 \quad (4)$$

where, because of (3), non-cooperative developers set an equilibrium production choice of  $q_i = 0$ , and derive zero utility as a result.

Naturally, the fact that cooperative knowledge production is profitable, is only a minimum requirement for any coalition to form. The main issue undermining coalition-formation is free-riding by non-producers. Here, developers have the incentive to let others form the coalition but share in its produce, without contributing themselves. A coalition will by consequence only form if it is both

$$\text{Internally stable: } u_i^M(s) \geq u_i^{NM}(s - 1) \quad \forall i \in S \quad (5)$$

and

$$\text{Externally stable: } u_i^{NM}(s) > u_i^M(s + 1) \quad \forall i \notin S \quad (6)$$

where  $S$  again denotes the set of coalition members, and where we assume that if a developer is indifferent between joining the coalition or staying outside, she will join. This notion of stability draws on the cartel stability literature, defining a cartel as stable when there are no incentives for any individual members to leave nor any outsiders to join.<sup>10</sup> In this sense, when a coalition  $s$  is internally stable, then coalition

<sup>10</sup>See e.g. Donsimoni et al. (1986) or d'Aspremont et al. (1983). Alternative notions of stability leading to larger coalitions, such as 'farsighted stability', are considered by Osmani and Tol (2009).

$s - 1$  is externally instable as outsiders will want to join. On the other hand, if that same coalition  $s$  is externally stable, then coalition  $s + 1$  will be internally unstable since coalition members will want to leave.

Employing the notion of stability given by (5) and (6), we verify whether a coalition formed in our setup would be stable. Doing so, we first assume that group-based benefits are never sufficiently large to overturn (3):

**Assumption 1** *The group-based benefits to public knowledge production are such that*

$$b + ab - c + (\beta + (b - a)\theta) < 0 \quad (7)$$

Which realistically implies that social preferences are less pronounced than the individual preferences for the knowledge good itself, expressed by the public and private benefits of production,  $a$  and  $b$  respectively. What happens when this assumption fails is captured by proposition 1 below, which also summarises our main stability result:<sup>11</sup>

**Proposition 1** *If the social benefits of cooperating in group are not too pronounced, a stable coalition of  $s^* < n$  members forms. Its break-even point of profitability is given by*

$$s^* = \frac{1}{\gamma} - a - \left( \frac{\beta}{b} + \left(1 - \frac{a}{b}\right)\theta \right) \quad (8)$$

*If group-based benefits are larger, so that  $b + ab - c + (\beta + (b - a)\theta) \geq 0$ , the grand coalition forms.*

In other words, when social preferences are less pronounced than the preference for the knowledge good itself -as well as for the private benefits  $a$  deriving from it- a stable coalition of size  $s^* < n$  forms. In this case, proposition 1 predicts that higher public benefits of public knowledge measured in terms of costs of production  $\frac{b}{c}$  ( $= \gamma$ ), lead to smaller coalition sizes. Because of the widening gap between benefits and costs, less developers are needed to make cooperative production profitable. A standard result in the literature.

Contrary to a model omitting social preferences however, the effect of the private benefit  $a$  is ambiguous here. On the one hand, individual benefits bring about smaller coalitions since public benefits of knowledge  $b$  are needed less to overcome its production costs. On the other hand, and especially when group approval of individual achievements is important compared to group belonging, larger private gains lead to larger coalitions. Here then, since cooperation is perceived as being based more on self-interest than on altruistic motives, the individual gain undercuts the extent to which knowledge production is considered by peers as a social achievement. Public

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<sup>11</sup>A thorough proof of the proposition is given in appendix A.

benefits will in this latter case be more imperative to developer welfare, resulting in larger coalitions.

In other words, if developers incur considerable individual gains from public knowledge production, but find peer approval to be important, our model predicts larger coalitions. This coincides with the larger presence of the ‘aspiring hackers’ in the bigger projects of the FLOSS data described earlier (see figure 2 in appendix C), since hackers in general are considered to have a lot to gain individually, but care less for group belonging or identity (David and Shapiro, 2008). Conversely, when coalition members exhibit strong social preferences favouring group identity building, such as the social programmers or learners in the FLOSS database, larger as well as smaller coalitions may form.

Lastly, when group based preferences are large enough to switch around condition (3), joining the coalition simply becomes too alluring for all non-members. The coalition size is maximised, which logically has developers rally around ever higher group-induced welfare levels. This process continues up to the point the grand coalition forms, and  $s^* = n$ .

## 4 Heterogeneous Social Preferences

When group-based preferences are such that assumption 1 holds, the stable coalition size  $s^* < n$  described above may not be reached for sheer lack of numbers. In this case, the question becomes whether a larger, yet inevitably more heterogeneous coalition could overcome the social dilemma instead.

Studying the FLOSS survey data given in figure 3 in appendix C, such a process may indeed be taking place. Engaged in their first projects, groups are often smaller and more homogeneous as well as enjoying larger direct private benefits  $a$ , since the learning curve is steepest at this point. Follow-up projects on the other hand mostly expand in size, suggesting that lower private benefits are compensated by forming larger coalitions. However, and importantly, such larger groups have in all likelihood also gained in diversity and heterogeneity. To study these dynamics, we introduce a heterogeneous community in what follows, where developers can differ in terms of their preferences for group belonging  $\beta$ , as well as reputation building  $\theta$ .

Suppose first a coalition of  $s$  members forms for a start-up project, out of a community of  $n$  identical developers. Suppose also that assumption 1 holds, in which case  $s = s^* < n$ . Then assume that, by moving from the first to the next projects, private benefits  $a$  are pushed down considerably. Now, whether this will have our coalition break up because its required size expressed by proposition 1 is larger than the community size itself, also depends on the mix of social preferences. If developers are highly sensitive to peer appreciation so that  $\theta \gg \beta$ , we learn from proposition 1 that this mitigates the increase in required coalition size  $s^*$ . Producing

public knowledge is in this case valued as more of a social achievement by peers, so smaller coalitions are needed. This would explain why there are indeed groups in the FLOSS database which more or less stick to their initial size in follow-up projects.

Contrarily, if group belonging and identity reign supreme so that  $\theta \ll \beta$ , the required coalition size is more likely to exceed the community's size as private benefits  $a$  edge down in follow-up projects, resulting in a situation where  $s^* > n$ . But does this mean all further cooperation is ruled out? The FLOSS data point in the opposite direction, as cooperation in general takes on larger forms in larger coalitions for follow-up projects. Indeed, other communities may join the ranks of our first community, which would come out reinforced as a result. The only remaining question is then whether such heterogeneous, merged communities can support stable coalitions.

Assume a first community of  $\bar{n}$  developers has strong social preferences for group belonging and identity  $\bar{\beta}$ , but draws less satisfaction from peer effects  $\underline{\theta}$ . Applying (5), internal stability is then established if for each member of the coalition we have

$$u_{1i}^M(s) = sb + ab - c + (\bar{\beta} + (b - a)\underline{\theta}) \geq 0 = u_{1i}^{NM}(s - 1) \quad (9)$$

Now consider a second community which, for simplicity's sake, has exactly the opposite preferences as the first. Internal stability here requires

$$u_{2i}^M(s) = sb + ab - c + (\underline{\beta} + (b - a)\bar{\theta}) \geq 0 = u_{2i}^{NM}(s - 1) \quad (10)$$

Following proposition 1, both (9) and (10) implicitly define the stable coalition size for each community respectively. We assume these are such that  $\underline{s}^* > \underline{n}$  and  $\bar{s}^* > \bar{n}$ , which reflects a considerable decrease of private benefits  $a$  after a start-up project. Since lower preferences for peer appreciation and higher preferences for group belonging bring about larger coalitions as private benefits  $a$  drop, we also have that  $\bar{s}^* > \underline{s}^*$ . Suppose now both communities decide to merge for a follow-up project, so that  $n = \underline{n} + \bar{n}$ . The stable coalition would then be characterised by

$$\bar{s}^* = \frac{c - ab - (\bar{\beta} + (b - a)\underline{\theta})}{b} \quad (11)$$

if, of course,  $\bar{s}^* < \bar{n} + \underline{n}$ . Logically,  $\bar{s}^*$  yields an internally as well as externally stable coalition for the community counting  $\bar{n}$  developers, as defined by (9). For the other community on the other hand, a smaller coalition size  $\underline{s}^*$  given by (10), would already have ensured stability. However, in our merged setting a coalition of size  $\bar{s}^*$  is internally stable for this second community as well, since for all coalition members of this community we have that

$$u_{2i}^M(\bar{s}^*) = sb + ab - c + (\underline{\beta} + (b - a)\bar{\theta}) \geq 0 = u_{2i}^{NM}(\bar{s}^* - 1) \quad (12)$$

where the last equality,  $u_{2i}^{NM}(\bar{s}^* - 1) = 0$  holds for the simple reason that at size  $(\bar{s}^* - 1)$ , coalition members hailing from our first community with  $\bar{n}$  developers will defect without exception. Under perfect information, the  $\underline{n}$  developers of the other community take this potential breakdown of cooperation into account, and act accordingly by contributing. Lastly, because  $\bar{s}^* > \underline{s}^*$ , the coalition characterised by (11) will also be externally stable with respect to developers of this second community. We generalise these findings in proposition 2.

**Proposition 2** *Let  $\bar{s}^*$  and  $\underline{s}^*$  be the stable coalition sizes emerging from two communities of developers, which are different in terms of social preferences so that  $\bar{s}^* > \underline{s}^*$ . Furthermore, assume both communities are insufficiently large for the coalitions to form separately, so that  $\underline{s}^* > \underline{n}$  and  $\bar{s}^* > \bar{n}$ . The merged community  $n = \underline{n} + \bar{n}$  then gives rise to:*

1. *A stable coalition of size  $\bar{s}^*$ , if  $n \geq \bar{s}^*$*
2. *Non-cooperation if  $n < \bar{s}^*$*

To put our findings in more general terms, proposition 2 predicts that mixed coalitions of heterogeneous agents will be stable, even when smaller, more homogeneous coalitions fail to form. Consequently, smaller groups with homogeneous preferences can overcome the social dilemma by broadening their base, resulting in larger coalitions made up out of diverse sub-groups.

Lastly, we show in appendix how proposition 2 carries over to a setting where assumption 1 does not hold, in which case we would start off with grand coalitions.

## 5 Conclusion

This paper has analyzed the ambiguity of private benefits in fostering coalition formation with publicly available knowledge goods. Such private benefits tied to public goods are considered as an important driver for the proliferation of pooled knowledge goods in social networks. Private benefits to contributors that have been widely studied in the literature are of two kinds: (1) direct private benefits such as individual problem solving or higher citation rates for researchers; (2) satisfaction of social preferences such as group belonging, group identity, pro-social individual reputation and status.

In the current literature on coalition formation for public good provision, the effect of these two kinds of private benefits tied in knowledge production is mostly considered to bring about smaller, stable coalition sizes. No theoretical explanation of the ambiguous effects of private benefits for contributors to public good -that is, in some cases, the private benefits lead to smaller coalitions and in some cases to larger ones- is provided in the literature. To build a more general model, this

paper integrated the theory of public goods and a social psychological model of group related social preferences into coalition theory. This allowed us to show the contrasted effects of social group identity and social approval/disapproval of individual pro-social attitudes on the coalition formation. The presence of agents giving high value to their individual pro-social reputation within a social network can make larger coalitions necessary in order to keep coalition formation stable.

Even though the results of the analysis apply to a broad set of voluntary pooled public knowledge goods, we applied the analysis to one of the most well studied and prominent case of voluntary pooling of public knowledge goods, which is the case of open source software. This comparison shows that the integration of social psychology in public good theory is relevant for understanding community formation behavior in this field. In addition, the model predicts that mixed coalitions of heterogeneous agents can be stable even when smaller, more homogeneous coalitions fail to form. However, additional empirical research is needed to further corroborate this finding.

## A Proof of proposition 1

First, suppose one coalition member leaves a coalition of  $s$  members formed in our setup, and that the  $(s - 1)$  members continue to produce because  $u_i^M(s - 1) = (s - 1)b + ab - c + (\beta + (b - a)\theta) \geq 0$  so that the free-rider receives a payoff of  $u_i^{NM}(s - 1) = (s - 1)b$ . Now, as defined in (5), internal stability requires

$$u_i^M(s) = nb + ab - c + (\beta + (b - a)\theta) \geq (n - 1)b = u_i^{NM}(s - 1) \quad (13)$$

which boils down to

$$u_i^M(s) = b + ab - c + (\beta + (b - a)\theta) \geq 0 \quad (14)$$

and which we have ruled out under assumption 1.

We can then move on to the second case, where the  $(s - 1)$  remaining members cease production once the free-rider leaves because  $u_i^M(s - 1) = (s - 1)b + ab - c + (\beta + (b - a)\theta) < 0$ , with  $u_i^{NM}(s - 1) = 0$  as a result. Internal stability now requires that

$$u_i^M(s) = sb + ab - c + (\beta + (b - a)\theta) \geq 0 = u_i^{NM}(s - 1) \quad (15)$$

which holds by our initial condition of profitability (4), in effect rendering cooperation profitable in the first place. As a result, it is this second case which characterises an internally stable coalition. Setting  $s = s^*$  in (15) and re-working, internal stability thus implies

$$s^* \geq \frac{c - ab - (\beta + (b - a)\theta)}{b} \quad \text{and} \quad s^* - 1 < \frac{c - ab - (\beta + (b - a)\theta)}{b} \quad (16)$$

Otherwise put,  $s^*$  is the largest integer of the relation  $\frac{c-ab-(\beta+(c-a)\theta)}{b}$ , or,  $s^* = I\left(\frac{c-ab-(\beta+(c-a)\theta)}{b}\right)$ . For any  $s > s^*$ , members would continue to produce after one member left the coalition, which cannot be an equilibrium as argued above. Contrarily, when  $s < s^*$ , members would not produce at all since production is not profitable, so no coalition would form.

Now, in order for the same coalition to be externally stable, (6) has to apply so that

$$u_i^M(s+1) = (s+1)b + ab - c + (\beta + (b-a)\theta) < sb = u_i^{NM}(s) \quad (17)$$

where the case of an internally stable coalition of  $(s+1)$  forming initially is again ruled out because of (7). Re-writing (17) furthermore, we arrive at the initial condition given by (7). Consequently, and re-working (16), the stable break-even point of profitability  $s^*$  in our setup is given by

$$s^* = \frac{1}{\gamma} - a - \left(\frac{\beta}{b} + \left(1 - \frac{a}{b}\right)\theta\right) \quad (18)$$

where we write the marginal public benefit  $b$  of knowledge production in terms of costs of production  $\frac{b}{c} (= \gamma)$ .

Suppose now that social preferences are so pronounced that assumption 1 is no longer valid. In this case, internal stability is still guaranteed for every possible coalition  $s \leq n$ , as (14) would hold across the board. External stability on the other hand, would be violated for every but one coalition: the grand coalition. Indeed, (17) breaks down at every coalition size  $s < n$  in this case, as more and more non-members would want to join the coalition and enjoy the group-based benefits. This process continues until every single developer has joined the coalition. ■

## B Continued proof of proposition 2: grand coalitions

Suppose now assumption 1 does not hold for both communities, because of very pronounced group-based social preferences. We then get

$$b + ab - c + (\beta + (b-a)\theta) \geq 0 \quad (19)$$

In this case  $\underline{s}^* = \underline{n}$  and  $\bar{s}^* = \bar{n}$ , and the only stable coalitions would be the grand coalitions. Any difference between the heterogeneous communities at this point, would derive strictly from differences in *community* size.

As soon as private benefits  $a$  decrease after the first start-up projects however, (19) could tilt the other way. In this case, the stable coalition size will no longer be

equal to the community size, and the question becomes whether

$$\bar{s}^* \leq \bar{n} \text{ and } \underline{s}^* \leq \underline{n} \tag{20}$$

If the required coalition size for follow-up projects exceeds the community size in both cases, which is the premise for proposition 2, we are back in the situation we described before. Of course, in the opposite case coalition sizes would actually shrink in follow-up projects. This would then rationalise the remaining follow-up flows coming out of the FLOSS data. ■

## C Figures: the case of FLOSS developers

Figure 1: Key characteristics of motivational clusters

Cluster	Profile	Key characteristics
1	Professionals	Non-ideological, expert, self-employed or company-sponsored to collaborate on FLOSS projects
2	Aspiring hackers	No need to modify existing code but like fixing bugs and learning new programs
3	Social learners	Become better programmers, learn how programs work, work with like-minded, "give back to community," support FLOSS ideology
4	Social programmers	Experienced, employment related needs to use, modify existing code and fix bugs; project choice influenced by social connections with other developers
5	"User-innovators"	Modifying existing software unimportant, learning and interacting with like-minded others unimportant; wanted to "give back to community," and launched own project

Source: David and Shapiro, 2008, p. 384.

Figure 2: Distribution of small and large project participants by motivation profiles identified by cluster analysis of FLOSS-US survey respondent

Cluster	Small project and large project populations only			
		Small (1-2)	Large (>29)	Total
1 ( <i>Professionals</i> )	%	5.2	5.5	5.3
	N	22	10	32
2 ( <i>Aspiring hackers</i> )	%	7.6	16.7	10.3
	N	32	30	62
3 ( <i>Social learners</i> )	%	49.1	45.0	47.8
	N	207	81	288
4 ( <i>Social programmers</i> )	%	14.0	12.8	13.6
	N	59	23	82
5 ( <i>User-innovators</i> )	%	24.2	20.0	22.9
	N	102	36	138
Total	%	100.0	100.0	100.0
	N	422	180	602
Pearson chi-squared(4)			11.09	
Prob > chi-squared			<b>0.03</b>	
Chi-squared goodness-of-fit(4)			60.75	
Prob > chi-squared			<b>0.00</b>	

Source: David and Shapiro, 2008, p. 394.

Figure 3: Transition matrix for developers' movements among projects of different membership sizes

Current/most recent project	First project		
	Small 1-2	Medium 3-29	Large >29
<i>Panel A: all developers</i>			
Small	111	42	32
Medium	30	80	22
Large	13	7	47
Pearson chi-squared(4)	140.58		
Prob > chi-squared	0.00		
<i>Panel B: developers for whom first and current/most recent projects were different</i>			
Large	51	42	32
Medium	30	29	22
Small	13	7	18
Pearson chi-squared(4)	7.96		
Prob > chi-squared	0.09		

Source: David and Shapiro, 2008, p. 389.

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