Open source projects as horizontal innovation networks - by and for users

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ABSTRACT

Innovation development, production, distribution and consumption networks can be built up horizontally – with actors consisting only of innovation users (more precisely, "user/self-manufacturers"). "Free" and "open source" software projects are examples of such networks, and examples can be found in the case of physical products as well.

User innovation networks can function entirely independently of manufacturers when (1) at least some users have sufficient incentive to innovate, (2) at least some users have an incentive to voluntarily reveal their innovations, and (3) diffusion of innovations by users is low cost and can compete with commercial production and distribution. When only the first two conditions hold, a pattern of user innovation and trial and improvement will occur within user networks, followed by commercial manufacture and distribution of innovations that prove to be of general interest. In this paper we explore the empirical evidence related to each of these matters and conclude that conditions favorable to user innovation networks are often present in the economy.

Keywords: *innovation networks, user innovation, open source software.*

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1.0 Introduction

Innovation development, production, distribution and consumption networks that are distributed horizontally across many software users exist in the field of "free" and "open source" software projects, [1] and in many other fields as well. These horizontal user innovation networks have a great advantage over the manufacturer-centric innovation development systems that have been the mainstay of commerce for hundreds of years: they enable each using entity, whether an individual or a corporation, to develop exactly what it wants rather than being restricted to available marketplace choices or relying on a specific manufacturer to act as its (often very imperfect) agent. Moreover, individual users do not have to develop everything they need on their own: they can benefit from innovations developed by others and freely shared within and beyond the user network.

In the "functional" sources of innovation lexicon, economic actors are defined in terms of the way in which they expect to derive benefit from a given innovation. Thus, if they are firms or individuals that expect to profit from an innovation by in-house use they are innovation "users." Innovation "manufacturers," in contrast, are firms or individuals that expect to profit from an innovation by selling it in the marketplace (von Hippel 1988). By user "network" we mean user nodes interconnected by information transfer links which

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[1] "Free" or "open source" software means that a user possessing a copy has the legal right to use it, to study the software's source code, to modify the software, and to distribute modified or unmodified versions to others. A software author uses his or her own copyright to guarantee these rights to all users by affixing any of a number of standard licensing notices, such as "Copyleft," to the code. Well-known examples of free or open source software are the GNU/Linux computer operating system, Perl programming language, and Internet e-mail engine SendMail (Raymond 1999).
The practice of granting extensive rights to users via licensing began with the free software movement started by Richard Stallman in the early 1980s. Stallman founded the Free Software Foundation (FSF) to counter the trend towards proprietary development of software packages and release of software without accompanying source code. The open source movement was started in 1998 by a number of prominent computer "hackers" such as Bruce Perens and Eric Raymond. This group had some political differences with the free software movement, but agreed in general with the licensing practices it had pioneered, and also had new ideas as to how to spread these practices more broadly.
Many thousands of free and open source software projects exist today and the number is growing rapidly. A repository of open source projects, Sourceforge.net, lists in excess of 40,000 projects and more than 400,000 registered users. Implementing new projects is becoming progressively easier as effective project design becomes better understood and prepackaged infrastructural support for such projects, such as is provided by SourceForge, becomes available on the Web.

may involve face-to-face, electronic or any other form of communication. User networks can exist within the boundaries of a membership group but need not. User innovation networks also may, but need not, incorporate the qualities of user "communities" for participants, where these are defined as "…networks of interpersonal ties that provide sociability, support, information, a sense of belonging, and social identity." (Wellman 2002 p. 4).

It is our contention that complete fully-functional innovation networks can be built up horizontally – with actors consisting only of innovation users (more precisely, "user/self-manufacturers"). Users participating in the network design and build innovative products for their own use – and also freely reveal their designs to others. Those others then replicate and improve the innovation that has been revealed and freely reveal their improvements in turn – or they may simply replicate the product that has been revealed and adopt it for their own, in-house use.

Non-users also may contribute to what we are calling user innovation networks. For example, in the case of open source software innovation networks, manufacturers of complementary goods and purveyors of complementary services can be motivated to contribute, if and as the innovations they freely reveal enhance profits from what they sell (E.g., manufacturers of proprietary computer hardware can have an incentive to create and contribute novel open source software that will improve the link between a popular open source software program and their proprietary hardware.) (Harhoff et al 2002). Also, computer programmers that have no use for the software they are developing may contribute, driven by enjoyment of the work itself, reputation effects, etc. (Lerner and Tirole, 2002). It is only our contention that such non-users are not essential, and that horizontal, distributed innovation networks containing user participants only can be fully functional.

Specifically, we propose that user-only innovation development, production, distribution and consumption networks can flourish when (1) at least some users have sufficient incentive to innovate, (2) at least some users have an incentive to voluntarily reveal their innovations, and (3) diffusion of innovations by users is low cost and can compete with commercial production and distribution. When only the first two conditions hold, we propose that a pattern of user innovation and trial will occur within user networks, followed by commercial manufacture and distribution of innovations that prove to be of general interest. In this paper we will explore these matters and will attempt to show that conditions favorable to user innovation networks often do exist in the real world economy.

1.1 Examples of user innovation networks

User innovation networks have existed long before and extend far beyond open source software. Such communities can be found developing physical products as well. Consider and compare the following two examples of early stage user innovation networks, the first in software, the second in sports. Note especially their "user-only" nature with respect to both innovation development and innovation diffusion.

> **Apache Server Software**
> Apache open source software is used on web server computers that host web pages and provide content requested by Internet browsers. Such computers are the backbone of the Internet-based World Wide Web infrastructure.
>
> The server software that evolved into Apache was developed by University of Illinois undergraduate Rob McCool for, and while working at, the National Center for Supercomputing Applications (NCSA). The source code as developed and periodically modified by McCool was posted on the web so that users at other sites could download, use, and modify and further develop it.
>
> When McCool departed NCSA in mid-1994, a small group of web masters who had adopted his server software for their own sites decided to take on the task of continued development. A core group of eight users gathered all documentation and bug fixes and issued a consolidated patch. This *patchy* web server software evolved over time into Apache. Extensive user feedback and modification yielded Apache 1.0, released on December 1, 1995.
>
> In the space of four years and after many modifications and improvements contributed by many users, Apache has become the most popular web server software on the Internet, garnering many industry awards for excellence. Despite strong competition from commercial software developers such as Microsoft and Netscape, it is currently in use by some 60% of the millions of web sites worldwide.
>
> **High performance windsurfing**
> High-performance windsurfing involves acrobatics such as mid-air jumps and turns. Previously, the sport tended to focus on traditional sailing techniques, using windsurfing boards essentially as small, agile sailboats.
>
> The fundamentals of high-performance windsurfing were developed in 1978 in Hawaii by a group of leading edge windsurfers. In an interview conducted by Shah (2000), high-performance windsurfing pioneer Larry Stanley describes the development of a major innovation in technique and equipment:

> "In 1978 Jurgen Honscheid came over from West Germany for the first Hawaiian World Cup and discovered jumping, which was new to him, although Mike Horgan and I were jumping in 1974 and 1975. There was a new enthusiasm for jumping and we were all trying to outdo each other by jumping higher and higher. The problem was that . . . the riders flew off in mid-air because there was no way to keep the board with you – and as a result you hurt your feet, your legs, and the board.
>
> Then I remembered the "Chip," a small experimental board we had built with foot straps , and thought "it's dumb not to use this for jumping." That's when I first started jumping with foot straps and discovering controlled flight. I could go so much faster than I ever thought and when you hit a wave it was like a motorcycle rider hitting a ramp; you just flew into the air. All of a sudden not only could you fly into the air, but you could land the thing and not only that, but you could change direction in the air!
>
> The whole sport of high performance windsurfing really started from that. As soon as I did it, there were about 10 of us who sailed all the time together and within one or two days there were various boards out there that had foot straps of various kinds on them and we were all going fast and jumping waves and stuff. It just kind of snowballed from there." (ibid p. 14-15)

By 1998 more than a million people were engaged in windsurfing and a large fraction of the boards sold incorporated the user-developed innovations for the high-performance sport.

Both of these user innovation networks have evolved and become more complex over time. Today, although they look different on the surface, they are in fact very similar in fundamental ways. Both now include many thousands of volunteer participants. Participants in open source software projects interact primarily via the Internet using specialized websites that volunteer users have set up for their use. Participants in sports innovation networks tend to interact by physically traveling to favorite sports sites and to contests designed for their sport. Most users of open source software simply "use the code," relying on interested volunteers to write new code, debug others' code, answer requests for help posted on Internet help sites, and help coordinate the project. Similarly, most participants in an evolving sport simply "play the game," relying on those so inclined to develop new techniques and equipment, try out and improve innovations developed by others, voluntarily provide coaching, and help coordinate network activities such as leagues and contests. Participants that do innovate tend to freely reveal their innovations to all participants, including free riders.

Often, commercial enterprises attach to or assume complementary roles to user innovation networks. Red Hat and VA Software are well-known examples of commercial involvement in the open source software context; professional sports leagues and commercial producers of sports equipment are examples in the case of sports.

In the remainder of this paper we will explore the phenomenon of and the economics of "user-only" innovation networks by first reviewing what is known about innovation by users (section 2). Next, we will explore what is known about the free revealing of innovations by users (section 3) and about the low-cost diffusion of user-developed innovations to other users and to manufacturers as well (section 4). Finally, we discuss some implications of horizontal, distributed innovation networks "by and for users themselves" (section 5).

2.0 Innovation by users

Innovation manufacturers rather than innovation users have traditionally been considered the most logical locus of innovation for products and services, because private financial incentives to innovate seem to be higher for them than for individual or corporate users. After all, a manufacturer has the opportunity to sell what it develops to an entire marketplace of users while spreading development costs over a large number if units sold. A user-innovator, on the other hand, can typically expect to benefit financially only from its own internal use of its innovation. Benefiting from diffusion of an innovation to other users in a marketplace has been traditionally assumed to require some form of intellectual property protection followed by licensing. Both matters are costly to attempt, with very uncertain outcomes.

Despite this traditional expectation, empirical studies of the sources of innovation in both industrial and consumer goods fields have shown that in many but not all of the fields studied, users rather than manufacturers are typically the initial developers of what later become commercially significant new products and processes (table 1).

Table 1: Empirical studies of functional sources of commercially-important Innovations

Study	Nature of Innovations and Sample Selection Criteria	Innovative Product Developed by: [a] N	User	Mfr.	Other
Knight (1963)	Computer innovations 1944-1962:				
	- systems reaching new performance high	143	25%	75%	
	- systems with radical structural innovations	18	33%	67%	
Enos (1962)	Major petroleum processing innovations	7	43%	14%	43%[b]
Freeman (1968)	Chemical processes and process equipment available for license, 1967	810	70%	30%	
Berger (1975)	All engineering polymers developed in U.S. after 1955 with > 10^6 lbs. Produced in 1975	6	0%	100%	
Boyden (1976)	Chemical additives for plastics - all plasticizers and UV stabilizers developed post World War 2 for use with 4 major polymers	16	0%	100%	
Lionetta (1977)	All pultrusion processing machinery innovations first introduced commercially 1940-1976 which offered users a major increment in functional utility[C]	13	85%	15%	
Shah (2000)	All important innovations in snowboarding, windsurfing and skateboarding equipment				
	- first of type (e.g., first skateboard)	3	100%	0%	0%
	- major improvements	45	58%[d]	27%	15%
von Hippel (1976)	Scientific instrument innovations:				
	- first of type (e.g., first NMR)	4	100%	0%	
	- major functional improvements	44	82%	18%	
	- minor functional improvements	63	70%	30%	
von Hippel (1977)	Semiconductor and electronic subassembly manufacturing equipment:				
	- first of type used in commercial production	7	100%	0%	
	- major functional improvements	22	63%	21%	16% [e]
	- minor functional improvements	20	59%	29%	12% [e]
VanderWerf (1982)	Wirestripping and connector attachment Equipment	20	11%	33%	56% [f]

See footnote 2 for table 1 notes[2]

[2] [a] NA data excluded from percentage computations.
[b]Attributed to independent b inventors/invention development companies.
[c] Figures shown are based on reanalysis of Lionetta's (1977) data.
[d] Includes innovations by users and by "user/manufacturers" that made a small number of copies for others to support their pursuit of their sport (called "lifestyle" firms by Shah).
[e]Attributed to joint user-manufacturer innovation projects.

In the specific case of open source software projects, software users also appear to be frequent – probably the most frequent – contributors of software code. Thus, Niedner et al (2000) report that contributors of code to open source projects asked to agree or disagree with statements regarding their possible motivations for this ranked gain from "facilitating my work due to better software" as the highest-ranked benefit (average level of respondent agreement with that statement was 4.7 on a scale of 5). Similarly, 59% of contributors to OS projects sampled by Lakhani and Wolf (2002) report that use of the output they create is one of the three most important incentives inducing them to innovate.

Table 2: Proportion of users innovating in diverse product categories

Innovation Area	**No. Users Sampled**	**% Developing and building innovation for own use**	**Were the innovating users "lead users"?**
Industrial Products			
Printed Circuit CAD Software (a)	136 user firm attendees at PC-CAD conference	24.3%	Yes
Pipe Hanger Hardware (b)	74 Pipe hanger installation firms	36%	NA
Library Information Systems (c)	102 Australian Libraries using computerized library information systems	26%	Yes
Apache OS server software security features (d)	131 Apache users	19.1%	Yes
Consumer Products			
Outdoor Consumer Products (e)	153 outdoor specialty mail order catalog recipients	9.8%	Yes
"Extreme" sporting equipment (f)	197 expert users	37.8%	Yes
Mountain biking equipment (g)	291 expert users	19.2%	Yes

Sources of Data: (a) Urban and von Hippel (1988); (b) Herstatt and von Hippel (1992); (c) Morrison, Roberts and von Hippel (2000); (d) Franke and von Hippel (2002); (e) Luthje (2000); (f) Franke and Shah (2002); (g) Luthje, Herstatt and von Hippel (2002).

[f] Attributed to connector suppliers. "Suppliers" are an additional "functional" locus of innovation not discussed in the text. Suppliers expect to profit from an innovation from increased sales of an *unchanged* innovation-related input or complementary asset associated with the production or use of that innovation. As an example of a supplier-developed innovation, consider development of an improved oil lamp by an oil company that neither wants to use or sell that innovative product. Instead, it expects to profit from increased sales of oil resulting from the production and use of the innovative lamp by others.

Studies that have examined the frequency of innovation among user populations have found that user innovation is not a rare event: from 10% to over 30% of user respondents report developing a new product for personal or in-house use in fields studied to date (table 2).

Finally, as can be seen in table 2, empirical studies find that innovation by users tends to be concentrated among "lead users" of those products and processes. Lead users are defined as users of a given product or service type that combine two characteristics: (1) lead users expect attractive innovation-related benefits from a solution to their needs and so are motivated to innovate, and (2) lead users experience needs that will become general in a marketplace, but experience them months or years earlier than the majority of the target market (von Hippel 1986). Note that lead users are not the same as early adopters of an innovation. They are typically ahead of the entire adoption curve in that they experience needs before *any* responsive commercial products exist – and therefore often develop their own solutions.

2.1 Economics of innovation by users

We have now seen that users do often innovate. Presumably therefore, some users, at least some of the time, must expect innovation to be profitable. Research on innovation-related incentives and capabilities provides a theoretical basis for the empirical observations regarding innovation by users in general and by lead users in particular. With respect to innovation by users rather than manufacturers, it has been shown that in some product categories users may reasonably expect a higher reward from innovating than can manufacturers. For example, if a user firm develops a new process machine for in-house use that will enable it to be first to market with a major new product line, it may make more profit from that machine than would a manufacturer-innovator (von Hippel 1988).

Second, user innovation costs can be significantly lower than manufacturer innovation costs when the problem-solving work of innovation developers requires access to "sticky"[3] – costly to transfer - information regarding user needs and the context of use.

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[3] The stickiness of a given unit of information in a given instance is defined as the incremental expenditure required to transfer that unit of information to a specified locus in a form useable by a given information seeker. When this cost is low, information stickiness is low; when it is high, stickiness is high. A number of researchers have both argued and shown that information required by technical problem-solvers is indeed often costly to transfer for a range of reasons (von Hippel 1994). The requirement to transfer information from its point of origin to a specified problem-solving site will not affect the locus of problem-solving activity when that

Such information is located predominantly at user sites and can be most cheaply accessed by problem-solvers located at those sites (von Hippel 1994). Ogawa (1997) has shown that the location of sticky information drawn upon by problem-solvers can significantly affect the locus of innovation. Riggs and von Hippel (1994) have shown that "functionally novel" innovations (which logically are those likely to draw upon a greater proportion of sticky user information) are significantly more likely to be developed by users rather than by manufacturers.

The impact of these two factors on the locus of innovation also allows us to understand and predict that user innovation will *not* be present or frequent in product categories such as engineering plastics (c.f. table 1). Engineering plastics are typically a lower-cost substitute for other engineering materials – a user is seldom prevented from implementing a desired innovation for lack of a novel engineering plastic. Also, sticky information regarding user needs is not an issue with respect to the development of new engineering plastics: manufacturer-innovators know they will obtain success in the marketplace if they can achieve improvements along dimensions of merit known to be valued by users such as cost or strength of materials.

The concentration of innovation activity among lead users within the user population can also be understood from an economic perspective. Given that innovation is an economically motivated activity (Schmookler 1966, Mansfield 1968), those users expecting significantly higher economic or personal benefit from developing an innovation – one of the two characteristics of lead users – have a higher incentive to and so are more likely to innovate. Also, given that lead users experience needs in advance of the bulk of a target market, the nature, risks, and eventual size of that target market are often not clear to manufacturers. This lack of clarity can reduce manufacturers' incentives to innovate, and increase the likelihood that lead users will be the first to develop their own innovative solutions for needs that later prove to represent mainstream market demand.

In the specific instance of open source software, software users can profit by using the software improvements that they develop. In contrast, there is no commercial market for open source software – because open source software developers make their innovations freely available as a public good. This eliminates manufacturers' direct path to appropriating

information can be shifted at no or little cost. However, when it is costly to transfer from one site to another in useable form - is, in our terms sticky - the distribution of problem solving activities can be significantly affected.

returns from private investment in developing open source products, and so often eliminates their incentive to innovate in this arena. (Recall, however that manufacturers may find indirect paths to profiting from open source software projects and so may contribute to them. For example, IBM may profit from developing improvements to the open source program GNU/Linux, if these improvements enhance Linux's functioning with a complementary good, such as proprietary computer software or hardware, that IBM does sell.)

3.0 Free revealing of innovations by users

We next turn to exploring users' options with respect to reaping profits from their innovations. Users in principle have a choice among three such options: they may license their innovation to others (and/or "license to themselves" and manufacture their innovation for the market); they may keep it secret and profit from in-house use; or they may choose to "freely reveal" it.

When we say that an innovator freely reveals proprietary information, we mean that all existing and potential intellectual property rights to that information are voluntarily given up by that innovator and all interested parties are given access to it – the information becomes a public good. Thus, free revealing of information by a possessor is defined as the granting of access to all interested agents without imposition of any direct payment. For example, placement of non-patented information in a publicly-accessible site such as a journal or public website would be free revealing under this definition (Harhoff et al, 2000).[4]

Empirical studies show innovating users often choose to freely reveal details of their innovations to other users and to manufacturers as well. Von Hippel and Finkelstein (1979)

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[4] "Free revealing" as so defined does not mean that recipients necessarily acquire and utilize the revealed information at no cost to themselves. Recipients may, for example, have to pay for a journal subscription or an Internet connection or a field trip to acquire the information being freely revealed. Also, some may have to obtain complementary information or other assets in order to fully understand that information or put it to use. However, if the information possessor does not profit from any such expenditures made by information adopters, the information itself is still freely revealed, according to our definition. Conversely, note that innovators may sometimes choose to subsidize the acquisition and evaluation and use of their freely-revealed information by others. For example, a firm may invest in extensive and expensive lobbying to get others to adopt an technical standard it has developed. Similarly, writers of computer code that they freely reveal may work very hard to document their code in a way that is very easy for potential adopters to understand. Such subsidization efforts do not affect the status of the information itself as being freely revealed according to our definition.

found this practice among users of clinical chemistry analyzer equipment produced by the Technicon Corporation; Allen (1983) found furnace design information openly revealed by iron producers in the 19th century iron-making industry, Lim (2000) reports that IBM freely revealed information on its "copper interconnect" semiconductor process and equipment innovations to equipment manufacturing firms and thereby to competing users; Morrison et al (2000) found improvements to library information software freely revealed by libraries; Franke and Shah (2002) found user-developed innovations being freely revealed within communities of sports enthusiasts. And, of course, contributors to open source projects are also known to freely reveal the novel software code they have developed at private expense to fellow innovators and to free riders on equal terms (e.g., Raymond 1999, Lerner and Tirole 2000).

Free revealing can be the dominant way innovations are diffused in some fields and under some conditions. Thus, Franke and Shah (2002) studied patterns of user innovation sharing in four communities of serious sports enthusiasts. Innovators in these communities quite universally agreed with the statement that they shared their innovation with their entire community free of charge – and strongly disagreed with the statement that they sold their innovations ($p<0.001$, t-test for dependent samples) (Table 3).

Table 3: User-developed sports innovations are freely shared within user innovators' sporting communities

Variable [a]	High Agreement
I share my innovation free of charge within the community	66.7%
I have sold my innovation to many inside the community	0.0%

[a] 7-point rating scale: 1 = very accurate; 7 = not accurate at all); n = 40

Source: Franke and Shah (2002) table 13. The four sporting communities Franke and Shah studied were devoted to the recreational practice of their sports at a relatively high level of skill. Each community was focused on a different sport: sailplaning, canyoning, bordercrossing and cycling by handicapped athletes. One hundred and ninety seven participants responded to a questionnaire, with 37.8% reporting creating new or improved equipment for the practice of their sport (c.f. table 1).

3.1 Economic case for free revealing

To economists, free revealing is surprising, because it violates a central tenant of the economic theory of innovation. In this classical view, appropriating returns to innovation requires innovators to keep the knowledge underlying an innovation secret or to protect it by patents or other means. After all, non-compensated spillovers of innovation-related information should represent a loss that innovators would seek to avoid if at all possible, even at some cost. Why then do we observe that some innovation-related information is voluntarily freely revealed?

In this section, we summarize available empirical studies and conclude that this question should be turned on its head: Why did we ever think that free revealing would not be common? First, extant studies show that innovators can often obtain private benefits from free revealing. Second, research shows that it is often not practical to benefit from intellectual property via either licensing or secrecy – even if innovators should wish to do this. When benefits from free revealing exceed the benefits that are *practically* obtainable from licensing or secrecy, then free revealing should be the preferred course of action for a profit-seeking firm.

Sources of benefit from free revealing

Benefits that an innovator may derive from freely revealing an innovation have been explored by Harhoff et al. (2000). A brief overview of the research on this topic, abstracted from Harhoff et al., begins with Allen (1983). Allen described a phenomenon he called "collective invention" that he observed in archival records related to improvements in energy efficiency in the nineteenth-century English iron industry. He observed that at least some innovators in that field publicly revealed data on their furnace designs and performance in meetings of professional societies and in published material. He proposed that such behavior could be economically justified by profit-seeking firms on several grounds: (1) gains in reputation for the firm or firm managers are sufficient to offset a reduction in firm operating profits caused by free revealing; (2) so many people knew the information that it could not have been kept secret in any case; (3) the innovation is to some extent specific to the innovator and so free riders would not gain advantage equal to that of the innovator; (4) gains in the value of assets complementary to the use or production of the innovation exceed losses associated with free revealing; (5) free revealing may increase the innovator's profit by enlarging the overall market for the product under consideration.

Mishina (1989) studied free revealing in the lithographic equipment industry. He showed that equipment using firms may sometimes gain from revealing their innovation to equipment manufacturers even if doing so entails a loss of comparative advantage. This loss may be more than offset by additional production cost reductions provided by the manufacturer's version of the new equipment. (For example, 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.)

Harhoff et al (2000) propose an additional class of incentives for free revealing related to the increased diffusion of freely revealed innovations. When an innovating user freely reveals an innovation, the direct result is to increase the diffusion of that innovation relative to what it would be if the innovation were either licensed at a fee or held secret. The innovating user may then benefit from the increase in diffusion via a number of effects. Among these are network effects, reputational gains, and related innovations induced among and revealed by other users. In addition, an innovation that is freely revealed and adopted by others can become an informal standard that may preempt the development and/or commercialization of other versions of the innovation. If, as was suggested by Allen, the innovation that is revealed is designed in a way that is especially appropriate to conditions unique to the innovator, this can result in creating a permanent source of advantage for that innovator. Note that being first to reveal a given type of innovation increases a user's chances of having *its* innovation widely adopted, other things being equal. This may induce innovators to race to reveal first.

Incentives to freely reveal innovations have also been explored in the specific context of open source software by Raymond (1999), Lerner and Tirole (2002) and others. Incentives proposed include the likelihood that free revealing of quality code can increase a programmer's reputation among peers and also among potential employers – thus increasing his or her value on the job market. Firms may also benefit from a reputation of being an employer of contributors to open source software projects. (To the extent that the incentives of employer and employee differ on this matter, there will be agency issues.) It has also been found that the cost disadvantage as perceived by innovators relative to free riders is likely to be low. Those who contribute code to open source projects report that they benefit from the work of coding itself in terms of both enjoyment and learning (Lakhani and Wolf 2002). These process benefits remain private even when the output of the process – the software code itself – is freely revealed (von Hippel and von Krogh 2001). Finally, a number of writers have proposed that communal norms, including altruism, may play a strong role in inducing free revealing in the field of open source field. For example, programmers may feel incented by "generalized reciprocity" (Ekeh 1974) to reveal their code because they have benefited from the code freely revealed by others.

Losses to innovators from free revealing come from the opportunity cost of not licensing or selling their software plus any advantage this action provides to competitors that free-ride on the innovation. With respect to the latter, the stronger the competition between the user-innovator and other users of the innovation, the larger will be the loss of competitive advantage that the innovator incurs by revealing. Conversely, when competition between innovation 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 others.

The effect of competition on willingness to free reveal has recently been documented by Franke and Shah (2002) in their study of four communities of sports enthusiasts mentioned previously. They report that 2 of the 4 communities studied were less competitive, having more an emphasis on joint experience and enjoyment; two were more competitive, having more a focus on relative performance and contests. One hundred and ninety seven participants responded to a questionnaire, with 37.8% reporting creating new or improved equipment for their sport (c.f. table 1). They found that a statement regarding free revealing of innovations ("I shared the innovation free of charge within the community" was significantly less agreed with by innovating members of the more rivalrous communities than by innovators within the less rivalrous communities ($n = 40$, $p < .001$). They also found that assistance provided by one community member to another during the innovation development process was significantly less within the more competitive communities ($n = 191$, $p < .01$).

Free revealing in the *absence* of competition has been explored by Morrison et al (2000). These authors studied innovation sharing by Australian libraries that had made innovative modifications to their computerized library information systems (OPACs). The libraries studied were not competitors in the marketplace: all were non-profit organizations and, although their budgets were probably partially determined by the number of patrons they attracted, they served markets that were non-overlapping with respect to geographic coverage and/or subject matter. Morrison et al found that users had shared 56% (22 of the 39) of the OPAC modifications they had developed with manufacturers and/or or users. Forty four percent had not been shared.

The relationship of three variables to user innovation sharing were explored. The first involved the cost of transferring information on user-developed OPAC modifications. These are likely to be relatively minor in any case – at most involving providing a copy of user-developed software code plus some informal consulting by staff from the innovating library. However, it was reasoned that pre-existing membership in a manufacturer-sponsored users' group should lower this cost still further – user-members would have a convenient forum in which to announce and describe their innovations to fellow users and to the manufacturer of their system. The second factor explored was the possibility that innovating users would be more likely to undertake the effort to inform other users and/or manufacturers of an innovation they had developed if they thought that those others would find it of value. The third factor had to do with the commercial value that manufacturers saw in each innovation. Manufacturer incentives to encourage the sharing of that information by users with their own engineers should logically be higher for innovations perceived as having commercial high value. (The second and third variables are not independent.)

Table 3: Logit Model of Innovation Sharing

	Coefficient	Standard Error
User belongs to OPAC user group	2.443	1.148
Manufacturer's evaluation of the commercial value of user's modifications	0.032	0.018
User's perception its needs are unique	-0.572	0.304
Constant	-0.780	1.283

$\chi^2_3 = 11.03$ □□ = 0.28 Classification rate = 78.57%

Source: Morrison et al (2000), table 7

A logit model of the innovation sharing decision incorporating these three variables shows all to be statistically significant. Further, the model showed a very strong discriminating ability. It forecast that 10 users would not share their innovations who did not, that 12 users who did share their innovations would. It predicted only 4 cases of sharing where it did not occur and 2 cases of not sharing where it did occur. Thus, the overall classification accuracy was 79%.

General impracticality of licensing and trade secrecy

If innovators wish to license their intellectual property rather than freely reveal it, they must first gain some form of legal protection for that property. In most subject matters, the relevant form of legal protection is the patent grant, generally the "utility" patent (design and plant patents also exist).[5]

Are patents an effective form of protection for innovators? The available empirical literature suggests, first, that innovators do not generally obtain much income from the licensing of patents and, second, that in most fields firm executives do not think that patents offer a very effective form of protection for intellectual property. With respect to the first point, Taylor and Silberston (1973) examined the impact of British and foreign patents in a very rich study of 44 British and multinational firms selected from five broad "classes" of industrial activity. They found that these firms gained relatively little from licensing, when benefits were computed as licensing fees and/or other considerations received minus patenting and licensing costs incurred by the innovating firm. Wilson (1975) studied data on royalty payments submitted by some U.S. corporations to the U.S. Securities and Exchange Commission in 1971 on Form 10K. He too, found corporate returns from licensing to be generally low.

The low returns from the licensing of patented knowledge found by Taylor and Silberston and by Wilson could in principle be caused either by weakness in protection afforded by patents or by a patent licensor or licensee disinclination to license. Other research suggests that the correct interpretation is that protection afforded by the patent system is itself generally weak, and that innovators in most fields probably could not expect to benefit from licensing their patented knowledge even if they chose to do so. A study by Scherer (1959) found only eight of thirty seven respondents ("executives responsible for technical change") reporting that patents were `very important' to their companies (Scherer 1959, 117). This result is especially interesting because Scherer selected his sample only

[5] In the United States, utility patents may be granted for inventions related to composition of matter and/or a method and/or a use. They may not be granted for "ideas per se, mathematical formulas, laws of nature, and anything repugnant to morals and public policy." Within subject matters potentially protectable by patent, protection will be granted only when the intellectual property claimed meets additional criteria of usefulness, novelty and nonobviousness to those skilled in the relevant art.
Trade secrecy law is an alternate form of protection applicable to innovations that can be kept secret. Trade secrets can in principle be licensed to others that will maintain the secret status of the information revealed to them under license. However, licensing trade secrets is often impractical. The owner must at least partially reveal the secret to potential buyers so that they may evaluate their potential purchase. This incurs the risk of the secret becoming widely known, thus losing both its status as a trade secret and it's value to a potential

from the firms which presumably value patents most highly - those which hold a large number of them. A similar finding was reported by Taylor and Silberston (1973), who report that 24 of the 32 responding firms said that 5 percent or less of recent R&D expenditures would not have been undertaken if patent protection had not been available (ibid, p. 30). Levin et al (1987) conducted a survey of 650 R&D executives in 130 different industries, and found that all except respondents from the chemical and pharmaceutical industries judged patents to be "relatively ineffective." Similar findings are reported by Mansfield (1968, 1985) and reaffirmed by Cohen et al. (2000).

The relative ineffectiveness of patents as a form of intellectual property protection in most fields is understandable. One important cause is the ease with which patents can be "invented around" in most fields. A second is that costs involved in obtaining patents, typically thousands of dollars, make patent protection economically unjustifiable for "minor" innovations. Yet empirical studies have shown that minor innovations are in fact responsible for much or most technical progress. Thus Hollander (1965), found that about 80% of unit cost reductions in Rayon manufacture were the cumulative result of minor technical changes.[6] Similarly, Knight (1963) studied the sources of improvement in general purpose digital computers during the period 1944 to 1962. He found that: "Many of the most economically valuable improvements in computer technology occur as the sum of numerous common engineering and production innovations." … "These advances occur as the result of equipment designers using their knowledge of electronics technology to produce a multitude of small improvements that together produce significant performance advances." (pp. VII-2 and 3.)

Software is better positioned than most other fields with respect to the feasibility of establishing a level of legal protection that can support the licensing of intellectual property. This is due to the legal status of software as "writings," which can be protected by copyright. Copyright is a low cost and immediate form of legal protection – it is applicable to many forms of original writings and images and "follows the author's pen across the page."

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licensee. In the special case of software innovations (considered a form of "writings") copyright protection is applicable and widely used.

[6] Hollander coded a technical change as "major" "…if its development was considered difficult to accomplish by men skilled in the pertinent arts before the development program." He coded a technical change as "minor" if its development was judged a relatively simple process. "Usually, a minor technical change involved evolutionary alteration in existing techniques whereas a major change involved a significant departure from existing methods." (1965, pp. 195-6)

Licensing of copyrighted software is widely practiced by commercial software firms. When one "buys" a copy of a non-custom software product one is typically actually buying only a license to use that software rather than buying the intellectual property itself. Licensing is also the basis of free and open source software practice. The rights that open source software users enjoy are conveyed to them by the software authors. These authors use their own copyright to grant licenses to users that allow them to use, study, modify and distribute their code (see footnote 1).

The legal protections copyright affords to software writings apply to the specific writings embodying the innovation rather than to the innovation itself. Thus, copyright does not prevent someone from studying the novel functionality encoded in a writing and then creating an original writing to perform the exact same function. The measure of protection copyright affords to software authors is therefore only the number of programmer-hours it would take for a would-be imitator to replicate the now known function in any given programming language. This protection level can be high in the case of very large programs such as Microsoft's Windows operating system. It can be quite low in the case of innovations having novel functionality that is easily understood and encoded in a software program of modest size.

Finally, we note that users may become manufacturers in order to benefit from a general diffusion of their innovation. In this instance they avoid the transaction costs and risks associated with licensing their innovations to independent parties by, in essence, licensing exclusively to themselves. Research on the commercialization of innovations developed by users finds this path seldom traveled in the instance of industrial products and processes (von Hippel 1988, Appendix). In contrast, a study reporting on the commercialization of sporting equipment innovations developed by users finds that users developing innovations with commercial potential did often begin to manufacture and sell products incorporating their innovations as a commercial business (Shah 2000). Starting a successful business is not a trivial undertaking. It is likely to seem a reasonable course of action for user-innovators only when their opportunity cost is low relative to likely profits[7]

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[7] Possibly the rarity with which user-innovators were observed to adopt the role of manufacturer in the case of industrial goods innovations versus sporting goods will prove linked to the level of investment that user-innovators have sunk into the effective performance of their existing user roles – and the continuing opportunities and interest that they see in continuing these. The user-innovators reported on in von Hippel

and where the new start-up can obtain a sustainable competitive advantage in the marketplace.

Consider next the practicality of protecting an innovation as a trade secret. As was the case with patents, much intellectual property does not qualify for protection as a trade secret because it cannot simultaneously be kept secret and exploited for economic gain. All innovators can in principle keep product innovations secret while developing them and before putting them on the market. However, once the product is on the market, the trade secrets it contains can generally be legally discovered by those skilled in relevant arts and so lose their status as trade secrets. User-innovators have the additional possibility of benefiting for an indefinite period from the *process* innovations they develop while keeping them secret behind their factory walls.

However, trade secrets are not likely to remain secrets for long. Mansfield (1985) studied a sample of 100 American firms and found that the period during which intellectual property can be kept secret in fact appears to be quite limited. He reports that "…information concerning development decisions is generally in the hands of rivals within about 12 to 18 months, on the average, and information concerning the detailed nature and operation of a new product or process generally leaks out within about a year."[8]

4.0 Innovation diffusion by users

Our third and final condition for the emergence and successful functioning of user innovation networks was that users must somehow be able to diffuse the innovation-related information that they have freely revealed at a low cost both to themselves and to would-be

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(1988, case history appendix) tended to be accomplished scientists and engineers employed by firms and universities. In contrast, the user-innovators studied by Shah (2000) tended to be young people who were dedicated to a sport (similar to "ski bums") and who did not yet have a paying job.

[8] In addition, a user-innovator may not be the only holder of "its" secret. Note in this regard that Rosenberg (1976) has shown that important innovations often come from outside of the industry of application. When this is so, and when innovations diffuse from one industry to another with a lag, it is likely that competing firms in the originating industry all will know the information and so incur no competitive loss relative to their rivals by revealing it to firms in other industries.
If research shows that an innovator's secret information is also frequently know by others, then all must estimate that the actual likelihood of keeping the information secret depends on the choice made by the possessor with the least to lose (or most to gain) from revealing it. If a holder of the secret judges that other possessors are likely to reveal it if they don't, any preference that they might have to hide their information is rendered moot.

adopters. Our reasoning regarding this condition begins by noting that innovators will only be interested in incurring diffusion costs that can be justified based upon the level of benefits they will receive from diffusing their innovation. Similarly, adopters will only be interested in learning about innovations at a cost justified by their expected innovation-related benefits. We have seen in section 2 that innovation streams that have a large cumulative impact are likely to be made up of relatively small individual innovations (Hollander 1965, Knight 1963). We have also seen in section 3 that benefits to innovators from free-revealing, while higher than benefits they could expect from licensing or secrecy, may well be low. On this basis we speculate that most innovations diffused via a user innovation network are likely to be of relatively low benefit to both diffusers and adopters, and so must be diffused at a low cost if they are to be diffused at all.

Kollock (1999) has used similar reasoning to argue that the advent of the Internet has been a major boon to the development of free and open source software development projects. As he points out, innovators can diffuse information about their innovative software programs – indeed, can diffuse the innovative programs themselves - very cheaply via the Internet. Also, costs can be very low for would-be adopters of open source software programs: they are transmitted in complete and ready-to-use form.

It is important to point out that low cost methods for diffusing innovation-related information exist in many fields that are *not* dependent on the Internet and that long predate it. Consider that those who share an interest may meet for a range of purposes such as conferences and contests. As a result, information diffusion costs in many fields are *episodically* very low, and innovators can store their innovations for occasional batch networking and diffusion at low incremental cost, the cost of coming to such a meeting having already been incurred. In these face-to-face settings, some information transfers are easily effected that would be difficult to transact over the Internet. As an example, consider again the high performance windsurfing innovation interview we quoted from at the start of this article. In that case fellow windsurfing enthusiasts gathered at an Hawaiian beach for a windsurfing contest. While there, they could transfer complex, poorly-encoded information in very low-cost, multimedia manner: "Watch how I do *this*," and "Run your hand along *this* curve I sanded into my surfboard – I think it makes all the difference for doing the type of flip I just showed you! Try it yourself while I watch and comment."

Finally, note that user innovation networks involving the production and diffusion of working copies of innovations – as opposed to information about them - are possible only when self-manufacture and/or distribution of innovative products directly by users can compete with commercial production and distribution. In the case of open source software this is possible because innovations can be "produced" and distributed essentially for free on the web, software being an information rather than a physical product. In the case of the sports innovation example, however, equipment (but not technique) innovations are embodied in physical product that, to achieve general diffusion, must be produced and physically distributed. These activities generally involve significant economies of scale. The result, in the case of the windsurfing example and for physical products generally, is that, while innovation prototyping and field trial and refinement can be carried out by users and within user innovation networks, production and diffusion of the physical products incorporating those innovations will usually be carried out by manufacturing firms.

5.0 Discussion and implications for public policy

We have now seen that conditions favorable to horizontal, user innovation networks may exist in many fields. That is: users do frequently innovate in many fields, and these users appear to often have the incentives to freely reveal and low-cost means for doing so.

Recall that in this paper we have focused on exploring why *users* in particular might innovate and then freely reveal their proprietary information on user innovation networks rather than attempt to hide or license that information. We have adopted this relatively narrow focus because it seems to us to be interesting and important to explore how and why innovation networks run exclusively for and by users function. Such networks offer the interesting prospect of direct user to user innovation processes that can dispense with manufacturers as intermediaries.

The concept of horizontal, user-only innovation networks that we have considered in this paper can be extended to the more general category of user *content* networks. As is the case for user innovation networks, user content networks offer content that users either post as of interest to others and/or questions that users post to the network for a possible answer. Such content networks exist in both user-founded and run and commercial forms. Prominent examples can be found in the medical field in the form of specialized websites where patients and others are free to both post and download information on specific medical conditions. When the service provided by such networks is simply to offer non-proprietary "content" in a more convenient and accessible form rather than to diffuse valuable innovations that have been freely revealed, the arguments for participation by users and others gets considerably simpler. One need consider only the costs and benefits associated with diffusion and not issues related to loss of proprietary intellectual property associated with the free revealing of innovations.

Explorations of the social policy implications of user innovation networks based upon free revealing are just beginning. A paper by Henkel and von Hippel (2003, forthcoming) explores the social welfare consequences of product innovation and product modification by users. Their major finding is that under most conditions, adding product innovation by users to regime in which only manufacturers innovate results in a increase in social welfare.

If innovation by users is significant in amount and quality – as current empirical research suggests it is – and if it is welfare-increasing, then it makes sense to weave awareness of and support for innovation by users into innovation-related public policy. A first step might be to increase awareness of and create a basis for the setting of public policies by collecting better data on the amount and nature and location of innovation by users. Currently, much innovation by users – which may in aggregate turn out to be a very large fraction of total economic investment in innovation – goes uncounted or undercounted. Thus, innovation effort that is volunteered by users, as is the case with many contributions to open-source software, is currently not recorded by governmental statistical offices. This is also the case for much of the innovation by user firms or organizations that is woven into the delivery of products and services by those users. For example, much process innovation by manufacturers occurs on the factory floor as they produce goods and simultaneously learn how to improve their production processes. Similarly, many important innovations developed by surgeons are woven into "learning by doing" as they deliver services to patients.

Next, to the extent that public policy currently subsidizes innovation by manufacturers, public policymakers might wish to conduct a review to insure that such subsidies are "innovation locus neutral." For example, one might explore the reasonableness of allowing a software development firm to deduct product development expenditures from taxes, while a user developing and freely contributing valuable improvements to open source programs used by millions cannot do so.

Finally, governments should be aware of the possible direct and indirect impacts of legislation on innovation by users. To illustrate the possibility of indirect impact, consider that users often construct their innovation by buying existing commercial products and modifying them. Current efforts by manufacturers to build technologies into products that restrict the way their products are used can undercut users' traditional freedom to modify what they purchase. This in turn can raise the costs of innovation development by users (Varian 2002). Governmental legislative initiatives, such as the Digital Millenium Copyright Act in the U.S., can have a similar effect, with negative consequences for social welfare.

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