Profiting from voluntary information spillovers:
How users benefit by freely revealing their innovations

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Abstract

Empirical studies of innovation have found that end users frequently develop important product and process innovations. Defying conventional wisdom on the negative effects of uncompensated spillovers, innovative users also often openly reveal their innovations to all users and manufacturers. Rival users are thus in a position to reproduce the innovation in-house and benefit from using it, and manufacturers are in a position to refine the innovation and sell it to all users, including competitors of the user revealing its innovation. In this paper we explore the incentives that users might have to freely reveal their proprietary innovations. We develop a game-theoretic model to explore the effect of these incentives on users' decisions to reveal or hide their proprietary information. We find that, under realistic parameter constellations, free revealing pays. We conclude by discussing some implications of our findings.

Keywords: innovation, spillovers, diffusion, lead users

1 Introduction

Research has shown that users of products and processes are the actual developers of many important innovations that are later produced and sold by manufacturers – where user-innovators are defined as individuals or firms or other entities that expect to benefit from their innovations by direct use, and manufacturer-innovators are defined as individuals or firms or other entities that expect to benefit from their innovations by selling them to others (e.g., Enos 1962, Knight 1963, Freeman 1968, Shaw 1985, von Hippel 1988). It has further been shown that innovation development activities are highly concentrated within the "lead user" segment of user communities – where lead users are defined as the subset in any user population that (1) experiences an emerging need sooner than the bulk of the user population (i.e., is „ahead of the trend"), and (2) anticipates relatively higher benefits from developing a solution to that need (von Hippel 1986, Urban and von Hippel 1988, Morrison et al, 2000, Shah, 2000, Lüthje 2000). Available evidence also indicates that innovating users frequently do not financially benefit from their innovations beyond benefits derived from in-house use. This pattern fits findings regarding the significant costs and low probability of success associated with efforts to protect and license intellectual property in many fields (Taylor and Silberston 1973, von Hippel 1988, Shah 2000).

Given the set of circumstances just described, conventional wisdom would suggest that innovating users would attempt to keep their innovation-related information secret. After all, noncompensated spillovers of information regarding user-developed innovations to non-innovating users – either directly or via a manufacturer - should represent a loss that innovating users would seek to avoid if at all possible. However, evidence to the contrary has been found in a wide range of settings. Users appear to often freely reveal details of their innovations to other users and to manufacturers (von Hippel and Finkelstein 1979, Allen 1983, Morrison et al 2000, Lim, 2000, Lakhani and von Hippel 2000). Possible economic reasons for free revealing of innovation-related information among users have been discussed by Allen (1983) in conjunction with his study of "collective invention" in the nineteenth century iron industry. In addition, the practice has been studied in a number of game-theoretic studies such as de Fraja (1996), Mishina (1989) and Harhoff (1996). However, formal models explaining this behavior in the context of free revealing of user innovations to manufacturers have not been proposed as of yet.

In this paper we begin by describing four incentives which could induce user-innovators to freely reveal their innovations. Then, we link these incentives to qualitative evidence regarding the free-revealing of innovations by users in a number of fields (section 2). Next we use a game-theoretic model to explore the effect of the four incentives and derive conditions under which it might pay users to freely reveal their innovations to other users and/or to manufacturers. We conclude that, under very plausible parameter constellations, it does indeed pay users to freely reveal their innovations to other users – even to direct rivals (section 3). Finally, we discuss the implications of free revealing of innovations by users, suggesting that it is a crucial element in an emergent innovation process characterized by a distribution of innovation-related activities between users and manufacturers. We also discuss possible extensions of our work in the final section of the paper (section 4).

2 Free revealing of user-developed innovations – incentives and qualitative evidence

We propose four types of incentives that we think can motive users to freely reveal their innovations to others. Each incentive is independent, and any or all can apply in a given context.

a) *Inducing manufacturer improvements*
By freely revealing an innovative product or process, a user makes it possible for manufacturers to adopt that innovation and improve upon it. When the improved version is offered for sale to the general market, the original user-innovator and other users as well are able to acquire it and gain from in-house use of the improvements. Any given user's gain is enhanced if more than one innovating user freely reveals innovations that are then adopted by a given manufacturer.
To illustrate this source of incentive, consider that manufacturers often convert user-developed innovations ("home-builts") into a much more robust and reliable form when preparing them for sale on the commercial market. Also, manufacturers offer related services, such as field maintenance and repair programs, that innovating users must otherwise provide for themselves. User-innovators purchasing their innovations from manufacturers can significantly benefit from these manufacturer-added improvements.

b) *Setting a standard advantageous to the user innovator*
By freely revealing an innovation, a user makes it possible for other users to adopt it as their solution as well. This adoption as a "standard" can be beneficial to the user-innovator if his innovation contains imbedded features particularly beneficial to that user that are not easily identified or removed, and if revealing of the innovation preempts the development of other versions. It is frequently the case that manufacturers cannot identify all user-specific features embedded in a product or service, because the innovating user typically has a much deeper understanding of the innovation's intended use and use context. Note that being first to reveal a given type of innovation increases a user's chances of having *his* innovation widely adopted, other things being equal.
As an illustration of this type of incentive, consider a user-innovator in the

field of metal refining that freely reveals an improved refining process it has developed. This innovating user finds revealing beneficial because its improved process utilizes an input (say, a particular industrial gas) which the innovator can obtain more cheaply than can competitors.

c) *Reciprocity and reputation effects*
By revealing an innovation, the innovator may create or discharge "generalized reciprocity" obligations (e.g., "X is known to have been helpful to the field, and so other members of that field will be inclined to reciprocate.") (Levi-Strauss 1949, Eckh 1974). He may also reap a gain in reputation. Note that the highest reputational gain generally goes to the first to reveal a given innovation.
As an illustration, consider that developers of important scientific innovations reap significant reputational gains by being first to reveal their findings via open publication to peers (Merton 1973).

d) *Low rivalry conditions*
When competition between users is low, e.g. due to geographical separation of markets, the revealing user does not suffer as a consequence of the advantages he provides to the other users. This is not so much an incentive as *absence of a disincentive*, and can be a crucial determinant of an innovator's behavior.

Empirical evidence for the free-revealing of proprietary innovations by innovating users can be seen in the 5 case studies which we describe next. In each case study commentary, we will refer to one or more of the incentives just listed a-d, which are the likely motivations for the innovation-revealing behavior observed.

2.1 Equipment to produce "copper-interconnect" semiconductors

IBM was first to develop a process to manufacture semiconductors that incorporated copper interconnections among circuit elements instead of the traditionally-used aluminum ones. This innovation provided a major improvement to semiconductor performance, and on the face of it, it would have paid IBM to not reveal its process to others. After a delay IBM did, however, "freely reveal" increasing amounts of proprietary process information to rival users and to equipment suppliers.

IBM freely revealed information about its innovation because it needed equipment to implement the process on a production scale. Detailed design and production of such equipment required the combining of information held by semiconductor equipment suppliers and IBM. Since development of novel process equipment is a very expensive matter in the semiconductor field, suppliers would only be willing to build equipment that could potentially be sold to the entire market. Revealing innovation-related information selectively so as to insure that the IBM process approach became the industry standard – but that IBM still maintained a lead in the marketplace - was therefore in IBM's best interest. Thus, IBM was motivated to "openly reveal" its innovation by incentives (a), inducing manufacturer improvements, and (b), setting a standard advantageous to the innovator user (Lim 2000, Harhoff 1996[1]).

2.2 Improvements to clinical chemistry analyzer equipment and tests

The Technicon Corporation was the first to produce automated clinical chemistry analyzers – a type of medical equipment used to determine the levels of chemical constituents of blood. The basic design of their product was taken from a system that had been earlier developed and used by laboratory clinicians – users of that type of equipment. This user-developed design was modular and well-suited to low-cost modification by other users who had an incentive to do this. After commercial introduction of the basic analyzer, many users developed test and hardware innovations and freely revealed these via publication and other means. Other users and the Technicon company then adopted many of these innovations (20+ in the case of the Technicon company itself) without payment to the innovators. Open revealing of innovations by users was encouraged by Technicon via a firm-supported research publication and via a research seminar series sponsored by the company (von Hippel and Finkelstein 1979).

Open revealing of innovations by users in this field fits incentives (a), inducing manufacturer improvements), (c), reciprocity and reputation effects, and for most innovating users (d), low rivalry conditions, as well. Innovating users in this instance were typically employees in the clinical labs of publicly-supported institutions. They were scientist-rivals rather than commercial rivals with respect to other users. Their ongoing research benefited when Technicon adopted and improved their innovations, and they also gained reputation-related benefits from peers and employers when they established their priority with respect to their innovations.

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[1] Lim (2000) describes IBM's motivation as follows: „IBM is also attempting to capture indirect benefits. According to my interviews, several IBM employees realized in the mid-1990s that it would benefit from lower equipment costs if the rest of the industry also adopted copper technology. This is consistent with the strategic sharing of information (Harhoff 1996). In line with this, IBM formed the alliance with Novellus and later relaxed somewhat on its secrecy. Although it continues to guard sensitive process information, it has begun to share its copper technology with other companies, including Siemens (Infineon), Sanyo, and a startup foundry in Taiwan (Table 8a). However, it is important to point out that this strategy of sharing technology was only feasible after IBM had established itself as the leader. Otherwise, another firm might have exploited the knowledge to beat it to market". See Lim (2000) for a detailed discussion.

2.3 Improvements to computerized library information systems

Library „OPACs" (Online Public Access) are computerized information systems that give patrons access to library collections (they functionally replace the traditional „card catalog" form of collection index) and to the rich information resources of the Internet. The first OPACs were developed by leading-edge users in the early 1970's. In the late 1970's, suppliers began to offer OPACs as commercial products. Prior to the late 1990's OPACs were not designed to make modification by users easy. Nonetheless, a study of Australian library users of OPACs showed that 26% had modified the code of the OPAC they had purchased (or developed themselves) to improve its functionality. The study also showed that innovating users freely revealed their innovations to other users and to their OPAC suppliers in manufacturer-sponsored "user's group" meetings and elsewhere. Manufacturers were willing to adopt user-requested or user-prototyped improvements in OPAC functionality – without any payment to user-innovators - if "enough" users wanted the same thing. So one or more users would sometimes engage in pre-meeting lobbying to generate widespread support for an innovation they wished to have adopted and supported by their OPAC supplier.

Innovating users in the library field were not rivals in the marketplace – each served a geographically or topically distinct group of patrons (d - low rivalry conditions). They benefited from openly revealing their innovations from incentives (a), inducing manufacturer improvements, and (c), reciprocity and reputation effects. Indeed, their benefit from (a) – potential improvements to their innovation made by manufacturers – was so great that they often collaborated with other users to lobby OPAC manufacturers to produce their innovation commercially (Morrison et al. 2000).

2.4 Development of open-source software

Open-source software products, such as Linux operating system software and Apache computer server software, are built up from modules developed by programmer-users of that software.[2] These user-innovators then openly reveal their

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[2] Open source software has its roots in the "free software' movement started by Richard Stallman in the early 1980s. Stallman founded the Free Software Foundation (FSF) as a means to counter the trend towards proprietary development of software packages, and the release of software without the underlying source code. The purpose of the foundation was to encourage development of software that would come with source code and be available to users for their own modification. A key feature of FSF based development is a licensing scheme called 'Copyleft.' Under Copyleft, the author of the program has the traditional and legal entitlements of copyright protection along with a license for users to redistribute and change software. The Copyleft license provides unique distribution terms that gives all users the rights to use, modify and redis-

developments to all other users and also to the volunteer individual or user organization that manages that open source software product. (This individual or organization is responsible for accepting and generally distributes improvements adopted as “official” by posting revised software code on the Internet.) Innovating users receive no direct payment from freely revealing their innovations in this manner.

Users are motivated to initially develop a module because they have an in-house need for functionality it provides. Users are then motivated to freely reveal their innovations by the incentives (a), inducing manufacturer improvements, and (c), reciprocity and reputation effects, described above. That is, they are motivated to have their improvement incorporated into the standard version of the open-source software that is generally distributed by the volunteer open source user organization, because it will then be updated and maintained without further effort on the innovator’s part. This volunteer organization is the functional equivalent of a manufacturer with respect to incentive (a), inducing manufacturer improvements, because a user-developed improvement will *only* be assured of inclusion in new “ official” software releases if it is approved and adopted by the coordinating user group. Innovating users also gain a reputational advantage by having a contribution accepted into the Open Source code (Raymond 1999). There is also often little competition between users of the software that would create an incentive to hide user-developed innovations (d - low rivalry conditions).

2.5 Participants in “lead user” studies

Lead user studies involve systematic, proactive efforts by supplier firms to learn about innovations developed by lead users that might merit commercial production and diffusion. During such studies, supplier firm personnel identify lead users who have innovated, and then invite those who appear to have done the most commercially-promising work to attend a “lead user workshop” sponsored by the supplier firm. In advance of participation, invitees must sign an agreement in which they assign the intellectual property rights to any innovation developed at the workshop to the supplier company. Experience shows that almost all lead user invitees

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tribute the programs code or any program derived from it but only if the distribution terms are unchanged. Thus the code and the freedoms become legally inseparable. The Copyleft concept prevents private hoarding of free software if it was just released under a public domain release (Morin 1993). All users are compelled to leave copies behind for others to benefit. The philosophy of the FSF movement has been recently extended by a number of individuals who are promoting the ‘Open Source’ concept. These individuals are less concerned about the freeness of “free software” and are instead interested in encouraging software companies to release source code for their products. These individuals believe that companies that release source code, under any type licensing, are inherently preferential to closed and proprietary firms (Raymond 1999).

do agree to sign the agreement, do attend the workshop and do reveal their innovative work to the supplier company and to each other.

As an example, consider a recent lead user study devoted to advances in wireless, mobile communications systems. The goal of the supplier sponsoring this lead user study was to identify innovations that could be incorporated into systems to be sold to „road warriors“ - mobile professionals who must accomplish demanding computational and data transfer tasks while traveling. Lead users invited to the workshop that had innovated in advanced wireless, mobile communication systems included:

- Scientists involved in animal tracking studies. Lead users in this field had developed systems to pick up data sent from radio equipment worn by free-ranging animals that traveled widely in remote polar regions.

- Researchers developing battle management communications systems for the US military. These lead users are developing systems to transmit voluminous, rapidly changing battlefield data to many military personnel – automatically tailored to the needs and location of the mobile battle unit or individual soldier receiving it.

- Researchers studying extreme meteorological phenomena such as hurricanes send mobile data collection units (aircraft and ground vehicles) into storms. Storm locations and directions of movement cannot be predicted with high accuracy. Lead users in this field have developed wireless communication methods to rapidly transfer voluminous meteorological data among the mobile units involved in these „storm chasing“ efforts.

Why do lead users such as these freely reveal the results of their innovative work? It can be shown (Lilien et al. 2000) that they are generally affected by incentives (a), inducing manufacturer improvements, (c), reciprocity and reputation effects, and (d), low rivalry conditions. That is, the innovating lead users can benefit if the supplier adopts and improves their innovation. They also may gain reputational advantages by reporting their accomplishment to fellow experts with related interests (c - reciprocity and reputation effects). Further, the lead users invited to participate in the workshop – in the illustrative example given and also in lead user studies in general – are often not rivals in the same marketplace (d - low rivalry conditions). That is, battle management people do not suffer competitive losses if animal trackers – or suppliers of communication systems to road warriors – gain advantage from adopting the innovations they have developed (Lilien et al. 2000).

3 The theoretical model

In the examples described above, users of a service or product develop innovations based on location-specific information and needs. Typically, there may be one or very few innovative users in a population of firms or individuals. Innovation may therefore – depending on the degree of rivalry – give innovative users a competitive advantage in their respective industry. The classical prediction concerning these users is that they will keep their innovations secret or use other methods of appropriation by which they can assure themselves of a high share of the total surplus generated by the innovation. But the empirical evidence developed above shows that this expectation is at least sometimes not met. Defying the conventional wisdom, innovative users may decide to openly reveal their innovation to all users and manufacturers. Rival users are then in a position to reproduce the innovation in-house and benefit from using it, and manufacturers are in a position to refine the innovation and sell it to all users, including competitors of the user revealing its innovation.

Our model addresses the users' decision to voluntarily and generally reveal information about their proprietary innovations. To keep it concise, we do not model a number of issues that may be of interest for a separate study. For example, we do not model explicitly how the heterogeneity among product users emerges, i.e., why some of them are endowed with innovations in our model and others are not. For our purposes here, it is immaterial whether innovative users have reached their position by chance or, for example, by a special ability to engage in marketing research that enables them to generate particularly precise predictions about the nature and extent of future demand.

We also do not model explicitly why transactions are not accompanied by monetary compensation – for example, why the revelation of an innovation is not subject to a licensing contract. We do this because, as was mentioned earlier, empirical evidence indicates that, in most fields, user-innovators grant access to their innovations without receiving monetary compensation under licensing or other forms of contracts. There are a large number of possible explanations for this. For example, it is well-known that contracts of this form are beset with problems of moral hazard and adverse selection, and that transactions costs for setting them up are high (Teece 1977). The assumption that licensing is not a particularly attractive mechanism to reap returns from innovation is widely shared.[3]

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[3] See, among others, Tirole (1989, ch. 10), Teece (1977), and von Hippel (1989). A known exception is the field of chemical process innovations (Freeman 1968). Here, the value of individual innovations is quite high, and the costs associated with patenting and licensing are seen as a worthwhile investment by the oil and chemical firms that are the user-innovators in this field.

3.1 The basic model with two users

We consider the case of two users, each of which may have developed an innovation. We will assume that these user firms are identical with respect to all other aspects that bear on their profitability. The user firm can profit from the innovation by keeping it secret (Mansfield 1985, Levin et al. 1987) or by revealing it to a manufacturer firm which will improve the product and offer it to both users. The users may then decide to adopt or not to adopt the improved innovation. This situation is reminiscent of our empirical examples 2.1 – 2.5. The outcomes to be studied depend on whether one or both users have developed an innovation, on the revelation decision and on the adoption decision of the two firms. The basic parameters of the game are three.

First, the extent of competition between the user firms relates increases in the payoff of one firm to losses for the other one. The higher the payoff of firm 1, the lower will be the payoff of firm 2 if competition is intense. Conversely, for firms with largely separate markets the impact of competition will be very small or low.

Second, we allow for different technologies employed by the two user firms. While standard oligopoly models typically assume that firms are identical with respect to their production technology, we find this assumption quite restrictive and – in many cases - unrealistic. The usual logic would suggest that firms will adopt the lowest-cost technology and that in the long run, only firms with that technology will be present in the market. In reality, the choice of production technology is likely to be path-dependent. Due to sunk cost investments, firms will not adjust their production technology immediately, and even over longer periods of time we are likely to observe pronounced differences in production technology. The most important implication of heterogeneity of this kind is that the value of innovations may differ across firms. In particular, if firm 1 develops an innovation, it is likely to be tailored to its own production technology. Transferred to a different production environment, the beneficial effect of the innovation (e.g. its contribution to cost reduction) may be substantially lower than in the innovator's context.

The third parameter describes the extent to which the manufacturer can improve the innovation or reduce its price, e.g. by virtue of large-scale production. Naturally, in an extended model this would again be considered an endogenous variable, but for the time being we consider it as exogenously given. We capture the basic nature of our model in the payoff matrix in Table 1.[4]

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[4] This matrix shows reduced-form representations of a simplified duopoly game (one scenario in each of the four sub-matrices). We are not explicit in this section about the beliefs undergirding the game(s) upon which the payoff matrix could be based. See the appendix for such a game in extensive form and comments on the beliefs.

3.2 Case 1: Innovation by one user

Consider the case of user 1 having developed an innovation and user 2 not having done so – the payoffs for this situation are depicted in the lower left submatrix in Table 1. The undisclosed innovation yields an increment δ in present discounted profits to the innovator. But user 1's gain also has a competitive effect for user 2. We note the strength of competition by α and specify the impact of the innovation on the other user's profit as $-\alpha\delta$, where $0\leq\alpha\leq1$. In a fully developed oligopoly model, α would be a function of technical and economic determinants. Note that a more dramatic improvement of the innovator's position is likely to hurt its competitors more than a marginal improvement would.

The innovative user 1 may decide to reveal the innovation to a manufacturer of the improved good. Revealing may have the advantage that the manufacturer can produce the product at lower cost than the innovator itself, or that it may have specific expertise in improving the product further which the innovator may lack. In this case, we assume that after revealing the innovation, the direct effect of the improved or less costly innovation on the user's profit is given by $\Delta=(1+\mu)\delta$ with $\mu\geq0$. We assume that revealing without adoption by the competitor leaves user 1’s direct gain at δ since, anticipating the non-adoption, the manufacturer will not incorporate the innovation into his products.

The second user firm will also profit from the innovation, but to a lesser extent than the innovator. This effect is due to the fact that the innovator will have tailored the innovation optimally to its own production environment. This specificity – we assume – cannot be unraveled by the manufacturer. Hence, the other user will only enjoy a marginal direct payoff of $\gamma\Delta$ with $\gamma\leq1$. The case of $\gamma=1$ denotes one of complete generality of the innovation, while $\gamma=0$ denotes the polar case of complete specificity. The impact of competition enters the payoffs again by subtraction of the other user's payoff times the competition parameter α. Hence, once the innovation has been revealed by the innovator, and once it has been adopted by his competitor, the innovator's payoff is given by $\Delta-\alpha\gamma\Delta$ while the other firm enjoys a payoff of $\gamma\Delta-\alpha\Delta$.

Given that one user has developed an innovation and the other has not, what would be the outcomes of the revelation and adoption decisions? First of all note that adoption by user 2 will not always occur. Comparing payoffs (conditional on revelation by user 1) we find that for adoption to occur we have to have

$$\gamma\Delta-\alpha\Delta > -\alpha\delta$$

Table 1

Payoff Matrix

User 2

		no innovation/ no adoption	**no innovation/ adoption**	**innovation/ no revelation/ no adoption**	**innovation/ no revelation/ adoption**	**innovation/ revelation**
	no innovation/ no adoption	**0** **0**	**0** **0**	δ $-\alpha\delta$	δ $-\alpha\delta$	δ $-\alpha\delta$
	no innovation/ adoption	**0** **0**	**0** **0**	δ $-\alpha\delta$	δ $-\alpha\delta$	$\Delta-\alpha\gamma\Delta$ $\gamma\Delta-\alpha\Delta$
User 1	**Innovation/ no revelation/ no adoption**	$-\alpha\delta$ δ	$-\alpha\delta$ δ	$\delta-\alpha\delta$ $\delta-\alpha\delta$	$\delta-\alpha\delta$ $\delta-\alpha\delta$	$\delta-\alpha\delta$ $\delta-\alpha\delta$
	Innovation/ no revelation/ adoption	$-\alpha\delta$ δ	$-\alpha\delta$ δ	$\delta-\alpha\delta$ $\delta-\alpha\delta$	$\delta-\alpha\delta$ $\delta-\alpha\delta$	$\Delta-\alpha\gamma\Delta$ $\gamma\Delta-\alpha\Delta$
	Innovation/ revelation	$-\alpha\delta$ δ	$\gamma\Delta-\alpha\Delta$ $\Delta-\alpha\gamma\Delta$	$\delta-\alpha\delta$ $\delta-\alpha\delta$	$\gamma\Delta-\alpha\Delta$ $\Delta-\alpha\gamma\Delta$	$\gamma^M\Delta-\alpha\gamma^M\Delta$ $\gamma^M\Delta-\alpha\gamma^M\Delta$

Notation:

δ - payoff to innovator without adoption by competitor
Δ - payoff to innovator with revelation and adoption by competitor, $\Delta=(1+\mu)\delta$
α - degree of competition ($0<\alpha<1$)
γ - generality/transferability of innovation ($0<\gamma<1$)
γ^M - level of generality chosen by manufacturer ($\gamma<\gamma^M<1$)

or

$$\gamma > \alpha\mu/(1+\mu)$$

Intuitively, if generality is too low, the adopting user 2 would not gain much in direct payoffs from the adopted technology, but the competitive impact of user 1 enjoying a large improvement in its competitive position would create a large indirect negative effect. Thus, γ has to be sufficiently large and α and μ have to be sufficiently small to let user 2 adopt the technology.[5]

For the innovative user, non-adoption is always dominated by adoption; hence, it is not explicitly included in the payoff matrix. With respect to revelation by user 1, comparing payoffs (conditional on adoption by user 2) shows that the innovator will reveal its innovation if (and only if)

$$\Delta - \alpha\gamma\Delta > \delta ,$$

which yields

$$\gamma < \mu/(\alpha(1+\mu)) .$$

Thus, the combined condition for observing revelation of the innovation by user 1 and adoption by user 2 is given by

$$\alpha\mu/(1+\mu) < \gamma < (1/\alpha)\, \mu/(1+\mu)$$

We can display the revelation and adoption decision graphically as a function of the three parameters α, γ and μ. We do so in Figure 1 for parameter values of μ=0.1 and μ= 0.5. The area under the curves denotes parameter values for which revelation will occur. The area above the respective straight lines characterizes parameter values for which adoption will occur. As can be expected, revelation is less likely to occur as the extent of competition in the product market grows and as the generality of the innovation increases. Both effects imply that the competitive effect of revelation will dominate the effect from the manufacturer's improvement of the innovation, ceteris paribus. Conversely, the greater the contribution that the manufacturing firm can provide, the more likely revelation is to occur, holding competition and generality constant. The adoption decision requires the improved innova-

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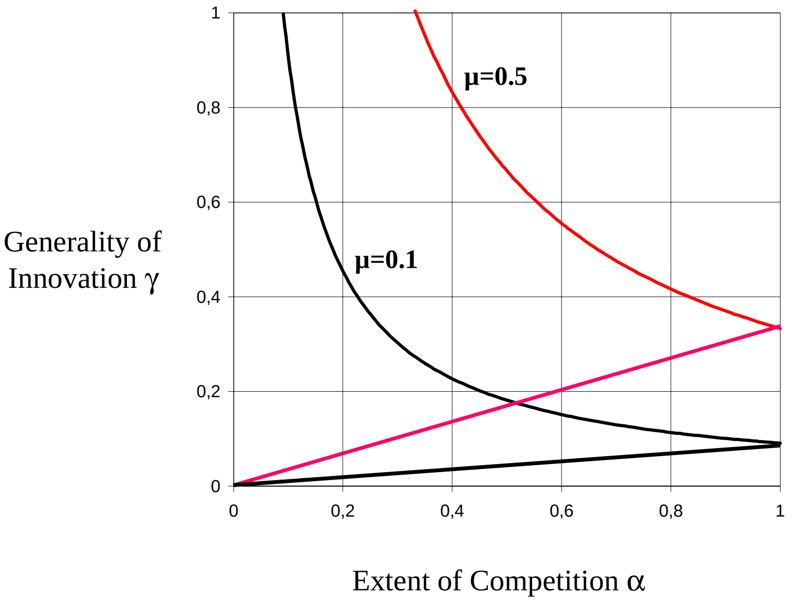
[5] This would be different if the benefits of revelation were independent of the adoption decision made by user 2. For example, user 1 may be large enough to create a sufficiently sized market for the manufacturer to incur economies of scale.

tion to be general enough, or competition to be weak enough in order to let the second user profit from adoption.

The payoffs in the upper right-hand submatrix describe the analogous case in which user 2 has developed an innovation and user 1 has not. Since the payoff matrix is symmetric, we do not discuss this case.

Figure 1



Determinants of Innovation Revelation and Adoption

1.3 Case 2: Innovation by both users

An interesting situation arises if both user firms have developed an innovation. We assume symmetry with respect to the size of the innovation, hence each user would profit by δ if the information was not revealed. The duopoly payoffs are then given by $\delta-\alpha\delta$. Of particular interest are the cases in the lower right-hand corner of the sub-matrix. If both users innovate, one of them reveals the innovation, and the second user chooses to adopt the other user's innovation once it has been improved by the manufacturer, the innovator's payoff is $\Delta-\alpha\gamma\Delta$ while the adopter enjoys a payoff of $\gamma\Delta-\alpha\Delta$. The own innovation by user 2 does not convey additional benefits. If both users innovate and reveal, the manufacturer has to choose one version of the innovation to be implemented in his improved product. We do not model this choice in detail, but simply assume that the payoffs are now given by $\gamma^M\Delta-\alpha\,\gamma^M\Delta$ for both firms, where $\gamma < \gamma^M < 1$. This inequality would be consistent with a random choice by the manufacturer which leaves the expected payoff to both users somewhere in between the benefit of the single innovative user after revelation and the non-innovator after adoption. It can also be interpreted as a conscious choice by a manufacturer which – by inspection of two alternative innovations – gains some insight into how to combine design features.

Suppose now that user 1 has revealed the innovation. Given the choice between revealing his own innovation and adopting that of user 1, user 2 would always prefer to reveal, since

$$\gamma^M\Delta-\alpha\gamma^M\Delta > \gamma\Delta-\alpha\Delta$$

is equivalent to

$$(\gamma^M-\gamma) + (\alpha-\alpha\gamma^M) > 0,$$

which is always satisfied due to $1 > \gamma^M > \gamma$. Choosing between “revelation” and “no revelation / no adoption”, user 2 prefers to reveal if

$$\gamma^M\Delta-\alpha\gamma^M\Delta > \delta-\alpha\delta$$

or

$$\gamma^M > 1/(1+\mu).$$

Since $\gamma^M > \gamma$, $\gamma > 1/(1+\mu)$ is a sufficient condition for this case.

The strategies “no revelation / no adoption” and “no revelation / adoption” lead to different outcomes only when the other user reveals. Since in this case “revelation” is always better than “adoption”, the line and column relating to the latter strategy effectively become irrelevant. This leaves us with a 2×2 submatrix, in which “no revelation / no adoption” by both users is always an equilibrium outcome, since a unilateral deviation never pays. If $\gamma^M > 1/(1+\mu)$, then “revelation” by both users also turns out as to be an equilibrium. In fact, in this case both users do better by revealing, so they might try to coordinate on this outcome. This coordination should be relatively easy to do, since the other equilibrium is ‘indifferent’, i.e., a deviation is not harmful.

The results for the case of two innovator users are therefore slightly more complex than those for the asymmetric situation. Here, competition (in the sense that both users are endowed with an innovation) may lead to secrecy if the innovations are sufficiently specific (i.e., γ is small, which, assuming γ^M grows with γ, implies that γ^M is small) or if the manufacturer's contribution μ is sufficiently small. If the innovations are sufficiently general and if the manufacturer can provide valuable improvements, firms will profit from coordinating their behavior. For this case we would expect to observe revealing of the innovations.

4 Concluding comments

Innovation if often a process to which several actors with complementary capabilities contribute. Bringing these actors together is often welfare-improving, since none of them has sufficient knowledge or information to produce the innovation on their own. Forces that may prevent actors to earn a return on their contribution to the overall innovation activities would therefore be seen as undermining the effectiveness of an innovation system. The usual candidates for causing such effects are transactions costs, informational asymmetries and the incompleteness of contracts. Taken alone or together, they may prevent economic agents from coming to the division of labor that allows each actor to most effectively contribute to the development of innovations. The conventional prescription is therefore to reduce such frictions, in order to enhance the overall efficiency of the economic system. Moreover, this view is the foundation for believing that any information transfer that occurs in such a system must be involuntary – knowledge spills out in this case, to the detriment of the party losing it to competitors or others, since each agent seeks to keep its information proprietary in order to reap the maximum possible return on it.

We think that this view is limited, and that it may actually misrepresent a large number of real-world cases. We agree to the notion that important forces introduce friction, and that the market for intellectual property is imperfect. Our assumption that licensing is not feasible, and that there are no side payments between users and between innovator users and manufacturers reflects this view. But this strong assumption does not imply that there will be no information transfer. First, we have pointed out that information transfers which are not accompanied by monetary compensation are frequent. Moreover, they occur intentionally – hence, they can be called voluntary information spillovers.

Our model seeks to reconcile this actual economic behavior with economic theory. We can show that in a world of self-interested agents with complementary capabilities, free revealing can be profitable. In the final sections of the paper, we first provide a discussion of our results, before we consider possible implications. Finally, we comment on future research that could build on our results.

4.1 Discussion of data and model

We began by reviewing five case studies in which innovating users have been found to freely reveal their innovations to other users and/or to manufacturers. On the face of it, as we noted above, this behavior is puzzling. Conventional wisdom argues that uncompensated spillovers of information regarding innovations to non-innovating users – either directly or via a manufacturer – will represent a loss to the innovating users. This implies that innovating users should seek to protect their innovations from would-be adopters and rivals rather than freely reveal them.

The explorations we have presented in this paper provide possible answers to this puzzle. Our explanation for the observed pattern of free revealing of innovation-related information by users began with a description of four independent types of incentives that could reward innovators that did freely reveal. We then developed a simplified game-theoretic model describing the interplay of those incentives for various intensities of rivalry in the marketplace, and identified a range of conditions under which users could be expected to benefit from freely revealing their innovations to others.

The user and manufacturer incentives described in the model developed in 3.1 have a good fit with the real-world conditions faced by user-innovators in the copper-interconnections, clinical chemistry analyzers, OPACs, open source software innovations and lead user cases described in section 2. In each of these cases, innovations freely revealed by users were adopted by manufacturers who then made them available to all users via commercial sale. Recall that, in the case of user innovations developed for open-source software products, the functional equivalent of the manufacturer is the volunteer user group having, by established custom, the exclusive right to add innovations to the “official” version of that product (Raymond 1999).

We propose that free-revealing by innovating users will be a common phenomenon for two reasons. First, as the reader will recall, the model we have developed shows considerable ranges of conditions under which free revealing could be expected to be profitable for innovating users. Second, for any area of innovation application, there are likely to be a number of users extant with relevant and valuable information, and who are experiencing different conditions with respect to the desirability of revealing that information. Note that all that is required for information diffusion to occur is that at least *one* such user be in a position to benefit sufficiently from openly revealing his version of the innovation-related information.

The reader may be able to intuitively appreciate that, for any given problem, many users are likely to exist that possess useful information <u>and</u> face conditions favorable to freely revealing by considering the following. Users in many markets face technically similar challenges. However, users in some of these markets will encounter these challenges earlier – and develop solutions to them earlier - than will users in other markets. Information seekers can solicit information from users or supplier firms in markets that are in this sense technically ”ahead“ of their own market. Although users who are asked to reveal information may have rivals in their own markets, the innovative information at issue may well have become common knowledge among those rivals with the passage of time. When this is so, users in these „advanced analog“ markets will be in a position to reveal their innovation with no risk of revealing valuable information to rivals.

As an example, consider the development of ABS braking systems for automobiles. The need for a vehicle braking system with the technical characteristics of ABS was encountered in severe form in the aircraft field years before demand for it developed in the automotive field – in part because airports cannot resolve icy conditions on runways by using the materials commonly used on icy motor roadways such as sand and salt. The result was, when auto firms came looking for solutions to their newly-encountered marketplace need, they could freely access relevant ABS solutions that had been developed by aerospace lead users and suppliers – because the information they sought had become commonly known among rivals in that field.

The model we have discussed in this paper does not directly address the possibility of direct user-to-user transfer without any involvement by a manufacturer or functional equivalent. However, direct user-to-user transfer does often occur, as has been documented in the case of process innovations in iron and steel (Allen 1983, von Hippel 1987, Schrader 1991). Our model is applicable to user-to-user transfers in which the receiving user creates an externality enjoyed by the sender. In this case, the parameter μ in our model can be interpreted as the size of the externality while the interpretation of the other parameters does not change. (Allen proposed that free revealing can be profitable for an innovating user when a revealed innovation is specific to an asset held by that innovator, and when revealing raises the value of that asset enough to offset the loss of profits associated with the revelation. Von Hippel and Schrader document *selective* rather than free revealing by innovating users. They found that selective revealing made economic sense for users that were rewarded by reciprocal, tit-for-tat revealings at a later date.)

Given that innovation by users is common, and given that many users will have an incentive to freely diffuse information about their innovations, measures to encourage and utilize innovations developed by users become a much more attractive proposition from the viewpoint of the overall economy. In contrast, if innovating users generally were not willing to freely reveal their innovations, then general diffusion could not occur unless either many users independently developed similar innovations, or a manufacturer either developed or licensed a similar innovation and offered it for general sale in the marketplace. Under such conditions it would clearly be more economical to encourage licensing by users and/or innovation by manufacturers – thus avoiding the cost of multiple independent innovations by users.

Our work also points to a major problem in the empirical assessment of knowledge flows. In an illuminating survey of the spillover literature, Griliches (1994) has already provided a cautious view of the advances made in this field. With few exceptions, authors in the area of spillover measurement interpret the measured impact of "knowledge pools" on R&D expenditures or output as the impact of unintended knowledge flows. In the usual interpretation, therefore, these measures give us an idea of the importance of knowledge externalities.[6] In contrast, our data and model suggest that the interpretation of spillover coefficients may not only measure the externality orginating from unintended spillover flows, but also the impact of information that has been revealed intentionally.

4.2 Suggestions for further research

If the phenomenon of free-revealing of innovations by users is indeed interesting and important, then it will be valuable to extend and improve the model of the phenomenon that we have presented here, and to develop other types of models as well. We list some possible model extensions below, on the possibility that other researchers may be interested in joining in the exploration of this new arena.

One important extension to the present model concerns the number of users. With more than two users, "pre-emptive revelation" can occur: facing the risk that some other user X will reveal his innovation and, with the manufacturer's support, establish it as the new standard, the innovative user 1 may prefer to reveal himself. Hence, one or more innovating users might end up revealing their innovations, although they had been better off keeping it for themselves.[7] For the industry as a whole, however, this prisoner's dilemma-type situation can be positive. We would get this situation also in our 2-player game if the strategy of "revealing" increased the revealing player's payoff even when the other innovator does not adopt. This

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[6] Cohen and Levin (1989, 1990) have argued that this view may have to be amended: they argue that firms without the capability to absorb knowledge will not profit from external knowledge. For some empirical evidence supporting this view, see Harhoff (2000).

[7] Arora et al (2000) argue that such an effect is responsible for an increased level of licensing by innovating users that they have observed in the chemical industry.

payoff increase could be attributed to other users (not explicitly modeled) who adopt the innovation, even if the other innovator does not adopt.

Finally, we note that the game-theoretic model we have developed does not incorporate time as a variable. Inclusion of time as a variable in future models would allow the representation and analysis of additional interesting and important matters associated with the free-revealing of information-related information by innovators. One such effect is the innovation "lock in" that can occur due to path dependence effects. New generations of technology often build upon preceding ones. The advantages to an innovator that openly reveals proprietary innovation-related information and reaps advantages when it becomes a "standard" are shown in our model for a single technical generation. A model incorporating time could show the extension of these benefits over time due to path dependence effects (Nelson and Winter 1983).

Appendix

For the sake of clarity, we had simplified our duopoly model in three respects: no explicit modeling of market demand and the firms' profit maximization; no explicit consideration of the players' beliefs; representation of the game in a simplifying reduced strategic form instead of a more precise extensive form. In this Appendix, we shall discuss the justification and implications of each of these simplifications.

Model of market demand and profit maximization

A commonly used approach models the demand that firm 1 faces as

$$D_1(p_1, p_2, a) = 1 - p_1 + ap_2,$$

where p_1 and p_2 denote the prices of firms 1 and 2, resp., and a parameterizes the degree of competition. Ignoring fixed cost for simplicity, the profit of firm 1 obtains as

$$\Pi_1(p_1, p_2, c_1, a) = (p_1 - c_1)(1 - p_1 + ap_2),$$

with c_i denoting the variable cost per unit of firm i. A calculation of Nash equilibrium strategies and profits shows that the variation of profits Π_1 and Π_2 with e.g. c_1 can be reasonably well approximated, in the relevant parameter range, by a linear function. Obviously, with a decrease in c_1 – due to an innovation by firm 1, say – Π_1 increases, while Π_2 decreases. Because of the near-linearity of the profit functions, this profit reduction for firm 2 is approximately proportional to the gain for firm 1. It is more pronounced the stronger competition is, i.e., the higher the competition parameter a. This shows that the payoffs we used can qualitatively also be deduced from a microeconomic model. The big advantage of our approach lies in the much simpler mathematical expressions.

The players' beliefs

In our discussion of the payoff matrix (Table 1) we implicitly assumed that both players know in which sub-matrix they are, i.e., if the other player is an innovator or not. This is not always the case: the innovation may be used only in-house, and the innovator (user 1, say) may make additional efforts to keep it secret. Hence, the decision to reveal an innovation or not has to be taken under uncertainty regarding the opponent's situation. Each user has thus to form beliefs about what this situation is, and his choice of strategy in general depends on these beliefs. Speaking in terms of the payoff matrix, user 1 has to form beliefs as to whether the payoffs in columns 1 and 2 are relevant (i.e., user 2 is no innovator), or those in columns 3-5 (user 2 is innovator). User 1 will assign probabilities to each possibility, calculate the expected payoffs, and choose his strategy accordingly. The same holds vice versa for the beliefs of user 2.

Why is our simplifying assumption that user 1 knows if his opponent is an innovator or not reasonable? First, even though an innovator may try to keep his invention secret, industry insiders usually have a good feeling of who is likely to come up with an innovation (e.g., Mansfield 1985). Second, as long as the other user does not reveal, the differences between him being innovator or not do not influence user 1's payoffs very much (compare columns 1 to 3 and 2 to 4). Only in the case that user 2 is an innovator and reveals (column 5), things change. But those innovations that are made public later on are probably the ones that are less carefully kept secret and most easily guessed by other industry participants. Hence, our simplification seems justified.

Extensive form of the game

The way we have designed the payoff matrix, the players choose their strategies simultaneously. This is obviously a simplification, since an adoption decision can only be taken after someone has revealed an innovation. In order to elucidate the implications of this simplification, and to demonstrate its justification, we shall in the following discuss the full extensive form of the game. Figure 2 shows the decision tree for the first four stages of the extensive game. To keep matters clear, Figure 3 shows stages 2 – 6 only for the (most interesting) sub-tree where both users are innovators.

- Stage 1: "Nature" – i.e., chance – determines who becomes an innovative user.
- Stage 2: If user 1 has become an innovator, he has to decide about revealing or not. It is sensible to assume that he has to take this decision without knowing if his opponent also is an innovator or not. Hence, being an innovator he knows that he is at one of the nodes 2 or 3 (counted from the left), but he does not know at which of those. In game-theoretic language, node 2 and 3 form an "information set". The same is true for nodes 1 and 4. The information sets are denoted by the dotted lines connecting the respective nodes.
- Stage 3: As stage 2, with user 2 instead of user 1 playing. As user 1 in the stage before, user 2 does not know if his opponent is an innovator or not. In addition, he does not know if user 1 has revealed; hence, node 1 to 3 are in the same information set, as well as nodes 4 to 6. This is realistic since, after a user revealed an innovation to the manufacturer, it may take a while until his competitors learn about the revelation. Note that, due to the information sets, user 1 does not really move *before* user 2: since each user has to take his decision without knowing what the opponent does, they effectively play simultaneously.
- Stage 4: When at least one of the users became an innovator and decided to reveal the innovation, then the manufacturer has to decide about incorporating it into the product or not.
- Stage 5: When the manufacturer has incorporated an innovation, then user 1 has to decide about adopting it or not.
- Stage 6: As stage 5, with user 2 instead of user 1 deciding about adoption. As in stages 2/3, information sets (dotted lines) denote that user 2 does not know about user 1's action. While this definition avoids unjustified asymmetry between the players, it is not really necessary: user 2's choice does not depend on user 1's choice the stage before, since the latter only contributes a constant additive term to user 2's payoff.

How do we get from this seemingly complicated decision tree to the simple matrix we used in our model?

First, the manufacturer's action can be excluded from explicit consideration because it can be easily deduced from the users' actions: according to our assumptions, the manufacturer incorporates the innovation(s) if and only if both users adopt the improved product. That is, the nodes depicted by unfilled circles in Figure 3 will not be reached (*we assume here that the manufacturer knows the users' payoffs; worth mentioning?*). Since the (anticipated) decision "no adoption" by at least one user leads to "no incorporation" by the manufacturer, we can, e.g., identify the combination "revelation" (user 1) and "no revelation / no adoption" (user 2) in our matrix with the decision "no incorporation" at node 2 (from the left) in stage 4 of the decision tree. Accordingly, the payoffs are δ-$\alpha\delta$ for both users in the matrix as well as the extensive form game.

Second, the strategy "revelation / no adoption" has been excluded from the matrix because it would lead to the same outcome as "no revelation / no adoption": with at least one user not adopting the improved product, the manufacturer would not build it.

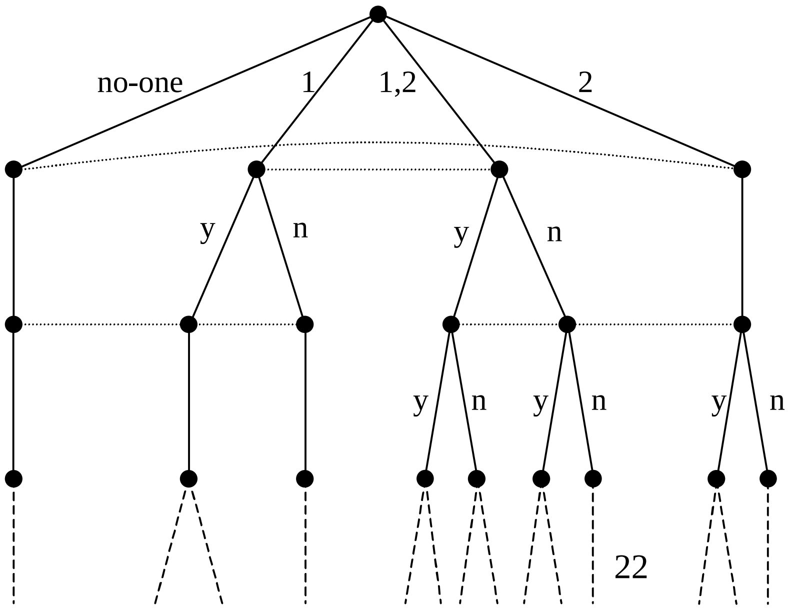
Third, assigning payoffs for user 1, user 2, and the manufacturer to each final node of the decision tree in Figure 3 and solving this extensive form game by backward induction leads to the same result as the analysis of our matrix: both players reveal (and adopt) if $\gamma^M > 1/(1+\mu)$.

Fourth, the detailed analysis we did for the sub-tree where both users are innovators can be done along similar lines for the other sub-trees. Also for them, our matrix approach turns out to be justified.

Hence, while our simple reduced form matrix representation leaves out some details, it leads to the same outcome as the extensive form game. The great merit of the matrix approach is its much higher simplicity.

Figure 2

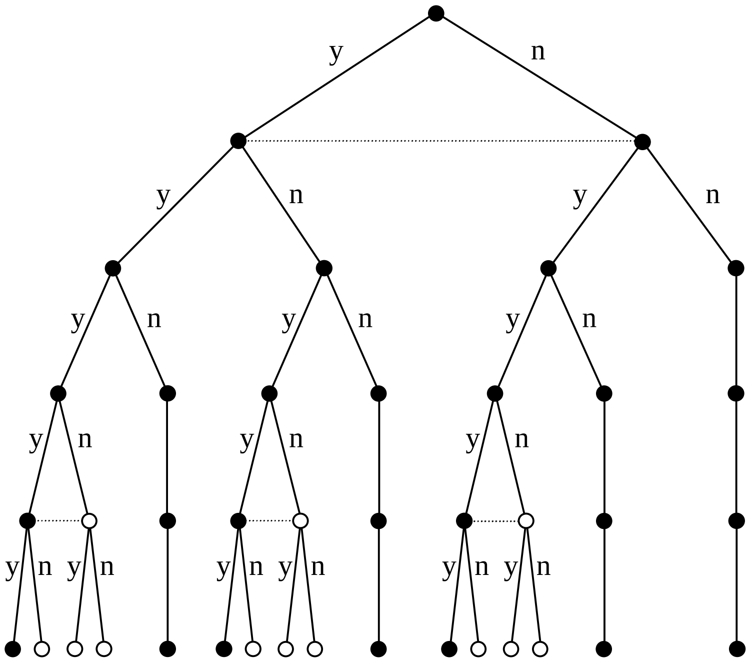
Extensive form game, stages 1-4



Stage	Player	Decision
1	Nature:	Who is innovator?
2	User 1:	Reveal?
3	User 2:	Reveal?
4	Manufacturer:	Incorporate?

Figure 3

Extensive form game, stages 2-6 (only sub-tree where both users are innovators)



Stage	Player	Decision
2	User 1:	Reveal?
3	User 2:	Reveal?
4	Manufacturer:	Incorporate?
5	User 1:	Adopt?
6	User 2:	Adopt?

References

Allen, Robert C. (1983) "Collective Invention." *Journal of Economic Behavior and Organization* 4, no.1(March):1-24.

Arora, Ashish, Andrea Fosfuri, Alfonso Gambardella (2000) “Licensing in the Chemical Industry” Unpublished working paper, first version April 1998, this version September, 2000. (Carnegie Mellon University, Pittsburgh PA)

Cohen, W. M. und D. A. Levinthal (1990). „The Implications of Spillovers for R&D Investment and Welfare: A New Perspective,” *Administrative Science Quarterly*. Vol. 35, pp. 128-152.

Cohen, W. M. und D. Levinthal. (1989). „Innovation and Learning: The Two Faces of R&D,“ *Economic Journal*, Vol. 99, pp. 569-596.

de Fraja, G. (1993). “Strategic spillovers in patent races,” *International Journal of Industrial Organization*, Vol. 11, pp. 139-146.

Ekeh, P. P. (1974). *Social Exchange Theory: The Two Traditions*. Cambridge, MA, Harvard University Press.

Enos, John Lawrence (1962). *Petroleum Progress and Profits: A History of Process Innovation*. Cambridge Mass.: MIT Press, 1962.

Freeman, C. (1968) "Chemical Process Plant: Innovation and the World Market." *National Institute Economic Review*, Vol. 45 (August 1968), p. 2957.

Griliches, Z. (1994). "The Search for R&D Spillovers," *Scandinavian Journal of Economics*, Vol 94 (Supplement), pp. 29-47.

Harhoff, D. (1996). „Strategic Spillovers and Incentives for Research and Development,“ *Management Science*, Vol. 42, No. 6, pp. 907-925.

Harhoff, D. (2000). „R&D Spillovers, Technological Proximity, and Productivity Growth - Evidence from German Panel Data,“ *Schmalenbach Business Review* (forthcoming).

Knight, Kenneth E. (1963) "A Study of Technological Innovation: The Evolution of Digital Computers." Unpublished Ph.D. dissertation, Carnegie Institute of Technology, Pittsburgh, PA.

Lakhani, Karim and Eric von Hippel (2000), "Emerging economics of virtual communities: “Free” user-to-user assistance in open source software," MIT Sloan School of Management Working paper # 4117 (May)

Levin, R. C., A. Klevorick, R. R. Nelson und S. G. Winter (1987). „Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity*, No. 3 (1987), pp. 783-820.

Levi-Strauss, Claude (1949); English translation 1969, *The Elementary Structures of Kinship*, Boston, Beacon Press.

Lilien, Gary, Pam Morrison and Eric von Hippel (2000), "Performance of lead user concept generation methods relative to traditional ones: An empirical study," MIT Sloan School of Management Working Paper #--

Lim, Kwanghui (2000), "The Many Faces of Absorbtive Capacity: Spillovers of Copper Interconnect Technology for Semiconductor Chips," MIT Sloan School of Management Working paper # 4110

Lüthje, Christian (2000), "Characteristics of innovating users," Technical University of Hamburg-Harburg Working Paper #---

Mansfield, E. (1985). "How Rapidly Does New Industrial Technology Leak Out?," *Journal of Industrial Economics*. Vol. 34, pp. 217-223.

Merton, Robert K. (1973) *The Sociology of Science: Theoretical and Empirical Investigations*. Edited by Norman W. Storer. Chicago:University of Chicago Press.

Mishina, K. (1989). Essays on Technological Evolution. Unpublished Ph.D. Thesis. Havard University.

Morin, R. (1993). "The meaning of freeware" *Unix Review*, Vol. 11 (12), pp. 101-102.

Morrison, Pam, John Roberts and Eric von Hippel (1999), "Determinants of User Innovation and Innovation Sharing in a Local Market ," MIT Sloan School of Management Working paper # 4080, (August), *Management Science*, forthcoming

Nelson, R. and S. Winter (1982) Nelson, Richard R., and Sidney G. Winter. An Evolutionary Theory of Economic Change. Cambridge, Mass.: Harvard University Press.

Ogawa, Susumu (1998?), „Does sticky information affect the locus of innovation? Evidence from the Japanese convenience-store industry" *Research Policy* Vol. 26, pp. 777-790.

Raymond, Eric S. (1999), *The Cathedral & the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*, (Cambridge: O'Reilly)

Schrader, Stephan (1991) "Informal technology transfer between firms: Cooperation through information trading" *Research Policy*, Vol. 20, pp. 153-170.

Shah, Sonali (2000), „Sources and Patterns of Innovation in a Consumer Products Field: Innovations in Sporting Equipment,“ MIT Sloan School of Management Working paper # 4105 (March).

Shaw, Brian (1985) "The Role of the Interaction between the User and the Manufacturer in Medical Equipment Innovation." *R&D Management*, Vol. 15, no.4 (October), pp. 283-92.

Taylor, C. T. and Z. A. Silberston (1973*) The Economic Impact of the Patent System: A Study of the British Patent System* Cambridge, Cambridge University Press.

Tirole, J. (1989). *The Theory of Industrial Organization*. Cambridge, Mass.: MIT Press.

Urban, Glen L., and Eric von Hippel (1988), "Lead User Analyses for the Development of New Industrial Products," *Management Science*, Vol. 34, no. 5 (May), pp. 569-82.

von Hippel, Eric and Stan N. Finkelstein (1979), "Analysis of Innovation in Automated Clinical Chemistry Analyzers," *Science & Public Policy*, Vol. 6, no. 1 (February), pp. 24-37.

von Hippel, Eric (1987) "Cooperation Between Rivals: Informal Know-How Trading," Research Policy 16: 291-302.

von Hippel, Eric (1988) *The Sources of Innovation* (New York: Oxford University Press).