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I. The OSS Model – A brief introduction

The neoclassical economic literature stresses the need to protect private property rights in knowledge, as an incentive to create knowledge and thereby foster innovations and technological progress. It is often argued that there would be no incentive to innovate unless the innovator is granted monopoly rights, through patents or through other forms of intellectual property rights, over his innovations. Indeed, this has been the predominant model of technological progress driving today's world economy. Against this backdrop, an alternative model of technological progress, embedded in the *Open Source Software* (OSS) movement, has attracted significant academic and policy attention in the recent years. This model is built upon the philosophy that knowledge can not be owned, but can only be shared – a view that is diametrically opposite to the widely held faith in private property rights in knowledge.

The OSS model differs markedly from the conventional proprietary software development model. In the latter model, modern software firms or individual software developers rely on licensing agreements based on *copyright law* to receive their reward as license fee (Dam, 1995; Granstrand, 1999). To prevent illegal use/sale/distribution (with or without minor modifications) of the proprietary software, the developers protect their *source code* (a string of instructions to be executed by a computer to accomplish a program's purpose) to restrict unauthorized users from accessing it (Meyer and Lopez, 1995). By contrast, OSS allows free and unrestricted access to the source code of the software, under a special kind of copyright agreement that allows everybody to run, rewrite, modify, distribute and redistribute the software.[2]

Today, an open source software development project is typically initiated by an individual or a small group with an interesting idea that they themselves want to develop. They constitute a *core group* for the project by inducting a number of paid developers to work with the organizer/management group. They have their own self governance (Markus et al., 2000; Cook, 2001). Initially, the *core group* develops a rough version of the code (software) that outlines the functionality envisioned. The source code for this first version is then made freely available on the web. In this organizational structure anyone from around the world is free to participate in the development of software and share their knowledge for its further development, again for free use by all.

In the OSS model, knowledge creation is supposed to be fostered by voluntary and collective participation by all in the software development process through knowledge sharing. The *core group*, in a sense, sets the ball rolling and *users and contributors*

[1] We gratefully acknowledge academic inputs and comments from Krishnendu Ghosh Dastidar, Rajiv Kumar and Manmohan Agarwal.

[2] This is the reverse of the conventional copyright system and therefore, OSS is also often termed as *copyleft* software.

from all over begin to contribute to an ever expanding knowledge stock. Technological progress in this model, therefore, is not driven by incentives to internalize the returns from the knowledge output (as in the case of proprietary software development), but sharing it with the rest of the community.

Linux, *Open Office*, *Firefox Mozilla* are all products of this OSS model. These are important and significant products that have brought the OSS model to position itself as a viable and successful alternative to the proprietary model in the software sector. The OSS model can no longer be dismissed as an off-beat initiative of a bunch of social activists with limited impact on software development in totality. Large businesses and many Governments around the world have now adopted OSS software as a matter of policy choice.

A critical question that arises in this context is what drives the economic agents of the OSS model of technological progress to create knowledge. While the existing literature on OSS has identified various factors (non-economic and economic) motivating the actors in this models, there has been very limited attempts to understand the underlying theoretical framework of the OSS model within the paradigms of neoclassical economics. ***This paper is an attempt to fill this gap in the literature.***

Essentially, there are two sets of agents acting as two complementary key pillars of the OSS model – (1) the core group and (2) the large body of individual user-contributors. For the purpose of this paper, we *assume* that the *core-group*, which sets the balling rolling, has a larger social perspective to promote the philosophy of free knowledge sharing.[3] Of course, one could perceivably think of modeling their behavior in a standard optimization framework, but this remains outside the scope of the present paper. Even if the core group acts in an altruistic frame of mind, the model of OSS can only be sustained in the long run by the continued patronage from the large pool of *user-contributors* through their intellectual contribution to the OSS for its further development and improvement. In a sense, these contributions are supposed to supplement the effort of the core group and take forward the OSS initiative to ensure sustained technological progress through knowledge creation and free dissemination. Given that the core group comprises of a relatively small number of individuals (and hence may be assumed to be a small deviant group of altruists in this hardcore "rational" and individualistic world), the user community is much larger and broad based and therefore requires a behavioral explanation of their decision to contribute.

In this paper, we attempt to analyze, within the framework of neoclassical micro-economic theory, the decision of the *user-contributors* to contribute to the open knowledge pool of the OSS rather than internalizing their knowledge output for private appropriation. Section II presents a conceptual framework by reviewing the existing literature on motivations to contribute. Our game theoretical models are presented in Section III. Finally section IV summarizes and concludes the paper.

[3] They are also often backed by the support and promotion from a large number of state and non-state actors In many different countries there are political initiatives trying to get public support for Open Source, e.g. by paying direct subsidies to open source projects, by standardizing on open source software in government agencies, or by requiring schools and universities to replace proprietary software by open source software whenever this is possible.

II. Motivations to Contribute – A Conceptual Framework

Although limited in number, much of the existing literature on OSS has focused on identifying individual's motivation to participate in the OSS model. Raymond (1999) is among the initial scholars championing the cause of OSS and he sought to explain the apparent paradox of individual's contribution to OSS in terms of *altruism* or a *gift economy*, whereby developers create and develop software for unrestricted distribution without expecting any private reward. Their objective is to maximize the combined pool of knowledge available to the society at large, which is essentially a multiple of their own respective individual contributions. The larger the number of contributors, the greater is the size of this multiplier. Raymond (1999) argues that OSS is a superior model in terms of the speed of development and the fixing of the bugs, due to the involvement of a large number of highly motivated programmers.

Lerner and Tirole (2001) is perhaps the first systematic attempt to identify the key research questions pertaining to the OSS from an economist's perspective. According to them, the incentives of individual user-contributors to contribute to OSS are well accounted for by economic paradigm, going beyond Raymond's (1999) altruism hypothesis. Low costs (in terms of time and effort) of contribution to OSS (largely based on the Unix platform that most programmers have learned at high school and college) coupled with the attraction of getting others to improve upon their contributions, often used for their own specific applications, may be seen as an important economic incentive. Moreover, there are non-pecuniary gains like peer recognition, reputation building and eventual career advancement, which also reflect different types of incentives driving their motivation to contribute.

In her candid survey of the existing literature on OSS, Rossi (2004) outlines the extrinsic as well as intrinsic motivations to explain individual contributions to OSS – the former including factors like reputation, user needs, learning and performance improvement and the latter reflecting altruism, reciprocity, generosity and hedonic satisfaction. While the nature of these various incentives has been fairly well explored in the existing literature, there has been very little work on explaining the various complementarities of these heterogeneous motivations of different individual OSS contributors. It is important to understand how these complementarities shape social interactions and social norms, in determining the final behavioral outcome of individual contributors.

The only theoretical analysis of OSS in the paradigm of neoclassical microeconomic theory is by Johnson (2002), in which OSS is modeled as the private provision of public goods. It explains the OSS development within the framework of Bayesian games and looks at the welfare implications of increasing the number of contributors for development probabilities. By comparing the results with that of the closed source model, the paper concludes that while the OSS model is superior in some situations, some valuable projects may not be produced at all under OSS due to problems of free riding, especially as the community becomes large.

Although, in line with Johnson (2002) our paper adopts a game theoretic framework to model OSS, the focus of our paper is somewhat different. We intend to analyze what determines the decision of user-contributors to contribute or not. This decision is modeled as an outcome of a strategic interaction among different user-contributors, all assumed to be *rational* economic agents who appreciate the mutual interdependence of their decisions in determining the final outcome. It is in this perspective that we use a game-theoretic framework to model the decision to contribute. We develop our model on the basis of a very simple conceptual framework.

With the introduction a new OSS by their core group, the technically competent user-contributors are faced with two options when they pick it up and modify/customize or further develop it according to their specific requirements – *either* they contribute their development back to the core group for uploading it in the public domain *or* they retain it for their own exclusive use (private appropriation) without bothering to contribute it back to the common knowledge pool. Given that he derives all benefits of the new technology by accessing it freely from the public domain, irrespective of whether he contributes or not, and given that contributions come at a cost (in terms of the time and resources devoted by the user), one may be tempted to conclude that a "rational" will always opt for option 2 and never contribute but enjoy the fruits of the efforts of the core group as well as other contributors to the OSS development. This is the standard free rider argument.

But this argument is invalid when the final outcome is viewed in a strategic framework. Rational users will realize that others' decision to contribute can not be divorced from his decision in this regard. Indeed, it makes sense to contribute only when there are possibilities of others contributing as well, because this leads to possible benefits of economies of scale by pooling contributions from a large number of users. This scale economy benefit can only be realized through joint contributions by different (multiple) users and hence the decision of these individual users can not be viewed in isolation from each other. It is in this perspective that we intend to model the decision making process of users regarding whether to contribute or not. Given that one user's decision to contribute depends on the behavior of other users, the final outcome may be modeled as optimization through strategic interaction using game theory. We consider different scenarios to develop our game theoretic models, depending on the characteristics of the user group in question. We show different situations under which users will contribute and carry forward the OSS movement.

III. Game Theoretic Models of User Contribution

In the tradition of methodological individualism, which forms the basis of modern neoclassical economics, we may view users as "rational" *self oriented* utility maximizing individuals concerned only with their own personal benefits (net), irrespective of the benefits received by others. Others' gains/losses are of no consequence to them. Accordingly, our first model of user contribution considers a set of homogenous user-contributors who are self oriented rational economic agents. However, we extend our analysis beyond this simple framework to introduce a more complex utility function, under the assumption that human beings are socially embedded and hence their utility functions (or welfare) depend not only on their own personal benefits but also on the gains/losses of others. Formally, if U denotes utility and B denotes (net) benefits with subscripts X and Y representing user X and Y, then

$U_X = f(B_X)$ if X is self-oriented

$U_X = f(B_X, B_Y)$ if X is socially integrated

In the latter case, of course, the way others' benefits/gains enter one's utility function may vary from individual to individual depending on his temperament and type.

Hence the users are likely to be heterogeneous in terms of their mental frame and preference pattern. We attempt to take this heterogeneity into consideration in our second set of models by clearly defining the typology of user characteristics. It may, however, be noted that we consider homogeneity or heterogeneity of players only in terms of their temperament. In all other respects (benefits, costs etc) the players are assumed to be identical, irrespective of their temperaments, as is.

We present our models in the standard *player-strategy-payoff* format.

III.1 Homogenous Self Oriented Users

Player
We assume that there are two players (X and Y) who are homogeneous self oriented users.

Strategy
Each player has a binary strategy set to select from - either he contributes (C) or he does not (NC).

Payoff
The benefits to each player depend on the extent of knowledge stock created by their contributions, either jointly or individually:
$B\ (X_c, Y_c)$ = Benefits when both users contribute
$B\ (X_c, Y_{nc})$ = Benefits when only user X contributes
$B\ (X_{nc}, Y_c)$ = Benefits when only user Y contributes
$B\ (X_{nc}, Y_{nc})$ = Benefits when neither X nor Y contribute
Let C_X and C_Y denote the costs of contribution for each of the players.

These benefits and costs are identical for both players. Therefore,
$C_X = C_Y = C$ and $B\ (X_c, Y_{nc}) = B\ (X_{nc}, Y_c)$

Accordingly, the following represents the payoff matrix of this game:

Player Y

Player X

Strategy	**C**	**NC**
C	$B(x_c y_c) - C$, $B(x_c y_c) - C$	$B(x_c y_{nc}) - C$, $B(x_c y_{nc})$
NC	$B(x_{nc}\ y_c)$, $B(x_{nc}\ y_c) - C$	0,0

Let us examine the nature of the benefits from joint versus individual contribution. Given the complementarities of contribution by different users and the associated scale economies, it is quite natural that the benefits from joint contribution must considerably exceed the benefits from individual contribution, i.e., $B(x_c,y_c) >> B(x_c,y_{nc}) = B(x_{nc},y_c)$.

Furthermore, the cost of contribution must be less than the benefits from joint contribution, $B(x_c,y_c) > C$, otherwise there is no incentive whatsoever to participate in the OSS model at all and for that matter knowledge creation in any form will be economially unviable. It is, however, unclear whether C is also less than the benefits from sole contribution or not. In case, it is, i.e., $B(x_c,y_{nc}) = B(x_{nc},y_c) > C$, then the model becomes trivial – it would be worth contributing irrespective of whether the other player contributes or not and OSS will progress without any difficulty. However, given the signifcance of the scale economies in joint contribution, it is perhaps more likely that there is a wide divergence between $B(x_c,y_c)$ and $B(x_c,y_{nc}) = B(x_{nc},y_c)$, so much so that while $B(x_c,y_c) > C$, $B(x_c,y_{nc}) = B(x_{nc},y_c) < C$. In other words, given the character of the OSS model, a single users contrbution in isolation does not quite make it economically viable – the benefits from sole contribution, though marginally positive but does not cover the costs of contribution. In fact, the divergence also implies that net benefits from joint contribution $(B(x_c,y_c) – C)$ will be sufficiently large to outweigh the benefits from a free-ride on the other players sole contribution $B(x_{nc},y_c)$.

These very reasonable postulates about the OSS model can now be formalized in terms of the following assumptions:

$B(x_c,y_c) > C$ ……………………………..………(1)
$B(x_{nc},y_c) < C$ ....…...……………...……(2)
$B(x_c,y_{nc}) < C$ ....…...….…….....………(3)
$B(x_c,y_c) – C > B(x_{nc},y_c)$………………..………..(4)
$B(x_c,y_c) – C > B(x_c,y_{nc})$ ...……………..........…(5)

In this game, we have two pure strategy Nash at (C,C) and (NC,NC). Given that (C,C) is preferred by both players, with complete information and common knowledge, this *will* be final outcome in a so-called *Assurance* game. With (C, C), or {contribute, contribute} as the outcome, the process of OSS development will move on unhindered.

III.2 Heterogeneous Socially Integrated Users

We now consider the case of users who are not self oriented (individualistic) but more socially integrated. We assume that the utility derived by one user is a function not only of the net benefit that *he* gets from a particular outcome but also of the net benefit that other users get. But they may have different temperaments or preference patterns regarding the benefits derived from contribution by themselves and by others. In the following models we intend to capture this heterogeneity among users with respect to their preferences/ temperament.

Player
We assume that there are two players (X and Y) both socially integrated.

Strategy
Each player has a binary strategy set to select from - either he contributes (C) or he does not (NC).

Payoff
To describe the payoff, we need to classify the types of players according to their temperament and preference pattern. We use the following nomenclature to depict the net benefits (NB) for a typical user (say X) under different situations:

Temptation (π_T) = NB_x (X_{nc}, Y_c)
Reward (π_R) = NB_x (X_c, Y_c)
Punishment (π_P) = NB_x (X_{nc}, Y_{nc})
Loser's payoff (π_L) = NB_x (X_c, Y_{nc})

	Player Y		
Player X		Contribute(C)	Not Contribute(NC)
	Contribute(C)	π_R,π_R	π_L,π_T
	Not Contribute(NC)	π_T,π_L	π_P,π_P

Following the logic of our assumptions in Model 1, we posit that:
$\pi_R > \pi_T > \pi_P > \pi_L$ – purely from the perspective of a self oriented individualistic user.

Now we define the player types according to the preference ordering of their utilities from different outcomes of the game.

Player Type 1: Ruthless

This type of player (X) is more concerned with his *relative* payoff vis-à-vis his counterpart rather than the absolute level of his payoffs. He would always like to make sure that his own benefits exceed the benefits of the other player, no matter what the absolute levels are. Accordingly, even though $\pi_T < \pi_R$, he will consider U_X (π_T, π_L) > U_X (π_R, π_R) because in the latter situation both are equally off compared to the former, even though the X's absolute payoff is less in the former. When both are equally off in (π_R, π_R) and (π_P, π_P), given that $\pi_R > \pi_P$, he will consider U_X (π_R, π_R) > U_X (π_P, π_P). Finally he will be worse off in (π_L, π_T) relative to (π_P, π_P) both in relative as well as absolute terms, he will consider U_X (π_P, π_P) > U_X (π_L, π_T).
Therefore combining these preferences for a typical *ruthless* player, we can write
$U_X (\pi_T, \pi_L) > U_X (\pi_R, \pi_R) > U_X (\pi_P, \pi_P) > U_X (\pi_L, \pi_T)$

Player Type 2: Liberal

This type does not mind if he is worse off than his counterpart in relative terms as long as his absolute level of payoff is higher in given situations, no matter what the payoff of the other player may be. Therefore his preference pattern will be strictly determined by his individual payoff namely: $\pi_R > \pi_T > \pi_P > \pi_L$
Therefore his preference pattern will be
$U_X (\pi_R, \pi_R) > U_X (\pi_T, \pi_L) > U_X (\pi_P, \pi_P) > U_X (\pi_L, \pi_T)$

The preference ordering of different player types are summarized below:

Player Type	**Preference Orderings**
Ruthless	$U(\pi_T, \pi_L) > U(\pi_R, \pi_R) > U(\pi_P, \pi_P) > U(\pi_L, \pi_T)$
Liberal	$U(\pi_R, \pi_R) > U(\pi_T, \pi_L) > U(\pi_P, \pi_P) > U(\pi_L, \pi_T)$

In this framework, there may be 4 different combinations of player types playing against each other. We consider each of these 4 games to depict the outcome.

Assuming common knowledge in these full information simultaneous move games, as before, we present the results.

Game 1: ***Both the Players (X & Y) are Ruthless Type***

Preference ordering for player X is U_X (π_T, π_L) > U_X (π_R, π_R) > U_X (π_P, π_P) > U_X (π_L, π_T). Preference ordering for player Y is U_Y (π_L, π_T) > U_Y (π_R, π_R) > U_Y (π_P, π_P) > U_Y (π_T, π_L). In this game if player Y contributes (C) then player X will prefer NC since U_X (π_T, π_L) > U_X (π_R, π_R). If player Y does not contribute (NC) then player X will prefer NC since to him U_X (π_P, π_P) > U_X (π_L,π_T). Hence NC is the dominant strategy for X. Likewise, by symmetry, NC is also the dominant strategy for Y, given that both are Ruthless Selfish type.
Therefore (NC, NC) is the Nash for this game.

Game 2: ***Player X is Ruthless but player Y is Liberal***

Preference ordering for player X is U_X (π_T, π_L) > U_X (π_R, π_R) > U_X (π_P, π_P) > U_X (π_L, π_T). Preference ordering for player Y is U_Y (π_R, π_R) > U_Y (π_L, π_T) > U_Y (π_P, π_P) > U_Y (π_T, π_L). In this game if player Y contributes then player X will prefer not to contribute since for him U_X (π_T, π_L) > U_X (π_R, π_R). When player X prefers not to contribute, player Y will also prefer not to contribute since according to his preference U_Y (π_P, π_P) > U_Y (π_T, π_L). Therefore both will end up not contributing to OSS and Nash will be (NC, NC).

Game 3: ***Player X is Liberal but Player Y is Ruthless***

Preference ordering for player X is U_X (π_R, π_R) > U_X(π_T, π_L) > U_X(π_P, π_P) > U_X(π_L, π_T). Preference ordering for player Y is U_Y (π_L, π_T) > U_Y (π_R, π_R) > U_Y (π_P, π_P) > U_Y (π_T, π_L). When player Y prefers not to contribute, player X also prefers not to contribute since according to his preference U_X (π_P, π_P) > U_X (π_L, π_T). Again, when player X does not contribute, player Y prefers not to contribute since to him U_Y (π_P, π_P) > U_Y (π_T, π_L). Therefore both players will end up not contributing to OSS and the Nash equilibrium will be (NC, NC).

Game 4: ***Both player X and player Y are Liberal***

Preference ordering for player X is U_X (π_R, π_R) > U_X (π_T, π_L) > U_X (π_P, π_P) > U_X (π_L, π_T). Preference ordering for player Y is U_Y (π_R, π_R) > U_Y (π_L, π_T) > U_Y (π_P, π_P) > U_Y (π_T, π_L). In this situation if player Y prefers to contribute then player X will prefer to contribute since to him U_X(π_R, π_R) > U_X(π_T, π_L). Again if player X contributes player Y will prefer to contribute since to him U_Y (π_R, π_R) > U_Y (π_L, π_T). Therefore both players will end up contributing and the Nash will be (C, C). Now, if player Y does not contribute, then player X will prefer not to contribute since U_X (π_P, π_P) > U_X (π_L, π_T). When player X does not contribute, player Y will prefer not to contribute since U_Y (π_P, π_P) > U_Y (π_T, π_L). Therefore both will end up not contributing and Nash will be (NC, NC). Therefore in this game, we have multiple Nash either at (C, C) or at (NC, NC). Again, given that (C,C) is preferred by both, this will be ensured in an *Assurance* game of complete information and common knowledge.

We now summarize the Nash results obtained in these different games:

Player's Type	**Player Y**	
Player X	**Ruthless**	**Liberal**
Ruthless	(NC, NC)	(NC, NC)
Liberal	(NC, NC)	(C, C), (NC, NC)

It is seen that there is only one situation where both players would contribute, namely when both are *liberal* types. Whenever the game includes at least one *Ruthless* type player, both players will end up not contributing.

IV. Conclusion

From the above behavioral models of User contribution to OSS, we arrive at interesting conclusions regarding the future of OSS and its sustainability. As discussed earlier, in the OSS model, innovations are initiated by the core group which also creates a network of user-contributors. Members of this user community are expected to take forward the development of this initial innovation by contributing to the common pool of knowledge. Without the active participation of and contribution by the user community, the OSS movement will not proceed further. The results of our game theoretic model provide interesting insights as to whether users would indeed be inclined to contribute, within a neoclassical framework of optimizing behavior.

In our first model, we show that if the user community comprises of a set of homogeneous self-oriented players, concerned with one's own payoff without bothering about the payoffs of others, the Nash outcome will ensure that they all contribute to the OSS development and take the OSS movement forward. This firmly establishes the economic rationale for the OSS movement as a sustainable and viable model of innovation and technological progress that does not rely on incentives to privately appropriate the creative outputs.

One may, however, challenge the basic premise (embedded in the notion of methodological individualism) in characterizing all users as self oriented. In the second set of models, therefore, we consider a set of socially integrated users with heterogeneous temperaments and attitude towards how they react to others' payoffs (apart from their own payoffs) in shaping their preference ordering of the various outcomes. We make a distinction between two types of users – Ruthless and Liberal. Ours results show that when the user community includes only *Liberal* type players, the OSS movement will progress unhindered with active contribution from all. On the other hand, when the game involves at least one *Ruthless* player, the OSS movement will perhaps come to a halt, as the user community does not contribute to the common knowledge pool.

The message that emanates from our paper is straight forward – as long as *Ruthless* types are excluded from the community of OSS users, the OSS model will prove to be a powerful alternative model of innovations and technological progress with active and sustained contributions from the user community comprising of *liberal* types.[4] The fundamental premise of neoclassical economics that protection of private property rights in knowledge holds the key to technological progress, is therefore placed under threat, at least in this context of the OSS model. In fact, to challenge this premise we do not *have* to deviate from the basic the framework of neoclassical economic analysis. Indeed, our paper has shown that the decision of user-contributors to freely disseminate the outputs of their creative pursuits (rather than protecting private property rights on them for internalizing the rewards exclusively) may be explained in terms of *rational* optimizing behavior in the framework of neoclassical economic theory, rather than mere altruism or social activism.

[4] An interesting follow up research question could be to explore if and how the temperament or mental frame itself may be endogenously determined, rather than being exogenously

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