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Simon Gächter, Georg von Krogh and Stefan Haefliger

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Karina Whitehead
Centre for Decision Research and Experimental Economics
School of Economics
University of Nottingham
University Park
Nottingham
NG7 2RD
Tel: +44 (0) 115 95 15620
Fax: +44 (0) 115 95 14159
karina.whitehead@nottingham.ac.uk

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PRIVATE-COLLECTIVE INNOVATION AND THE FRAGILITY OF KNOWLEDGE SHARING[*]

Simon Gächter

University of Nottingham

CESifo and IZA[**]

Georg von Krogh

Stefan Haefliger

ETH Zurich[***]

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[**] University of Nottingham, School of Economics, Sir Clive Granger Building, University Park, Nottingham NG7 2RD, United Kingdom. E-mail: simon.gaechter@nottingham.ac.uk.

[***] ETH Zurich, Department of Management, Technology, and Economics MTEC, Kreuzplatz 5, 8032 Zurich, Switzerland. E-mail: gvkrogh@ethz.ch, shaefliger@ethz.ch.

Private-collective innovation and the fragility of knowledge sharing

Incentives to innovate is a central element of innovation theory. In the private-investment model, innovators privately fund innovation and then use intellectual property protection mechanisms to appropriate returns from these investments. In the collective-action model, public subsidy funds public goods innovations, characterized by non-rivalry and non-exclusivity. Recently, these models have been compounded in the private-collective innovation model where innovators privately fund public goods innovations (von Hippel and von Krogh, 2003). Private-collective innovation can be illustrated in the case of open source software development. The current paper contributes to the work on private-collective innovation by investigating incentives that motivate innovators to share their knowledge in an initial situation devoid of community activity. We use game theory to predict knowledge sharing behavior, and test these predictions in a laboratory setting. The results show that knowledge sharing is a coordination game with multiple equilibria, reflecting the fragility of knowledge sharing between innovators with conflicting interests. The experimental results demonstrate important asymmetries in the fragility of knowledge sharing and, in some situations, much more knowledge sharing than theoretically predicted. A behavioral analysis suggests that knowledge sharing is not only affected by the material incentives, but also by social preferences. The results offer general insights into the relationship between incentives and knowledge sharing and contribute to a better understanding of the inception of private-collective innovation.

Keywords: innovation, private-collective innovation model, knowledge sharing, incentive, open source software, experimental economics, game theory.

1. Introduction

Explaining why and under what conditions innovation happens is a major task of innovation theory. The mainstream view has been that innovation is most effectively supplied by innovators who privately fund their innovations, and use intellectual property mechanisms to secure the appropriation of returns from these investments. Innovators retain the rights to their knowledge and any spillover of knowledge to the public represents a loss of revenue from innovation-related investments. An additional view is that due to public interest or market failure, some innovations must be supplied as public goods (non-exclusive and non-rival) funded by public subsidy. Basic science is often cited as an exemplar of this form of innovation, where scientific knowledge must be made accessible to all in order to advance society and the economy.

Since the turn of the century, the open source software phenomenon rapidly caught the interest of organization scholars and management practice. Open source software such as Linux, Apache, or Firefox, brought the open source software movement from obscurity into the public domain and in the process generated much debate amongst academics and practitioners. A closer investigation of open source software uncovered that this way of innovating deviated significantly from the current view about incentives to innovate. While open source software is a public good defined by open source licenses that secure access for all to the product (O'Mahony, 2003), open source software is also created by software developers who voluntarily and freely share their knowledge, in what has been called the "private-collective innovation model" (von Hippel and von Krogh, 2003). This deviation spurred a number of studies on open source software developers' motivations (e.g. Lakhani and Wolf, 2005; Hertel et al. 2003). On the one hand, a finding was that participation in a community of software developers could explain the excessive public goods contributions that open source software represent. The social norms in the community rewarding innovators' reciprocal contributions to the public good offset their incentives to defect. On the other hand, these studies also left a puzzle open to research: what motivates the inception of private-collective innovation? Answering these questions, we believe, is crucial to the advancement of this new view of innovation. By understanding why innovators share knowledge, we can better discern the conditions under which this new form of innovation will occur, and thereby assess the general utility of private-collective innovation beyond open source software.

Private-collective innovation can be illustrated in a dyadic relationship: one innovator (firm, entrepreneur, leader, open source software developer) shares knowledge with (at least) one other innovator so that her knowledge becomes a public good. In general, this knowledge can be tacit and explicit (Nonaka, 1994), but explicit knowledge (e.g. articles, comments, ideas, engineering plans, design drawings, formulas, algorithms, procedures, software, etc.) is commonly made non-exclusive and non-rival (Arrow, 1984). At the inception of private-collective innovation, any innovator can make a choice to share her explicit knowledge as a public good, or keep it private and, if needed, use intellectual property mechanisms to appropriate returns from the innovation. Under many circumstances, the incentives to conceal knowledge rather than share it can be strong. For example, if a software developer has an idea for a new product that shows great market potential if licensed as a commercial product, the incentive to deflect from private-collective innovation can indeed be strong. Several studies conclude that knowledge sharing is often hampered due to such massive conflicts of interest (e.g. Huber, 1982; 1991; Michailova and Husted, 2003; Cabrera and Cabrera, 2002; Osterloh and Frey, 2000), and therefore one can expect knowledge sharing to be fragile at the inception of private-collective innovation. Authors have suggested that a cost-benefit analysis could shed more light on how different interests and incentives influence innovators' propensity to share knowledge (Foss and Mahnke, 2003: 78-79). In sum, two questions stand out in the inception of private collective innovation: First, how fragile is knowledge sharing, and second, what incentives in terms of costs and benefits are sufficient to induce sharing rather than concealing of knowledge at the inception of private-collective innovation?

Before we proceed with the theory development and laboratory research to answer these questions, we make two rather weak assumptions that characterize many economically interesting situations of knowledge sharing:

1. Sharing knowledge is value enhancing for the party who receives the knowledge.
2. Mutual knowledge sharing makes knowledge public and precludes the appropriation of received knowledge for one’s own private benefit. By implication, a necessary (but not sufficient) condition for appropriation is unilateral knowledge sharing.

Assumption 1 states that knowledge sharing is value enhancing (net of adoption costs of the new knowledge) for the innovator who receives the knowledge. This is an innocuous assumption, because in case it does not hold, knowledge sharing is not of economic interest. Notice that an enhancement of value occurs already if one party shares his or her knowledge. In case of *mutual* knowledge sharing, value is further enhanced by assumption. Assumption 1 does not state whether the act of sharing knowledge is costly or not for the knowledge sharing innovator. The model derived below allows for costs of knowledge sharing. Notice further knowledge is non-rival and therefore distinct from other resources, such as land or money. Sharing it does not diminish the rewards from it for the individual who held the knowledge in the first place but is valuable to the party who receives the knowledge.[1]

Assumption 2 says that mutual knowledge sharing precludes the appropriation of received knowledge for one’s own private benefit. The reason for this is that mutual knowledge sharing makes

[1] For example, in open source software, the software developer who shares his source code with another developer will still possess a copy of the source code that can be used to solve technical problems on his computer. More importantly, the receiving developer will gain from the solution shared by the sending developer.

knowledge a *public good*, which cannot be privately appropriated. As mentioned above, appropriation refers to the capacity of the holder of knowledge to receive a return equal to the value created by this knowledge, for example by keeping it secret or by protecting it through means of intellectual property (Arrow, 1984; see also Teece, 1986; Grant, 1996). An individual, who both conceals his knowledge and learns from the knowledge bestowed upon him by others, may possibly receive a higher return from concealing knowledge rather than sharing it with his opponent *provided* he is able to turn the combined knowledge (his concealed knowledge and the knowledge received from the opponent) into a return above the returns from knowledge sharing. In this case, sharing knowledge entails opportunity costs of sharing (the foregone appropriation payoffs) that come in addition to possible out-of-pocket costs of sharing.

An example illustrates. Suppose a programmer faces a technical problem. She can combine her software with the technical solution she received from others, and thereby learn to solve the problem more efficiently, as suggested above. This knowledge is valuable towards the problem. Assume that it is now possible for the programmer to create software that, thanks to the combined knowledge, allows her to appropriate the market value for her private benefit. If this is feasible, she might choose to conceal the superior solution, or alternatively, release a binary version of the code and license the software to third parties in return for a fee. If she chooses to share her knowledge as well, the combined knowledge is public and cannot be appropriated any more. However, if the software is protected by an open source software license, the receiving individual cannot (legally) appropriate returns from knowledge in the manner described. She can conceal, but cannot combine it with her proprietary software and license it to third parties. Most open source licenses guarantee the rights of current and future users of the software, to freely download, inspect, modify, and release modified and unmodified versions of the source code (not the binary version) to third parties.

Conducting research on the motivations to initiate private-collective innovation is challenging. Once innovators have shared knowledge and set innovation in motion, they can also be identified by field research. However, since the decision to share knowledge for innovation is private, it is difficult if not impossible to study it in the field, and especially, identify those innovators who decided not to share their knowledge (see Nonnecke and Preece, 2000). By using an experimental method, we observe both knowledge sharing and concealing and find that knowledge sharing is highly fragile. The paper contributes to the work on private-collective innovation by asking what incentives motivate innovators to share their knowledge in an initial situation devoid of community norms and activity. The next section briefly reviews some existing research, and discusses the role of incentives in private-collective innovation. We develop a game theoretic model of knowledge sharing at the inception of private-collective innovation. We show that knowledge sharing is a coordination game with multiple equilibria. Since there are many outcomes of knowledge sharing, we develop an experimental research design to identify behavioral strategies given different incentives. The third section explains the research design and methods, and the fourth section presents the results. A major finding is that there are important asymmetries in knowledge sharing and, in some situations, much more knowledge sharing than theoretically predicted. A behavioral analysis suggests that knowledge sharing is not only affected by the material incentives, but also by social preferences. Section 5 contains a brief discussion and concludes the paper.

2. Incentives for knowledge sharing in private-collective innovation

Incentives to create and share knowledge and to innovate are a central element of innovation theory. Three models have predicted the conditions under which innovation occurs. In the private-investment model, innovators privately fund innovation and then use intellectual property protection mechanisms, such as patents or copyrights, to secure the appropriation of returns from these investments (Demsetz, 1967; Arrow, 1984). The innovation remains a private good for the innovator who retains the rights to consume it, sell it, or provide access by third parties for a fee. For example, a software company can appropriate returns from the development of a software package by copyrighting it, and then licensing it to a customer in return for a fee.

An alternative to privately funded innovation, the collective-action model, relies on collective or public subsidy for public goods innovations (e.g. Stephan, 1996; Dasgupta and David, 1994). The collective action model assumes that innovators relinquish control of knowledge or other assets they have developed to a project and so make them a public good. Public goods innovations, such as research findings, are defined by their non-exclusivity and non-rivalry (e.g. Olson, 1965): All have equal access to the innovation and the rewards from the innovation do not diminish with more people using it. Since contributions to a collective action project are a public good, those who will benefit from that good have the option of waiting for others to contribute and then free riding on what they have done. Safeguarding the provision of public goods, therefore, hinges on different solutions to the problem of free-riding (Olson 1965). For example, the government chooses to collect taxes from the public, and invests in basic research and development with no or limited restrictions on the use of the research results.

von Hippel and von Krogh (2003) developed a compound model of the incentives in the "private-collective innovation model". Innovators fund public good innovations voluntarily and privately in this model. Open source software is an exemplar of the private-collective innovation. In thousands of open source software projects in existence today, ranging from the operating system GNU Linux to the Firefox browser, individuals, research teams, universities, firms, and governments spend their limited time and use their talent to create software free for all to inspect, download, use, modify, and freely redistribute to others in a modified or unmodified form. The term "open source software" refers to the licenses that simultaneously guarantee such "openness" and make it a public good innovation (O'Mahony, 2003).

Open source software development is a major social and economic phenomenon that poses an important puzzle for innovation theory: what are the incentives for skilled software developers to contribute voluntarily to the creation of a public good (Lerner and Tirole, 2002a)? The private-collective model proposed that the efforts and participation of innovators in a community impact on the incentives to innovate. Research uncovered a number of such incentives including the application and testing of the software by many (Raymond, 1998; Lakhani and Wolf, 2005; Shah, 2006), the adaptation of open source software to solve a specific technical problem on the developer's computer (Franke and von Hippel, 2003), the learning that takes places as users share knowledge and jointly develop open source software (Kuk, 2006), the individual software developers' creation of software modules that can be combined into a whole software product (Baldwin and Clark, 2006), the reputation that single individuals can achieve in merit-based hierarchies of developers (Roberts et al., 2006), the developers' obligation to help fellow software users solve problems in installing programs on their computers (Lakhani and von Hippel, 2003), or the developers' identification with the community (Hertel et al., 2003). In their review of research on open source software, Bergquist and Ljungberg (2001) suggested a cornerstone of open source software developer communities is that they evolve strong norms of reciprocity enabling them to operate as gift economies. When software developers receive "gifts" in terms of advice, acknowledgment or software from others they feel some "obligation" to reciprocate by giving new or improved software files, advice, and tips[2].

The private-collective model of incentives to innovate presupposes an active community of innovators, and to this date, the model did not explicitly cover the inception of innovative activity (von Hippel and von Krogh, 2003). Private-collective innovation can be understood as routine collective action (Useem, 1998) where innovators build on existing technology to create new and useful technology. However, the incentives provided during the inception of innovation differ substantially from those afforded once the community is established and working in a routine fashion to supply the public good. According to Elster (1986), the initiation of the collective contributions to a public good requires different levels of incentives compared to the level required to sustain it. Consider four examples of research on open source software that underscore this point. First, an initial gift (Bergquist and Ljungberg, 2001) must be exchanged prior to the emergence of the reciprocity norm in a community. Open source software developers may only feel grateful and obliged to return a gift if first they have received useful software, appreciation or advice. Second, Lerner and Tirole (2002a) proposed that when a developer releases a first working version of open source software to the public,

[2] Studies have also identified private-collective innovation incentives in other fields than software including product development and cultural goods (e.g. de Vries et al., 2006; Jeppesen and Fredriksen, 2006).

other developers will join the software development effort if they find the software product useful. Based on the statistics of new developers joining the Freenet open source peer-to-peer project, the role of a working software (public good) in generating development activity was confirmed (von Krogh et al. 2003). Third, Baldwin and Clark (2006) showed that the interaction among contributors in open source communities provide benefits in terms of the options to use software components available in a modular software architecture. Through substitution, upgrading (and other operations) of technical components a developer enhances the value of her work. The value of these options, and hence the incentive to contribute, hinges on a modular structure of the (existing) software architecture already developed by many developers. Fourth, in private-collective innovation, many tasks go beyond the direct coding of software and these too need an active community. Shah (2006) found that long-term developers take on mundane tasks, such as giving advice to newcomers or maintaining mailing lists that reach beyond their immediate, individual goals of satisfying their technical needs. The motivations for contributing to the community change over time and are influenced by the governance structure in the open source software project.

The situations of knowledge sharing captured in our assumptions characterize the inception of private-collective innovation prior to any community norms and outside the incentive and property structure of firms. In the following we will describe the basic incentives that exist in knowledge sharing, given our two assumptions outlined above.

2.1. *The knowledge sharing game*

The generic properties of the conflicts of interest in knowledge sharing that follow from the two assumptions can be readily illustrated in a sequential dyadic relationship. An example of sequential knowledge sharing is the individual decision to contribute code to an existing project in open source software development and add the own solution to what is already published.

Figure 1 illustrates the “knowledge sharing games”. For the sake of an easy description, we call the two innovators ‘Leader’ (L) and ‘Follower’ (F). Both innovators have the choice to share (*s*) or conceal (*c*) knowledge. In the knowledge sharing game of Fig. 1, the leader moves first and decides whether to share or conceal his knowledge. The follower is informed about the leader’s choice and decides whether to share or conceal her knowledge. Notice that the model allows the follower to decide whether or not to share knowledge even if the leader has decided to conceal.[3] After the follower’s choice, the game ends and payoffs are realized: b_i (i = L,F) denotes a base payoff, v_i is the value enhancement (net of adoption costs) through sharing knowledge, a_i is the appropriation payoff, and k denotes the expenses at market prices for sharing explicit knowledge. These payoffs will be derived from the assumptions and explained in detail below.

[3] In our example above, this would correspond to adding a solution to an existing project even if the project leader has not (yet) contributed code.

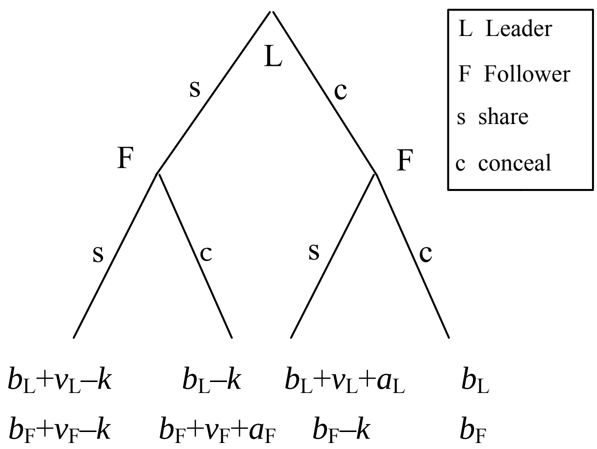

Fig 1. *The knowledge sharing game.*

Before analyzing the incentive structure and the inherent conflicts of interest in the knowledge sharing game, payoffs must be specified. Each actor receives some basic payoff $b_i \geq 0$, i = L, F, even if he or she is confined to own knowledge. An example would be programmers who produce software that is of use to them even if they do not receive any knowledge from another programmer. According to Assumption 1, net value is enhanced for the recipient of knowledge. In Fig. 1, this is reflected in payoffs $v_i > 0$, i = L, F, to player i if player $j \neq i$ shares his or her knowledge. For instance, if the leader shares his knowledge, then, irrespective of the follower's choice, the follower receives payoff v_F in addition to her basic payoff b_F. If the follower shares her knowledge, then the leader's base payoff b_L is augmented by payoff v_L. If player j conceals, then v_i=0, i = L, F.

Assumption 2 says that public goods knowledge (which is created by mutual sharing) cannot be turned into a private payoff. Therefore, a necessary (but not sufficient) condition of turning received knowledge (in combination with one's own knowledge) into private benefit is that knowledge sharing is unilateral. Only the innovator who can combine own knowledge with knowledge obtained, and does not share his or her own knowledge, can *possibly* enjoy an appropriation payoff, denoted by $a_i \geq 0$, i = L, F. Therefore, the follower only gets her appropriation payoff, a_F, if the leader shares and she conceals. Likewise, the leader only gets his appropriation payoff, a_L, if he conceals and the follower shares her knowledge. Notice that the appropriation payoff can be zero (which is why asymmetric sharing is only a necessary, but not a sufficient condition). This is the case, for instance, if in open source software projects appropriation is excluded by an open source license (O'Mahony, 2003). The appropriation payoff is the crucial variable in the subsequent experiment as will become clear in the game-theoretic analysis. Intuitively, the appropriation payoffs constitute the opportunity costs of sharing knowledge, because benefits from appropriation are foregone if knowledge is shared.

One might argue that in real life sharing explicit knowledge for innovation is costly (shipping documents, meeting people etc. creates costs). The cost for knowledge sharing is modeled with the variable *k*.[4] These costs are 'out-of-pocket expenses' distinct from the opportunity costs that are created by appropriation benefits. If knowledge sharing is costless, $k = 0$ (the internet makes knowledge sharing between programmers a costless activity, see von Hippel and von Krogh, 2003; Kogut and Metiu, 2001).

2.2. *Theoretical predictions*

After the description of games, we are now prepared for a benchmark game-theoretic analysis of the conflicts of interest inherent in this knowledge sharing game. To keep the benchmark analysis simple, we assume that players are rational and purely self-interested (this assumption will be discussed below).

Observe the implications of positive out-of-pocket costs $k > 0$. In case $v_i > k > 0$, the sequential knowledge sharing game is a sequential prisoner's dilemma game, where the only equilibrium is mutual concealing. This holds irrespective of the appropriation payoffs a_i.[5] Therefore, in the present model, knowledge sharing by self-interested actors is not possible if $k > 0$ (of course, mutual concealing is inefficient). Since both players want to conceal in the sequential prisoner's dilemma, there is no genuine conflict of interest either. Therefore we confine our attention to the consequences of opportunity costs in sequential knowledge sharing if $k = 0$ for both players. The following proposition summarizes the theoretical properties of the knowledge sharing game.

Proposition:

(i) *Mutual concealing is* always *an equilibrium outcome.*

(ii) *A necessary condition for mutual sharing as an equilibrium outcome is that* $a_F = 0$. *A necessary and sufficient condition for sharing in all subgames is that appropriation payoffs are zero for both players* ($a_L = a_F = 0$).

(iii) *In all constellations of appropriation payoffs* $(a_L \geq 0)\xi(a_F \geq 0)$, *there always exist equilibria with unilateral knowledge sharing* (*in addition to mutual concealing*).

The first basic message of the proposition is that the knowledge sharing game generically possesses multiple equilibria. Appendix A contains the complete list of all equilibria. The proposition (i) makes clear that in addition to possible unilateral and mutual knowledge sharing equilibrium outcomes, mutual concealing is always an equilibrium. The intuition for this result is that, under $k = 0$, the follower will, in both subgames where she has to make a decision, be either indifferent between

[4] We assume that (i) *k* is the same for both players because market prices for shipping costs or access to the internet are the same for everyone, and (ii) $k < v_i$, i = L,F (the costs of knowledge sharing are smaller than the value that is created by sharing knowledge).

[5] If the leader and the follower would decide simultaneously and $k > 0$, then the knowledge sharing game were a prisoner's dilemma.

sharing and concealing (in the subgame after the leader chose *c*, or in the subgame after the leader chose *s* and $a_F = 0$) or be strictly better off by concealing (in the subgame after *s* and if $a_F > 0$). Thus, for the follower concealing is *always* a best response. By backward induction, it is a best response for the leader to choose *c* as well, since he is indifferent between sharing and concealing in this case.

Proposition (ii) says that mutual sharing will *only* occur as an *equilibrium* outcome if the follower cannot appropriate payoffs. Since the follower is indifferent between sharing and concealing in this case, she may resolve her indifference by sharing. Given that she shares, the leader may also share, provided $a_L = 0$. In this case he is as well indifferent between sharing and concealing (the leader's payoff is b_L+v_L anyway). As soon as $a_F > 0$, the follower will conceal, if the leader shares and mutual sharing cannot be an equilibrium anymore. Thus, $a_F = 0$ is a necessary condition for mutual sharing; $a_L = a_F = 0$ is necessary and sufficient.

The rationale for proposition (iii) is that in case of indifference between sharing and concealing, both choices are a best response. That is, when matched with the opponent's best response of sharing, concealing can be a best response, and vice versa.

2.3. *Discussion*

The proposition shows that genuine conflicts of interest, where one innovator wants to conceal and the other share can only arise if only one innovator has positive opportunity costs to sharing knowledge. There is no conflict of interest in the mutual knowledge sharing (concealing) equilibria, because in such equilibria it is in both innovators' interest to share (conceal) their knowledge.

The proposition also makes clear that only the absence of out-of-pocket costs allows for (mutual) knowledge sharing. A particularly interesting situation is the one where no innovator has opportunity costs of sharing (i.e., $a_F = a_L = 0$). For example, this situation is characteristic of many open-source licensed projects (von Hippel and von Krogh, 2003). The analysis shows that the resulting 'open-source knowledge sharing game' is no prisoner's dilemma, but a game with multiple equilibria with different efficiency consequences. Mutual knowledge sharing can occur simply because innovators are indifferent between sharing and concealing and are prepared to resolve their indifference by sharing. It is exactly this feature of being indifferent that allows for mutual sharing among self-interested innovators.[6] However, by the same token, mutual concealing is an equilibrium as well, albeit an inefficient one.

The proposition is key for understanding the fragility of knowledge sharing, because it highlights the structure of the conflicts of interest inherent in knowledge sharing. The dual findings that (i) mutual concealing is always an equilibrium outcome, and (ii) that as soon as $a_F > 0$, only

[6] An example would be a programmer who develops software for himself. Sharing it does not diminish the utility of the software for him, but may be beneficial for another programmer. So given that he is not worse off by sharing, and somebody is potentially better off, he might be easily prepared to share his software with others.

equilibria with unilateral knowledge sharing or mutual concealing exist, gives a theoretical meaning to the "fragility of knowledge sharing". In section 3 and 4 of this paper, we complement this theoretical result with evidence of the behavior that causes knowledge sharing fragility.

We close this section with two remarks that arise from the proposition. First, since knowledge sharing is a game with multiple equilibria, it is an open question which equilibrium innovators will play. This is inherently an empirical question attended to in the remainder of the paper.[7] Second, recall that we conducted the benchmark game-theoretic analysis under the simplifying assumption that innovators are rational and selfish (i.e., they only maximize their own payoffs). However, research in psychology and experimental economics has revealed repeatedly that many people are not selfish but are equipped with 'social preferences'. That is, in addition to the pecuniary payoffs, people care, for example, also for equity, efficiency, and reciprocity (Camerer, 2003, Chap. 2). Since the equilibria differ in payoff and efficiency consequences, these social preferences might matter as well in the context of private-collective innovation. The full theoretical implications of these social preferences are beyond the scope of this paper, and here we only sketch their possible behavioral consequences.

Consider first the followers in the subgame after the leader has concealed his knowledge. Here the follower is indifferent between sharing and concealing with respect to his or her material payoff (recall Fig. 1). How will followers resolve this indifference? *Selfishness* (i.e., simply maximizing one's own pecuniary payoff) does not make a prediction here, because both sharing and concealing are consistent with selfishness since the payoffs are b_F anyway.

There is evidence that many people are *efficiency-seeking*, if efficiency can be achieved at a low cost (e.g., Charness and Rabin 2002, Engelmann and Strobel 2004). This certainly is the case for followers, because they are indifferent between sharing and concealing. Yet, if they share, efficiency is increased for all levels of a_L, because the sum of payoffs is larger if the follower shares than if she conceals. Moreover, efficiency increases in a_L. Therefore, in this subgame, efficiency-seeking predicts sharing by the follower.

The motivation of *inequality aversion* (or envy) (Fehr and Schmidt 1999, Bolton and Ockenfels 2000), makes the opposite prediction. Since follower's sharing leads to an unequal payoff distribution in favor of the leader, which is even exacerbated by higher levels of a_L, inequality aversion predicts that followers will conceal in this subgame.

If followers (maybe in addition to inequality aversion) think concealing is unkind and therefore attribute a greedy intention to leaders who conceal ("he conceals because he wants to

[7] See, e.g., Camerer et al. (1997), Weber et al. (2001) and Camerer (2003, Chap. 7) for discussions of the difficulties of coordination.

appropriate my shared knowledge"), then *reciprocity* predicts that followers who want to 'punish' the greedy intention, would conceal in this subgame.[8]

How will followers decide in the subgame after the leader has shared? If $a_F > 0$, then selfishness predicts that the follower will conceal, because she is better off by concealing than by sharing. A desire to maintain an advantageous payoff difference to the leader ("inequality-seeking") strengthens this prediction. If $a_F = 0$, then, according to the material incentives, the follower is indifferent between sharing and concealing. Efficiency-seeking as well as equity considerations predict in this case that the follower will share. Notice that the proposition states this situation is when $a_F = 0$ and where mutual sharing is possible, if the follower resolves her indifference by sharing. Yet, if the follower enjoys being better off than the leader, she might conceal – her payoffs are still b_F+v_F, but the leader only gets b_L. Thus, a taste for maintaining a positive payoff differential can preclude mutual sharing even if $a_F = 0$. By contrast, provided the follower has a strong enough *dislike* for advantageous inequality, she might also share even if $a_F > 0$.

Turning next to the leader, formulating conjectures is more difficult because for this innovator predictions not only depend on his own tastes with respect to efficiency-seeking and inequality aversion, but also on his beliefs about his follower's behavior. However, the following can be suggested about the leader's behavior: if he believes that the follower will share after he conceals, he has an incentive to conceal. If he believes that the follower will respond with concealing after he has concealed, then he might also share and hope that the follower shares as well.

3. Research design and methods

The generic incentive *structures* of the inception of private-collective innovation follow from the two basic assumptions discussed in section 1. As indicated above, it is difficult if not impossible to examine defection of private-collective innovation in the field, and therefore the decision to share knowledge provided this incentive structure. In the following, the behavioral consequences of the model will be tested in a laboratory decision situation that has the same incentive structure as the theoretical model described above. Paying the experimental subjects according to the payoffs of the model ensures that the subjects face the monetary equivalent of the incentives that are assumed in the model (see Smith, 1982 for a comprehensive methodological discussion of this 'induced value' technique). Thus, one can observe real economic decisions by human decision makers who face real stakes in a decision situation which is *isomorphic* to the model of knowledge sharing.

Since (i) the only crucial variables are the appropriation payoffs, and (ii) none of the theoretical results requires $b_L \neq b_F$ and/or $v_L \neq v_F$, we simplify the analysis without loss of generality

8 To choose *c* in case L chose *c*, is a 'punishment' for L, if L expected F to choose *s* instead, since L's payoff is smaller under *c* than under *s*. For formal models of the role of intentions in games see Rabin (1993), Dufwenberg and Kirchsteiger (2004), and Falk and Fischbacher (2006).

by assuming $b_L = b_F = b$, and $v_L = v_F = v$. We also assume that $k = 0$, i.e., out-of-pocket costs are absent. In the experiments, we implemented the extensive form game of Fig. 1. We chose the following parameters: $b = 10$ and $v = 20$. We did not change these parameters during the experiment since, theoretically, they are of minor interest. The appropriation payoffs vary between four levels: a_i □ {0, 10, 20, 30}, i = L, F. The rationale for four levels of a_i is as follows. Notice that for $a_i = 0$ or 10, the social optimum (i.e., the sum of payoffs) is always achieved in mutual sharing. If $a_i = 20$, then both mutual and asymmetric knowledge sharing are socially optimal. If $a_i = 30$, then the social optimum is that only one player shares knowledge and the other conceals. We included this payoff situation in the design as well, since there is evidence from experiments that efficiency-seeking is often an important behavioral motive. It is particularly interesting to examine how combinations of a_L and a_F influence the likelihood of knowledge sharing, and therefore we vary these payoffs systematically, by playing all sixteen payoff combinations $a_F \xi a_L$ that are possible ({0, 10, 20, 30}ξ{0, 10, 20, 30}).

Each participant in the experiments played sixteen games – each of the games resulting from $a_F \xi a_L$ for one time. Subjects were randomly allocated to their roles as leaders or followers. After they had read the instructions (a sample copy can be found in Appendix B), they made their decisions in each of the sixteen games without feedback. We programmed and conducted the experiments in z-Tree (Fischbacher 1999). For simplicity, subjects saw only the sum of payoffs ($b + v$) or b alone on the screens. Moreover, we told subjects that the only payoffs that would change in each of the sixteen games are the payoffs for the follower (called y on the screens) that result from the 'share'-'conceal' combination (L chooses s, F chooses c) and the payoff for the leader (called x on the screens) in the 'conceal'-'share' combination (L chooses c, F chooses s). We did not inform subjects beforehand about the values of x and y. They were told that only these two payoffs would change from period to period. Subjects did know, however, that there would be sixteen periods. The order of x-y combinations was randomly determined but the same for all subjects.[9]

We avoided possibly value-laden content labels for the choices following common practice in experimental economics. The players were not referred to as 'Leaders' or 'Followers', but as 'decision maker 1 and 2'. Choices were framed neutrally and did not make reference to knowledge sharing.

[9] One might object that despite no feedback some 'virtual learning' (Weber 2003) might go on that affects all players similarly because they all play the games in the same order. To test whether this procedure has an impact on our results, we ran further experiments (with 51 subjects) where we randomized the sequence of games for each individual (i.e., each individual played the sixteen games in a different sequence). For each of the sixteen games we apply tests of proportion to test the null hypothesis that the frequency of leaders' sharing decisions in the experiments where everyone played the sixteen games in a same order is the same as in the control experiment where people play the games in different orders. We apply the same test to the followers' sharing decision both after the leader has shared and concealed. Thus, we perform 48 tests. We cannot reject the null hypothesis (at $p<.05$) of equal proportions of sharing decisions in 45 out of 48 tests. We conclude that our results reported below are robust to the sequence of play.

Specifically, choices were called 'left' or 'right' (in the game of Fig. 1, 'left' corresponds to 'share' and 'right' to 'conceal').[10] Leaders decided simply whether to choose the option *left* or the option *right.* For followers, we applied the strategy method (Selten 1967). That is, followers had to make a *left-right* decision for both the case that the leader chose *left* and the case the leader chose *right.* Followers as well did not receive any feedback. The rationale for the strategy method is twofold: First, it allows the observation of the follower's behavioral reactions to *both* possible leader choices. This would not be possible if the follower had been restricted to making a decision after he or she has seen a specific leader choice.[11] Second, asking for contingent choices has the added advantage that one does not have to give feedback in each round. This makes decisions between individuals statistically independent, a feature which is advantageous in the statistical analysis of the data. In particular, since with the strategy method without feedback decisions are independent between subjects, we can use the observed sharing frequencies to calculate the expected probability that some randomly matched leader-follower pair (not just the actually matched pair) plays a certain strategy combination, and, of particular interest, what the probability of mutual sharing is. This would not have been feasible without the strategy method and independence of decisions.

To determine payoffs, leaders and followers were matched randomly in each period. However, as mentioned, we did not provide feedback between the sixteen games but rather at the end, where subjects received the sum of earnings from each of the sixteen games in cash. In each of the sixteen games, payoffs were determined according to the decisions of a randomly matched leader-follower pair. During the experiment, payoffs were denoted in 'points'. At the end we exchanged the accumulated sum of points into Swiss Francs at an exchange rate of 1 point = 0.04 Swiss Francs.

We conducted the experiments at the Universities of St. Gallen and Zurich, with 228 undergraduate students from various fields as experimental subjects. They provided a total of 3616 sharing/conceal decisions. The experiments lasted 30 minutes and subjects earned on average 15 Swiss Francs (approx. $ 12.3). Across all games, leaders and followers earned very similar amounts.

4. Experimental results

We present the results from the experiments on knowledge sharing in the inception of private-collective innovation as follows. First, we describe the follower's decisions contingent on the leader's

[10] The research methodology behind this design choice is to look at the basic incentive structure behind knowledge sharing. Future research should address the role of context for the fragility of knowledge sharing.

[11] There is evidence that in simple coordination games like ours the strategy method does not lead to systematically different responses than ordinary game playing. See Brandts and Charness (2000) for a systematic analysis. They study coordination games with and without the strategy method. In the experiments without the strategy method, subjects are simply confronted with the choice of a first mover and then make their decision. Under the strategy method, subjects make decisions for all possible moves of another player. The behavioral results do not differ between the methods.

choice and then the leader decisions. Second, we support the findings from the descriptive analysis by way of an econometric analysis. Third, we provide a summary analysis on the 'fragility of knowledge sharing'.

4.1 *Descriptive analysis*

Since the only parameters in the experiments are combinations of $a_F \xi a_L$, we will present most results as a function of these parameters.[12]

Result 1: (i) *Contingent on leader's sharing, followers share in about 73 percent if* $a_F = 0$. *If* $a_F > 0$ *the probability that the follower shares drops dramatically* (*to less than 30 percent*) *and decreases further in* a_F. *This holds for all levels of the leader's appropriation payoff* a_L.

(ii) *For the case the leader conceals, we find that, across all* $a_F \xi a_L$*-combinations, the probability that followers share is on average 45.3 percent.*

The main support for Result 1 is Figs. 2a and 2b. The figures show, for each of the sixteen $a_F \xi a_L$-games, the frequencies at which the followers shared in the subgame after the leader shared (Fig. 2a) and in the subgame after the leader concealed (Fig. 2b). A comparison of these figures shows that the leaders' decision strongly affects the followers' sharing behavior.

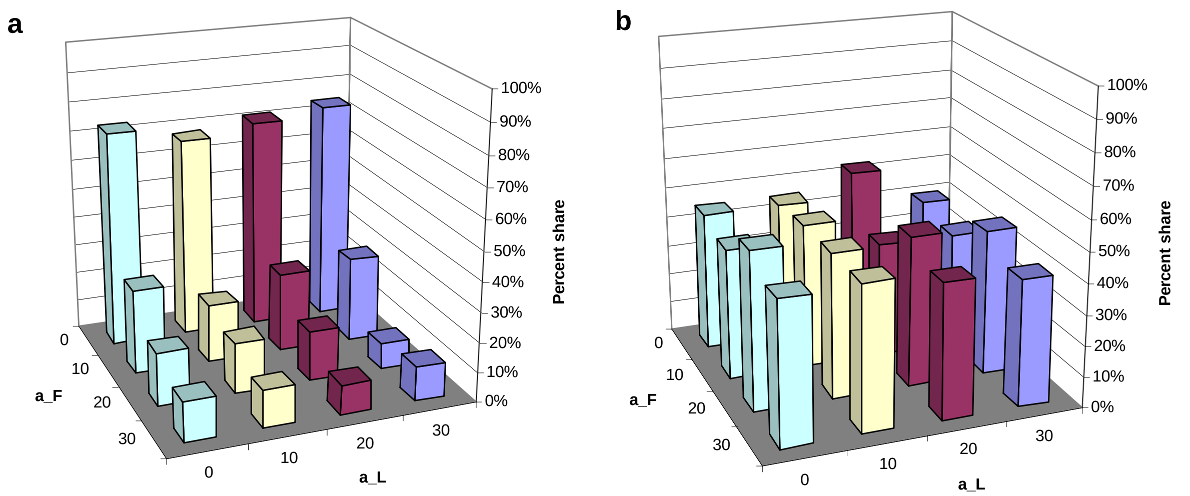

Fig 2. *Percent of followers who share if* (a) *the leader shares and* (b) *if the leader conceals*

[12] Appendix C (i) documents for all sixteen games the frequency of L's sharing choices, as well as F's choices after the leader shared and after the leader concealed, and (ii) since we have information from the full strategy set of our knowledge sharing game, we also document the expected frequencies at which the various strategies are played.

Fig. 2a illustrates the contingent probability at which the follower is prepared to share knowledge, in case the leader shares. Recall that under the joint assumptions of rationality and selfishness one should not observe any knowledge sharing in case of a positive appropriation payoff a_F. If $a_F = 0$, then rational and self-interested followers are indifferent between sharing and concealing. This implies that, theoretically, behavior is undetermined in this case. To the extent that followers care for payoff equality and efficiency, they might be willing to resolve their indifference by sharing. For all levels of a_L this was the case for between 67 to 74 percent of the followers. The rest concealed, which may be explained by selfishness and/or the desire to earn a higher payoff than the leader. The followers' willingness to share dropped dramatically for $a_F > 0$. This holds for all levels of a_L. If $a_F = 10$, the likelihood that a follower shares was between 20 and 29 percent. If $a_F = 30$ it dropped even further to between 10 to 14 percent only. Notice that selfishness predicts zero sharing in case of $a_F > 0$. In this light, there is still substantial knowledge sharing, which may be explained by a desire to avoid a payoff advantage over the leader and/or by efficiency considerations.

Fig. 2b illustrates the contingent probability at which the follower is prepared to share knowledge, in case the leader conceals. Sharing is consistent with selfishness (which in this subgame is consistent with both sharing and concealing), and with efficiency-seeking. Concealing is predicted by inequality aversion, the punishment of greedy intentions, and selfishness. Thus, as explained in section 2.4, different social preferences make different predictions in the subgame after which the leader has concealed. The results show that Followers chose to share in between 37.5 and 53.6 percent of the cases. The average over all $a_F \xi a_L$-combinations was 45.3 percent (which is not significantly different from 50 percent (t-test with individual average sharing rates as observations)).

The next result concerns the probability that the leaders share knowledge in the inception of private-collective innovation.

Result 2: *The probability that leaders share is affected negatively by both their own and their followers' appropriation payoffs.*

Figure 3 is the main support for Result 2, which shows the percent of cases in which the leader shared in each of the sixteen $a_F \xi a_L$-games.

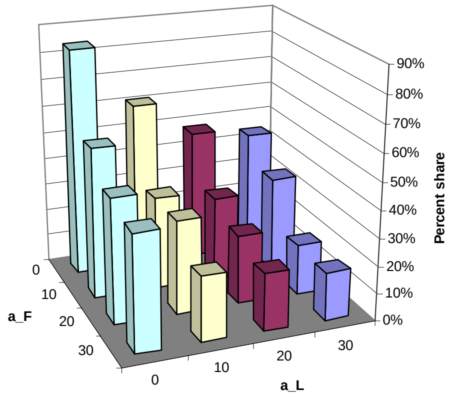

Fig. 3. *Percent of leaders who share.*

As Fig. 3 shows, the likelihood that the leader shares knowledge decreases in both a_F and a_L. In case both appropriation payoffs are zero, leaders share in 84.2 percent of the cases. The probability that the leader shares is lowest if $a_F = a_L = 30$ (it equals 17.5 percent). Thus, in the inception of private-collective innovation, the leader takes into account not only his appropriation payoff a_L, but also his follower's appropriation payoff a_F.

4.2 *Econometric analysis*

An econometric analysis supports Results 1 and 2 further. Table 1 provides econometric evidence for the impact of the appropriation benefits a_F and a_L on (a) the followers' knowledge sharing decision after the leader decided to share; (b) the followers' knowledge sharing decision after the leader concealed, and (c) the leaders' knowledge sharing decision. As the share or conceal-decision is binary, we ran a logit regression with the binary variable (1=share, 0=conceal) as the dependent variable. The independent variables are dummies for the respective levels of a_F and a_L; the omitted benchmarks are $a_F = 0$ and $a_{L.} = 0$. To account for the fact that a subject's decisions might be correlated across games, we calculate robust standard errors with clustering of decisions at the subject level (between subjects decisions are independent by design).[13] Since coefficients of logit estimations are hard to interpret, we report the marginal effects in Table 1, that is how an increase in a_i, i = L,F, influences the probability of sharing.[14]

	(a) Followers' share or conceal decision after leader has shared	(b) Followers' share or conceal decision after leader has concealed	(c) Leaders' share or conceal decision

[13] A random effects panel model yields very similar results.

[14] Specifically, we calculate the marginal effects when all dummies are zero. The marginal effect measures dy/dx for a discrete change of a dummy variable from 0 to 1.

	(a)	(b)	(c)
Dummy a_L = 10	-0.0450 (0.0221)*	0.0044 (0.0225)	-0.1701 (0.0263)**
Dummy a_L = 20	-0.0218 (0.0219)	-0.0067 (0.0206)	-0.2524 (0.0300)**
Dummy a_L = 30	-0.0286 (0.0189)	-0.0596 (0.0216)**	-0.2833 (0.0363)**
Dummy a_F = 10	-0.4572 (0.0365)**	-0.0508 (0.0240)*	-0.1914 (0.0311)*
Dummy a_F = 20	-0.5685 (0.0353)**	0.0286 (0.0187)	-0.2832 (0.0367)**
Dummy a_F = 30	-0.6039 (0.0365)**	-0.0132 (0.0267)	-0.3453 (0.0390)**
Observations	1824	1824	1824
Wald $\chi^2(6)$	183.5**	17.75**	149.73**
Pseudo R^2	0.2113	0.0043	0.0916

Robust standard errors in parentheses; * significant at 5%; ** significant at 1%

Table 1. *Marginal effects of logit estimation of the sharing decision.*

Column (a) reports the results of how followers change their knowledge sharing decision, relative to the benchmark game where $a_L = a_F = 0$. Holding the leaders' appropriation payoffs constant, we find that the drop in follower's knowledge sharing rate is quite dramatic and highly significant. Relative to the benchmark, the likelihood that a follower will share drops by more than 45 percent, if her appropriation payoff changes from 0 to 10. The likelihood of sharing drops by more than 60 percent, once $a_F = 30$. The leader's appropriation payoff does not matter: a χ^2-test cannot reject the null hypothesis that the three dummies are jointly not different from zero (p=0.194). In other words, followers in their knowledge sharing decision do not take the leader's appropriation payoff (which occurs in another subgame of the game) into account when deciding whether to share knowledge or not.

Column (b) shows the follower's knowledge sharing decision, after the leader has concealed. The estimated changes in probability of sharing are small (although in two cases significant) and we do not find a systematic pattern. This is no surprise, since in the subgame after the leader has concealed knowledge, different social preferences make different predictions (see the discussion in section 2.4). Therefore, to the extent that people have different social preferences, there will be no uniform impact of a_L on follower behaviour, which is what we find.

Column (c) documents the leaders' sharing rate, relative to the benchmark. The leader is highly significantly less likely to share both the higher his own appropriation payoff a_L is, but also the higher the follower's appropriation payoff a_F is.

4.3 *The fragility of knowledge sharing*

As seen, the opportunity costs of sharing affect the likelihood of mutual knowledge sharing strongly. Therefore, we close the empirical analysis by examining the *fragility* of mutual knowledge sharing. For this concluding analysis we utilize the possibilities inherent in collecting data with the help of the strategy method with no feedback between rounds. The design with the strategy method (i) provides many independent observations and (ii) allows the observation of strategies, not just realizations. Therefore, the likelihood of a certain outcome, given that two randomly matched players (not just the actually matched pairs) interact, can be estimated (see Appendix C for details on the expected strategy profiles).

We operationalize 'fragility' as the change in the expected probability of mutual knowledge sharing, when the opportunity costs of sharing change. Notice that the fragility of mutual knowledge sharing is a composite of the leader's and the follower's sharing behavior. It is therefore an empirical question whether the leader or the follower's behavior is more important for the fragility of mutual knowledge sharing. The result is as follows:

Result 3: *Knowledge sharing is substantially more fragile in a_F than in a_L.*

Formally, define $\pi_{ss}(a_L,a_F)$ as the probability of mutual sharing of two randomly matched players, dependent on the appropriation payoffs a_L and a_F. Fig. 4 depicts the empirical observation of $\pi_{ss}(a_L,a_F)$, which is the expected frequency of mutual knowledge sharing as a function of all sixteen ($a_F \xi a_L$)-games. For a given game, the expected frequency results from the probability that the leader shares times the probability that the follower shares.

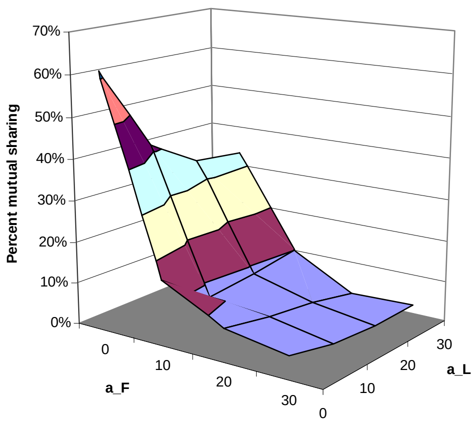

Fig 4. *The fragility of knowledge sharing – percentage of mutual sharing.*

We define the marginal change of the probability π_{ss} in the appropriation payoffs (i.e., $\Delta\pi_{ss}(a_L,a_F)/\Delta a_i$, i=L,F), as the fragility of mutual sharing induced by i's appropriation payoff a_i, i = L,F. Fig. 4 shows that $\pi_{ss}(a_L,a_F)$ is convex in a_i, i = L,F, and more fragile in a_F than in a_L. Of particular interest is $\Delta\pi_{ss}(0,0)/\Delta a_i$, i=L,F, i.e., the marginal change in the probability of mutual sharing once an appropriation payoff becomes positive. The expected probability of mutual sharing drops dramatically, once $a_F > 0$. Compare in particular $a_F = 0$ and $a_F = 10$, when $a_L = 0$, which reveals a marginal drop in mutual sharing of 45.9 percentage points. The drop is much smaller in a_L than in a_F, namely 19.99 percentage points (compare $a_L = 0$ and $a_L = 10$ when $a_F = 0$). Thus, in the inception of private-collective innovation, mutual knowledge sharing is substantially more fragile in the followers' than in the leaders' appropriation payoff.

5. Discussion and conclusion

We investigated the relationship between incentives and knowledge sharing in the inception of private-collective innovation. The first part of the study showed that incentives in knowledge sharing give rise to a 'knowledge sharing game', a coordination game with multiple equilibria (rather than a public goods game, although mutual knowledge sharing makes knowledge a public good between players). Some of these equilibria entail mutual sharing. However, the analysis also revealed that knowledge sharing is fragile: As soon as innovators face opportunity costs of sharing, mutual sharing ceases to be an equilibrium of the knowledge sharing game. By contrast, mutual concealing is always an equilibrium in the knowledge sharing game, albeit an inefficient one. The theoretical analysis also revealed that many equilibria entail unilateral knowledge sharing where one innovator shares his or her knowledge, whereas the other conceals. These equilibria describe situations of genuine conflicts of interest in knowledge sharing. In the second part of the study, we implemented the model in a controlled laboratory experiment with monetary incentives that were isomorphic to the incentive structure of the knowledge sharing game in private-collective innovation. The experimental results demonstrated important asymmetries in the fragility of knowledge sharing and, in some situations, much more knowledge sharing than theoretically predicted. The behavioral analysis suggests that knowledge sharing is not only affected by the material incentives, but also by social preferences.

The implication of this work for theory and research is threefold in our view. First, to our knowledge, the present study is the first to investigate the role of incentives to share knowledge in the laboratory. The study provided evidence that straightforward economic incentives matter strongly in knowledge sharing decisions. From an economic viewpoint, sharing or concealing knowledge affects costs and benefits of the innovators involved. These results confirm the importance of conducting a cost/benefit analyses of knowledge sharing situations (Foss and Mahnke, 2003; see also Takeishi, 2002; Szulanski, 2000). The study also demonstrated the benefits of an experimental setup for studying knowledge sharing in various situations, in particular where decisions are difficult or impossible to observe directly in the field. Building on the results from the present study and the findings of other game theoretical work on knowledge sharing (Harhoff et al. 2003; von Hippel, 1987), innovation researchers need to identify further the empirical parameters that enable private-collective innovation in various fields.

Second, since many people not only care for their own costs and benefits but also entertain 'social preferences', knowledge sharing will – in addition to the straightforward economic incentives – also likely be affected by inequality aversion, reciprocity, and efficiency considerations. The finding of the current study, that the extent of knowledge sharing amongst the participants in the laboratory experiment exceeded the theoretical predictions from the economic model, supports the conjecture in the literature that social preferences impact on knowledge sharing (di Norcia, 2002; Wasko and Faraj, 2000; Faraj and Sproull, 2000; Orlikwoski, 1992; Kim and Mauborgne, 1998; Kogut and Zander, 1996; Bergquist and Ljungberg 2001). An effort should be made in future studies to distinguish between the various forms of social preferences that impact on sharing decisions in the laboratory. This work should also attempt to investigate the transition from a "pure" sharing decision of the leader and the immediate follower, to those situations where interactions between leaders and followers recur, and/or other innovators enter the game. The results from this work will shed more light on the transition from the inception to the maintenance of private-collective innovation.

Third, the current study has implications for the understanding if and how private-collective innovation can diffuse to other fields beyond open source software, biotechnology and some types of cultural goods. Recall that the incentive structure in the inception of private-collective innovation makes knowledge sharing highly fragile. This is likely the case in any field where some innovator contemplates to reveal her knowledge freely to the public. By showing that the probability of knowledge sharing drops in the presence of opportunity costs of sharing, we operationalized and demonstrated the fragility of knowledge sharing. Mutual sharing of knowledge is indeed susceptible to relatively low incentives for deviation. This result is crucial for the inception of private-collective innovation: In the absence of opportunity costs to knowledge sharing, innovators are more likely to make their work freely available than in the presence of high opportunity costs. In the case of open source software, the findings suggest that the presence of opportunities to sell innovations in the software market, and the capital market for software entrepreneurs should influence the decision to publish software under an open source license. However, the institutional arrangements in open source software licenses provide an elegant solution to the problem of the fragility of knowledge sharing at the inception of private-collective innovation: Open source software licenses make it illegal and difficult to appropriate published code, thus *limiting followers' opportunity costs*. If I share under an open source software license, I know that a follower cannot appropriate and sell this software. In fact, I may hope that the follower uses the software and feeds back to me her own software improvements.

One should expect private-collective innovation to flourish only in settings where institutional arrangements limit followers' opportunity costs, and not in others ($a_F = 0$, $a_L = 0$)**.** In the absence of such arrangements, one should expect private or collective action models to dominate innovation. Informed by this idea, future work should investigate the inception of private -collective innovation in different areas of innovative activity with different institutional arrangements. Furthermore, within open source software projects, licenses come in various forms providing innovators with different limitations and possibilities to appropriate returns from innovation (for an overview, see Lerner and Tirole, 2002b). Future research should investigate to which extent these licenses create effective incentives for establishing private-collective innovation.

Since knowledge sharing plays a crucial role for innovation, the relationship between incentives and knowledge sharing offers a fertile ground to study the role of incentives beyond the firm-market dichotomy. The capitalist firm is usually defined in terms of asset ownership, contracting and incentives (Holmstrom and Milgrom, 1994; Foss, 1996). But there exists a continuum of external sourcing methods and hybrids between firms and markets (Leonard-Barton, 1995), which vary in terms of ownership and contracting, open source software communities representing one of them. As Holmstrom and Milgrom (1994) comment, little is known regarding the interdependencies among the defining characteristics of firms. The role of private-collective innovation in software reinforces the need to study non-traditional forms of economic organization and their institutional character. Knowledge sharing and incentives could function as guideposts for innovation scholars into organizations that blend characteristics of firms and markets, because knowledge flows are intimately connected to the sources of innovation (von Hippel, 1988).

We close with a methodological remark which concerns the use of laboratory experimental methods to study issues in organization science. We argued that studying the causal consequences of incentives in knowledge sharing situations requires the full observation of all costs and benefits, as well as the actual decisions to share or conceal. Since these requirements are impossible to meet entirely in the field, the current research devised a laboratory study where the theoretical model of knowledge sharing was implemented. Experimental results such as these must be seen as complementary to field investigations. In particular, the tight results from the laboratory can help guide field research, which has the advantage of being 'more realistic' but also the drawback that causal inferences are often not feasible. Thus, the present paper joins some recent studies[15] that have resorted to laboratory methods in order to study specific phenomena relevant to organization science, that are as well very hard to investigate in the field.

[15] Recent examples comprise the formation of corporate cultures (Weber and Camerer 2003), bargaining (Zwick and Chen 1999), deception in organizational decision-making (Brandts and Charness 2003), leadership (Weber et al. 2001), and incentives in mergers (Montmarquette, et al, 2004).

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Appendix A: Equilibria of the sequential knowledge sharing game.

The extensive form game of Fig. 1 has the following unique normal form representation, where the Leader is the row player and the Follower the column player. Since the Follower has to make decisions at two information sets, she has four strategies at her disposal, which we denote as *ss*, *sc*, *cs*, and *cc*. The Nash equilibria of the extensive form game can be found in its strategic form representation. We assume that players are rational and purely self-interested.

	ss	*sc*	*cs*	*cc*
s	b_L+v_L-k, b_F+v_F-k	b_L+v_L-k, b_F+v_F-k	b_L-k, $b_F+v_F+a_F$	b_L-k, $b_F+v_F+a_F$
c	$b_L+v_L+a_L$, b_F-k	b_L, b_F	$b_L+v_L+a_L$, b_F-k	b_L, b_F

Result A1 (Nash equilibria of the sequential knowledge sharing game if sharing is costly):
If $v_i > k > 0$, *then the only Nash equilibrium is the strategy profile* (*c*, *cc*), *i.e., the leader conceals, and the follower conceals in both subgames. This holds irrespective of* a_i, i=L,F.

Result A2 (Nash equilibria of the sequential knowledge sharing game if sharing is costless):
If $k = 0$, *the equilibrium strategies depend on* a_i, i=L,F. *We get the following pure strategy Nash equilibrium profiles (**bold** strategy profiles are subgame perfect)*:

- *If* a_L=0, a_F=0: ***(s, ss)***, ***(s, sc)***; ***(s, cc)***; ***(c, ss)***; ***(c, cs)***; ***(c, cc)***.
- *If* a_L>0, a_F=0: ***(s, sc)***; ***(s, cc)***; ***(c, ss)***; ***(c, cs)***; ***(c, cc)***.
- *If* a_L=0, a_F>0: ***(s, cc)***; (*c*, *ss*); ***(c, cs)***; ***(c, cc)***.
- *If* a_L>0, a_F>0: ***(s, cc)***; (*c*, *ss*); ***(c, cs)***; ***(c, cc)***.

Both results follow from the payoffs specified in the strategic form representation.

There also exist a host of *mixed strategy equilibria*. They have the following form. In all mixed strategy equilibria, the leader plays a pure strategy of either concealing or sharing with probability 1. In other words, in all mixed strategy equilibria it is only the followers who mix. Their mixing probabilities are as follows:

- If a_L=0 and a_F>0, then the follower mixes *s* and *c* in both subgames with probability 0.5. The leader conceals.
- If a_L=10 and a_F>0, there are two equilibria, both in which the leader conceals: (i) the follower in the subgame after the leader has chosen *c* plays *c* with probability 0.6 and *s* with probability 0.4. In the subgame after *s* the follower plays *c* with probability 0.4 and *s* with probability 0.6. (ii) The follower in the subgame after the leader has chosen *c* plays *c* with probability 0.33 and *s* with probability 0.67. In the subgame after *s* the follower plays *c* with probability 0 and *s* with probability 1.
- If a_L=20 and a_F>0, there are two equilibria, both in which the leader conceals: (i) the follower in the subgame after the leader has chosen *c* plays *c* with probability 0.67 and *s* with probability 0.33. In the subgame after *s* the follower plays *c* with probability 0.33 and *s* with probability 0.67. (ii) The follower

in the subgame after the leader has chosen *c* plays *c* with probability 0.5 and *s* with probability 0.5. In the subgame after *s* the follower plays *c* with probability 0 and *s* with probability 1.

- If a_L=30 and a_F>0, there are two equilibria, both in which the leader conceals: (i) the follower in the subgame after the leader has chosen *c* plays *c* with probability 0.7143 and *s* with probability 0.2857. In the subgame after *s* the follower plays *c* with probability 0.2857 and *s* with probability 0.7143. (ii) The follower in the subgame after the leader has chosen *c* plays *c* with probability 0.6 and *s* with probability 0.4. In the subgame after *s* the follower plays *c* with probability 0 and *s* with probability 1.
- If a_L=0 and a_F=0, there exist two equilibria, in both of which the follower mixes between *s* and *c* with probability 0.5. In one equilibrium the leader shares and in the other he conceals with probability 1.
- If a_L>0 and a_F=0, there exist four equilibria, which have the same structure as the equilibria described above for a_F>0. In two equilibria, the leader shares with probability 0 and in two equilibria he shares with probability 1. The mixing probability of the followers correspond to those for a_L=10, a_L=20 and a_L=30.

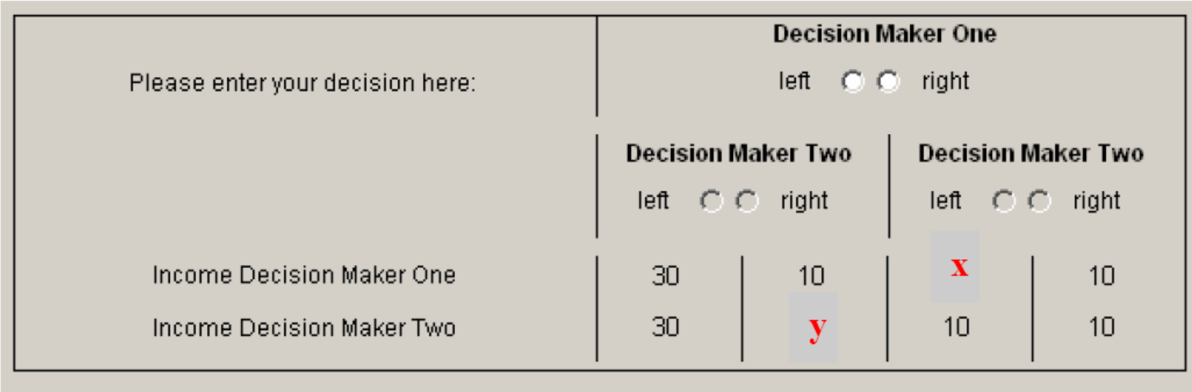
Appendix B: Experimental Instructions (originally in German)

This experiment is about economic decision processes. Please read the following instructions carefully. During the experiment you are not allowed to talk. If you have any questions, please refer directly to the experimenter. The points incurred as income during the experiment are converted to Swiss francs and paid out cash. In the experiment, your income is calculated in points. They convert as follows:

1 Point = 4 Rappen.

Description of the decision situation:

- The decision situation in this experiment involves two decision makers.
- The first decision maker decides first: He can chose either "left" or "right".
- The second decision maker also faces the choice between "left" and "right". He has to decide before he knows how the first decision maker decided. This means that the second decision maker has to choose between "left" and "right" both for the case where the first decision maker chose "left" as well as for the case where the first decision maker chose "right".
- The relevant decision situation is displayed schematically in the following, just like you will see it later on the screen:



The exact description of how decisions are made follows below. The incomes for both decision makers derive from the combination of both decisions. If, for example, the first decision maker chooses "left" and the second decision maker chooses also "left", for the case that this is what the first decision maker does, both receive an income of 30 point. If both chose "right", respectively, they receive an income of 10 points each.
You can always read the income for the first decision maker in the first row. The second row indicates the income for the second decision maker.
Altogether, you have to decide for **16 situations**. The incomes generated by the decision combinations vary across the situations as follows:

(1) if the first decision maker chooses "left" and the second one chooses "right" thereupon,

(2) if the second decision maker chooses "right" and the second one subsequently chooses "left".

In the above display, the incomes from these situations are marked with x and y. Only the incomes x and y vary from period to period across the situations. During each period, the current values of x and y will be labeled in red on the screen. All other incomes remain **unchanged** across the 16 periods.

How do you make decisions?

- You will be assigned the role of first or second decision maker **at random**. Your role assignment will be communicated on the screen.
- Through all 16 periods you will be either the first or the second decision maker.
- During **every one** of the 16 periods of the experiments you will be rematched to another **randomly chosen** counterpart.
- If you are the **first decision maker** you have to decide in every period whether you choose "left" or "right".
- If you are the **second decision maker** you have to decide in every period whether you choose "left" or "right" for **both** possible decisions ("left" or "right") by the first decision maker.
- The income from all decision situations will be aggregated and converted to Swiss francs.
- During the 16 periods you will not know how your counterparts decided. You will be informed about your income at the end of the experiment.
- Your income derives in every period from the combination of decisions, given your decision and your counterpart's decision.

- Before the start of the actual experiment, you will have to answer two control questions on the screen.

Appendix C: Table C1: Decisions and strategies of all games

In this appendix we document the frequency of individual decisions for each of the sixteen games. We also analyze the strategies and equilibria that subjects actually played.

	s_L	s_F after s_L	s_F after c_L
a_L=0, a_F=0	0.84211	0.73214	0.45536
a_L=10, a_F=0	0.61404	0.67857	0.45536
a_L=20, a_F=0	0.48246	0.71429	0.53571
a_L=30, a_F=0	0.44737	0.74107	0.40179
a_L=0, a_F=10	0.55263	0.28571	0.42857
a_L=10, a_F=10	0.34211	0.19643	0.47321
a_L=20, a_F=10	0.30702	0.26786	0.37500
a_L=30, a_F=10	0.35088	0.28571	0.37500
a_L=0, a_F=20	0.45614	0.17857	0.51786
a_L=10, a_F=20	0.34211	0.16964	0.47321
a_L=20, a_F=20	0.25439	0.16964	0.49107
a_L=30, a_F=20	0.18421	0.08929	0.47321
a_L=0, a_F=30	0.42105	0.13393	0.46429
a_L=10, a_F=30	0.23684	0.12500	0.47321
a_L=20, a_F=30	0.21053	0.09821	0.43750
a_L=30, a_F=30	0.17544	0.11607	0.41071

Table C1: *Frequency of chosen actions.*

Recall from Section 2 that a theoretical property of the sequential knowledge sharing game is the multiplicity of equilibria in the absence of out-of-pocket costs of knowledge sharing. Thus, in the next step we investigate which of the equilibria are behaviorally relevant. We describe them in Table C2, which summarizes the distribution of choices over the strategy space as a function of the opportunity costs of sharing.

The leader has two strategies, share (*s*) and conceal (*c*). The follower, however, has four strategies (see also Fig. 1): She can (i) share both if the leader shares and conceals (denoted *ss*), (ii) conceal if the leader shares and share if the leader conceals (denoted *cs*), (iii) share if the leader shares and conceal if he conceals (denoted *sc*), and (iv) conceal irrespective of the leader's choice (denoted *cc*). Therefore, the strategy space of the whole game is (*s*, *c*)ξ(*ss*, *sc*, *cs*, *cc*). Since we have applied the strategy method in our design, we can observe the behavior in the complete strategy space of the sixteen games.

Table C2 shows the strategies and – given the subjects' actual choices – lists the expected distribution of strategy combinations for the relevant cases of (a_Fξa_L)-combinations (each row sums to 100 percent). Under the assumption that a leader and follower are randomly and independently matched, the expected distribution is determined by multiplying the observed frequency of *s*- or *c*-choices by the leader and the frequency of the respective strategy by the follower. For instance, in the game with (a_L=0, a_F=0), leaders decided for *s* in 84.21 percent of the cases, and followers chose the strategy *ss* in 38.39 percent. This makes an expected frequency of observing the (s, ss)-strategy combination of 38.39ξ84.21=32.33 percent. Equilibrium strategies are shaded, and bold letters indicate subgame perfect strategy combinations.

	Outcome is ...							
	mutual concealing		unilateral knowledge sharing				mutual sharing	
	(c, sc)	(c, cc)	(s, cs)	(s, cc)	(c, ss)	(c, cs)	(s, ss)	(s, sc)
a_L=0, a_F=0	5.50	**3.10**	6.01	**16.54**	**6.06**	**1.13**	**32.33**	**29.32**
a_L>0, a_F=0	15.31	**10.69**	3.53	**11.33**	**19.21**	**3.32**	20.37	**16.24**
a_L=0, a_F>0	5.45	**22.28**	17.87	**20.28**	4.98	**19.63**	4.54	4.97
a_L>0, a_F>0	6.98	**33.88**	9.86	12.35	5.38	**27.04**	1.96	2.54

Table C2. *Expected frequency of strategy combinations given subjects' choices*.

Strategy profiles (c, sc) and (c, cc) induce a *mutual concealing* outcome ((c, sc) is a non-equilibrium profile, however). When no player has opportunity costs of sharing knowledge, then the expected frequency of mutual concealing is 8.60 percent. When both players have positive appropriation payoffs, then the expected frequency of mutual concealing jumps up to 40.86 percent.

The four strategy profiles [(s, cs), (s, cc), (c, ss), (c, cs)] induce *unilateral knowledge sharing*, which allows at least one party to benefit if appropriation is possible. For instance, if (a_L>0, a_F>0), then we expect unilateral knowledge sharing in 54.63 percent of the cases. Particularly interesting is the strategy combination (c, cs), which induces unilateral sharing that results in an unequal payoff benefiting the leader. In our data, the expected frequency at which followers are prepared to resolve their indifference in favor of the leader if the leader conceals is 27.04 percent.

Finally, the strategy profiles (s, ss) and (s, sc) induce a mutual sharing outcome (compare Fig. 1). In case no player has a positive appropriation payoff, that is if a_L=0 and a_F=0, we observe that the expected frequency of strategy combinations leading to mutual sharing (as an equilibrium) is 61.65 percent. This percentage drops dramatically, once at least one player has positive opportunity costs of sharing his or her knowledge. In case only the leader has positive opportunity costs (a_L>0, a_F=0), the expected frequency of strategies that induce mutual sharing outcomes is 36.61 percent (16.24 percent are consistent with equilibrium play). In case only the follower has positive opportunity costs (a_L=0, a_F>0), mutual sharing does not occur in equilibrium. However, we observe mutual sharing in 9.51 percent of all strategy combinations. In case both have positive appropriation benefits (a_L>0, a_F>0), the likelihood of strategies supporting mutual sharing drops to 4.5 percent.

In summary, mutual sharing occurs in particular if it is an equilibrium of the knowledge sharing game. Yet, for reasons discussed in section 2.4, we observe mutual knowledge sharing even if it is not an equilibrium.