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Jeroen P.J. de Jong and Eric von Hippel

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Jeroen P.J. de Jong[1,2]

Eric von Hippel[3]

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[1] EIM Business and Policy Research, Zoetermeer, The Netherlands, E-mail: jjo@eim.nl. Tel: +31 79 322 22 68.
[2] Rotterdam School of Management, Erasmus University, Rotterdam, The Netherlands.
[3] MIT Sloan School of Management, Cambridge: Massachusetts, USA, E-mail: evhippel@mit.edu.

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Abstract

A detailed survey of 498 "high tech" SMEs in the Netherlands shows process innovation by user firms to be common practice. Fifty four percent of these relatively small firms reported developing entirely novel process equipment or software for their own use and/or modifying these at significant private expense. Twenty five percent of the user innovations in our sample were transferred to commercializing producer firms. Many transfers were made without any direct compensation, i.e. 48% were simply given away.

Very importantly from the perspective of effective diffusion of user innovations, innovations with higher commercial potential for producers – and with more general appeal for users - are much more likely to be transferred. The pattern we document of frequent innovation by individual user firms at substantial cost, followed in many cases by voluntary, no-charge information spillovers to producers, suggests that "open source economics" may be a general pattern in the economy.

Keywords

User innovation, SME innovation, innovation transfer, innovation diffusion, innovation measurement, open source.

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1. Introduction and overview

Empirical research by innovation scholars has now clearly documented that many of the innovative products we buy from producers are in fact developed, prototyped, tested and improved by "lead users." These individuals and firms often innovate in order to solve their own, ahead-of-market needs. Later, when a commercially-attractive market emerges for these products, producers adopt or learn from products lead users have already developed as an important feedstock to their own product development and commercialization efforts.

While the importance of lead users as a feedstock of product design and use information is now generally understood, little is known about the crucial process by which user-developed innovations are transferred to producers, and about the terms under which such transfers are effected. In this paper, we explore these matters.

Our empirical findings are based upon analyses of a sample of 498 Dutch 'high-tech' small and medium-sized enterprises (SMEs), a sample spanning a broad range of industries. In brief overview, we find that 54% of these high tech SMEs report developing new and/or modifying existing process equipment or software for in-house use within the last 3 years. The average cost incurred by a user firm in our sample to develop its most recent process innovation was €235 000, and the average cost for the most recent process modification was €119 800 – significant amounts for these relatively small firms.

With respect to transfer of the user-developed innovations to producers, our major findings are that 25% of the most recent process innovations users had developed were now being produced by equipment producers or software vendors for commercial sale. The innovations transferred tended to be those of stronger and more general interest to users, and thus of more value to producers as commercial products. Further, a total of 48% percent of these innovations were given to producers by users at no charge.

User-innovators in our sample do not appear to be broadcasting free information regarding their innovations to all and sundry. Indeed, most indicate that they are not in favor of general diffusion of their information at no charge. Instead, many appear to be narrowcasting information about their innovations to equipment producers which whom they have a preexisting relationship. Still, the end result is that their innovation is made available to the entire user population – because their selected producer puts it on the market as a commercial product.

In net, free innovation transfer seems more widespread in the economy than has been heretofore understood. The transfer patterns we observe have some interesting similarities to those usually associated with open source software innovations, and it seems reasonable that similar economic justifications could apply. If so, there are important implications for both innovation research and innovation policymaking.

In the remainder of this paper, we provide a literature review on previous work on the incidence of user innovation and the transfer of user innovations, and on the economics of IP-protected and open innovation transfers (section 2). We then explain our research context and methods for our survey (section 3). We next report on our findings (section 4). The paper ends with a discussion (section 5).

2. Literature Review

In this paper, we report upon empirical work that explores the development and transfer of process innovations by user-innovators. We define user-innovators as firms or individual consumers that benefit from *using* a product or a service they develop. In contrast, producer-innovators are firms or individuals that benefit from *selling* a product or a service they develop. Lead users are a subset of all users. Their primary distinguishing feature is that they are ahead of important market trends, and so experience new emerging needs ahead of the bulk of the market. As a result, lead users often innovate in order to solve their own, ahead-of-market needs – often before producers are even aware of those new needs (von Hippel, 1988; 2005).

In this section, we first briefly review studies exploring user innovation in process equipment. Next, in order to create a platform for our discussion of innovation transfer patterns observed in our survey, we discuss the nature and economics of intellectual property rights, and the economics of “free” innovation transfer. Finally, we review what is currently known about the transfer of user innovations to producers.

2.1 User Innovation

Empirical studies across many fields have found that process equipment users rather than equipment producers are the typical developers of process equipment innovations judged to be most important by equipment users and producers (Enos 1962, Freeman 1968, Lionetta 1977, von Hippel 1977, VanderWerf 1992). Empirical studies across a range of fields and countries also – without exception - document that user development of process equipment is a common activity. *Many* user firms develop and modify process equipment to serve their own, in-house needs. This is shown in both samples consisting of very specific, narrow categories of innovation, and also is shown in broad, multi-industry studies.

Studies of user innovation frequencies affecting narrow categories of process innovation include Urban and von Hippel (1988), who found that 24.3% of a sample of 136 U.S. users of printed circuit design software either modified commercial software or designed their own. Morrison et al. (2000) found that 26% of 102 Australian libraries using OPACs - software-based library search systems – either designed their own systems or modified systems they had purchased. Lüthje (2003) found that 22% of a sample of 261 German surgeons affiliated with university clinics either modified their surgical equipment or devised new equipment. Franke and von Hippel (2003) found that 19% of a sample of 131 technically sophisticated Apache webmasters modified the security features of Apache software to better suit their needs.

Broad, multi-industry studies of the frequency of user development of process innovations show that more than 20% of process user firms develop process innovations and/or modifications for in-house use. A cross-industry study by Statistics Canada surveyed a statistical sample of 4,200 Canadian manufacturing plants. It showed that, for plants using one or more of 26 specific advanced production technologies, 28% had developed their own production equipment related to one or more of these technologies, and 26% had modified commercial equipment implementing these technologies to better serve their needs (Arundel and Sonntag 1999). A similar survey by Statistics Canada in 2007 of 39 advanced production technologies found that 21% had developed and 22% had modified one or more of these technologies (Statistics Canada 2008, Schaan and

Uhrback 2009). De Jong and von Hippel (2008) conducted a cross-industry study of a representative sample of 2,416 SMEs in the Netherlands, and found that 21% of all SMEs develop and/or significantly modify existing equipment or software to satisfy their own process-related needs.

2.2 Economics of intellectual property rights

The economic reasoning which has led governments to grant innovators intellectual property rights is familiar to many. It begins with the assumption that private individuals and firms will invest in innovation only if and as they expect to make attractive profits from doing so. If imitators can get free access to information innovators have spent money to develop, it seems reasonable that innovators' profit expectations will drop: after all, they will then expect to be competing in the marketplace with imitators that have lower costs because they have been able to "free ride" on innovators' investments.

Free riding is likely because information is slippery stuff. For example, it has been shown that industrial secrets generally become known to competitors after only a short while. Thus, Mansfield (1985) studied 100 American firms and found 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." Indeed, research shows, perhaps as a consequence of such pervasive and rapid information spillovers, that social rates of return on innovation are generally higher than private rates of return. This in turn implies that private rates of return should somehow be increased so that society gets "enough" innovation.

There are many ways to increase innovators' private returns from innovation to compensate for the effects of free riding by imitators. For example, governments can and do offer R&D subsidies and tax credits to lower innovators' private costs. Governments also can and do enhance innovators' private returns by granting those who qualify temporary monopolies on their innovation-related knowledge via intellectual property law. Of course, economists and policymakers understand that encouraging innovators by granting even temporary monopoly rights to specific information, usually creates significant economic costs that society must bear. Innovators' routes to increased profits involves restricting access to and/or charging fees for utilizing their protected information. This information would otherwise be free and universally available – because information today is reproducible at a marginal cost close to zero. The result is the creation of what is called a "deadweight loss" to the economy. Patent and copyright owners can charge more than they could if access to the information was free. Additional applications of the information that would pay if only access were free are not undertaken – and this creates further economic loss.

2.3 Economics of free revealing

When we say that an innovator "freely reveals" proprietary information, we mean that the information is opened to others at no cost, and all parties are given equal access to it—the information becomes a public good (Harhoff, Henkel, and von Hippel 2003). Until the economics of free revealing began to be understood and appreciated, the losses associated with intellectual property rights, noted above, had seemed a necessary evil to both academics and policymakers. For this reason, with occasional exceptions such as a well-known study by Machlup (1958), debates about the intellectual property system did not deal much with its fundamental desirability. Instead they were largely restricted to the desirability of various refinements to the system, such as increasing or decreasing patent quality, and decreasing or increasing the length of a copyright grant. An appreciation of the economics of voluntary free revealing has now changed the terms of this debate – because free revealing also encourages innovation via private rewards, but without requiring public grants of temporary legal monopolies to innovators.

Routine and intentional spillovers of innovation-related knowledge developed by profit-seeking firms at private expense was first described by Allen (1983). He reported upon what he called collective invention in historical records from the nineteenth-century English iron industry. In that industry, Allen noted the surprising fact that employees of competing firms routinely publicly revealed information on their innovative furnace design improvements and related performance data in meetings of professional societies and in published material.

After Allen's initial observation, a number of other authors searched for voluntary, intentional knowledge spillovers among profit-seeking firms and frequently found it. Nuvolari (2004) found similar voluntary spillovers in the early history of mine pumping engines. Contemporary voluntary spillovers by users has been documented by von Hippel and Finkelstein (1979) for medical equipment, by Lim (2000) for semiconductor process equipment, by Morrison, Roberts, and von Hippel (2000) for library information systems, and by Franke and Shah (2003) for sporting equipment. Henkel (2003) has documented free revealing among manufacturers in the case of embedded Linux software.

More general interest in the phenomenon was sparked by the emergence of "open source" software development projects into public prominence in the 1990's. Clearly, it seemed to observers, open source software was a phenomenon of major economic importance – and, in the many open source software projects using the popular General Public License (GPL), it was enforced *policy* that project contributors would routinely and systematically freely reveal the software code they had developed at private expense to an information commons (Stallman 1998).

Research into *why* innovators would freely reveal their innovations at no charge then taught how the behavior could be economically rational. Innovators that freely revealed could still profit from their private innovation investments. However, they were not doing so via the traditional route of temporary monopoly profits that intellectual property rights were designed to enable. Routes to private profit via free revealing of innovations include increases in innovators' reputations. These could in turn increase the profits of innovating firms (Allen 1983) or the job prospects or salaries of individual contributors (Lerner and Tirole 2002). Also, innovators granting costless access to their innovations usually increase its diffusion relative to what would occur if they charged fees for access. Increased diffusion, in turn, often increases the value of the innovation to the innovator via what are called network effects. (The classic example: the greater the number of people who adopt telephones, the greater value the telephone has for each owner: after all, there are more people to call.)

It has also been learned by experience that innovators freely revealing their innovations often get valuable feedback and improvement suggestions and designs from adopters (Raymond 1999). Further, adopting manufacturers may be able to produce the innovation and sell it at a price lower than users' in-house production costs (Harhoff et al, 2003). In addition, individual participants in open and collaborative innovation projects such as open source software development projects, say they derive valuable private benefits from the fun and learning they gain from participation (Lakhani and Wolf 2005).

In all of these diverse pathways to profit, the underlying principle is that you give away one thing – your innovation - and profit from a related increase in the value to you of that thing itself, and/or of related 'complements' (Teece 1986). When many users develop and contribute related innovation "options," it has been shown that the private value to each user-innovator participating in the project is enhanced (Baldwin and Clark 2006). The net result of all this research is a new appreciation of how innovators can actually profit by "giving away" innovations they develop at private expense.

2.4 Innovation transfer from users to producers

The transfer of innovations from user-innovators to producers can take several pathways. Licensing or sale of user-developed intellectual property related to processes is often done in chemistry-related fields (Enos 1962, Freeman 1968). Peer to peer transfer with no monetary transaction involved is a frequent pattern in open source software and other information products (Benkler 2006). User-innovators also do sometimes start companies to produce commercially what they initially designed for their own use. Von Hippel (1988) found this pattern to be relatively rare in the scientific instruments fields he studied. Shah (2000) found the pattern to be relatively common among developers of sporting equipment innovations. Shah and Tripsas (2007) found many user-innovators in the field of juvenile products 'accidentally' founded companies to produce their innovations when the products they created for their own use were observed by others and copies asked for.

Gault and von Hippel (2009) explored a sample of 1,219 Canadian manufacturing plants that had all developed new process equipment innovations for their own use, and/or had modified process equipment to better suit their needs. Twenty five percent of these firms knew that one or more innovations they had developed had been adopted by process equipment producers. When asked about the terms under which they transferred innovations to others, 75% of process modifiers and 47% of modifiers included transfers at no fee as a method they used. User-innovators that had transferred their innovations reported that they did so to obtain various kinds of private benefit including: to allow a supplier to build a more suitable final product; to gain feedback and expertise; and, to enhance reputation.

Baldwin et al (2006) have modeled the pathways commonly traversed as user innovations are transformed into commercial products. First, one or more users recognize a new set of design possibilities and begin to innovate. Users then join into communities, motivated by the increased efficiency of collective innovation. Transfer to producers then comes via some users forming small companies to produce user-developed innovations for the community and others. Over time, the nature and size of market demand becomes clearer via the activities of these pioneering users and firms. In cases where the emerging picture suggests significant commercial potential, larger manufacturers may choose to enter and/or user-founded firms may increase in size and significance.

3. Research Context and Methods

3.1 Sample and data collection

The Dutch research institute EIM manages a panel of high-technology SMEs in the Netherlands which it surveys every year. The panel was created to explore the nature of high-tech SMEs' business processes, and to assess the effectiveness of innovation and entrepreneurship policies (EIM, 2006). In the fall of 2007, EIM gave the authors of this paper permission to include several questions about user innovation in this annual survey, and the data and findings we report upon here are derived from responses to these questions.

The panel defines high-tech firms as those who actively engage in R&D, and who develop and/or apply new technologies in their products (Grinstein and Goldman, 2006). They are innovative and process-intensive firms. Following the Dutch definition of SMEs, the panel contains only independent commercial organizations with 1-100 employees. Data were collected with computer assisted telephone interviewing. During a period of four weeks in November and December 2007, surveys were completed with

514 of the 779 panelists (66%). Respondents were all directors or managers with a good overview of their firms' practices, including innovation. It appeared that since the start of the panel (November 2005), 16 respondents had been purchased by larger organizations, or had grown to the point of having more than 100 employees. These respondents were discarded from further analysis. Our data therefore reflect answers by 498 respondents. Since all respondents were participants in a panel that had been surveyed before (EIM, 2006), we were able to enrich our data by including previously-collected data on background variables such as industry classifications.

High tech SMEs, due to their distinguishing features, are mainly found in specific industries. Specifically, 8% were manufacturers of chemicals, rubbers and plastics (NACE codes 23-25); 24% were manufacturers of machinery and equipment (NACE 29-33); 13% were active in other types of manufacturing including food and beverages, metals, textiles and wood products (NACE 15-22, 26-28, 34-37); 6% were technical wholesale traders (NACE 51.8); 19% were in IT and telecom services (NACE 72 and 64.2); 25% in engineering and R&D services (NACE 73 and 74.2); and 5% in other types of services.

With respect to size of firms in our sample, 44% of the respondents had 1-9 employees , 41% had 1049 employees, and 15% had 50-100 employees. In general, high tech SMEs tend to be somewhat bigger firms that regular Dutch SMEs (EIM, 2006). Comparisons of these distributions with the full sample of 779 panel members suggested that non-response bias was not present. Drawing on χ^2-tests we found no significant differences for either industry types ($p = 0.40$) or size classes ($p = 0.58$).

Survey variables and administration details

In the high tech SME survey, we utilized two indicators of the presence or absence of user innovation: (1) had the respondent *developed new* process equipment or software for its own use; (2) had the respondent *modified existing* process equipment or software for its own use. The boundary between user development of new equipment or software and user modification of existing equipment or software is not precise. Previous work has shown that even for new developments, innovating actors adapt and incorporate the components of existing machines and software into their new designs (von Hippel, 1988; 2005). Both ‘development of new’ and ‘modification of existing’, therefore, can best be viewed as zones in a continuum.

Our survey followed an identical procedure with respect to data collection for both user development of new process equipment or software, and user modification of existing equipment or software for own use. In both cases we started with screening questions. First, user innovation development (or modification) was explicitly defined by the interviewer, and respondents were then asked if they had, within the past three years, developed any equipment or software for their own use because there was no market supply. All respondents answering affirmatively were next asked to describe the equipment or software they had developed or modified *most recently*, and to explain why they had done this. Our request to focus on respondents’ most recently-developed innovation had two advantages. First, it implicitly identifies a random sample of research objects of user innovations within firms (Churchill, 1999). Second, because respondents provide details on recent examples that are still in the top of their minds, their answers are likely to be more reliable.

The survey then continued with detailed questions on the innovation identified as most recent, including details regarding the involvement of other parties, firms’ expenditures, application of intellectual property rights (IPRs), whether producers had adopted their innovations, and more. Relevant variables that we used in the analyses presented hereafter are summarized in table 1.

In five cases, we also gathered qualitative data on the particular circumstances of a transfer of a user process innovation to a producer. These cases were collected by asking users in our sample that had transferred their innovations to a producer to identify that producer, and to supply a contact person – so that we could collect information from both sides of the transaction. Of 90 respondents who said they had transferred their innovations, 28 were willing and able to supply this information to our telephone interviewers. We followed up half of these cases chosen at random, and received cooperation from five of the 14 producer contacts who had been identified by the users. (Five out of a group of 14 is a reasonable fraction: recruitment of the original panel of high-tech SMEs by EIM had found only one of three contacts willing to participate in the panel).

Table 1. Data collected for specific, "most recent" user innovations

Category	*Variable*	*Description*	*Values*
Background variables	Type	Type(s) of user innovations developed within the past 3 years	0 (new development); 1 (modification)
	Industry	Industry type	0 (manufacturing); 1 (services)
	Size	Firm size	Number of employees
Networking	Producer assistance	Firm was supported by producers, for example with information, advice or specific contributions	0 (no); 1 (yes)
	User assistance	Firm collaborated with others users, e.g. for information, advice or specific contributions	0 (no); 1 (yes)
	Familiar with other users	Firm knows other users realizing similar innovations	0 (no); 1 (yes)
Expenditures	Time investment	Estimated time invested to develop the innovation (answers given in person-years, -months, -week and/or -days, all recoded in person-days)	Number of person-days
	Direct expenses	Estimated financial expenses, other than wages, to develop the innovation	Amount in €
	Total expenses	Estimated total expenses (including wage costs) to develop the innovation	Amount in €
Transfer	Protection	Firm applied for IPRs to appropriate the innovation	0 (no); 1 (yes)
	Type of protection	If yes, type of IPR	1 (patent) 2 (trade mark) 3 (copyrights) 4 (trade secret)
	Willingness to share	Multiple-item scale of four items ($\alpha = 0.83$): 'Other parties interested in this innovation are welcome to inspect it and imitate it' 'We are willing to share the design of this innovation with others' 'We are willing to actively help others to adopt this innovation' 'We are prepared to share this innovation for free'	1 (definitely not) 2 (probably not) 3 (neutral) 4 (probably yes) 5 (definitely yes)
	Transfer	Firm is aware of any producer firm that adopted the innovation	0 (no); 1 (yes)
	Type of compensation	If yes, firm received … to compensate for transferring the innovation	0 (none/for free) 1 (royalties) 2 (informal/discount)

Sample cleaning

Our survey asked respondents to briefly describe their most recent process new developments or modifications. An example of a description of a new process development: "We developed a precision fertilizer application machine, steered by GPS, for use in our operation to create new types of plants." An example of a description of a modification to an existing process: "We use a specific device to test our products. The supplier's software was adapted because it did not meet our requirements."

One important use for these descriptions was to screen our sample for any cases that did not appear to be innovations at all, or did not appear to be *user* innovations. Thus, the following case was excluded because it did not appear to be an innovation of any sort: "My new stable burned down and I rebuilt it." Also, the following case was excluded because it appeared to be a producer innovation rather than a user innovation:

"We modified a machine we supply, to transport and install tomb-stones in narrow cemetery lanes. Our customers asked for it."

As a result of this screening, 13% of the cases in the sample of new user developments, and 10% of the cases in the sample of user modifications were discarded as not actually fitting our criteria. The remaining sample contained details of 364 reported user innovations.

4. Findings

In this section we first report upon the frequency and nature of process innovation by Dutch high tech SMEs. We then report upon the transfer of many of these innovations to process equipment manufacturers.

4.1 Frequency of user innovation

Our survey found a high incidence of user process innovation among Dutch high-tech SMEs. As can be seen in Table 2, 54% percent of all respondents reported that, within the preceding 3 years, they had newly developed and/ or modified their own process equipment or software to satisfy their in-house needs. Forty one percent reported developing new process equipment or software, and 32% reported modifying existing process equipment or software during this period.

Table 2. Frequency of user process innovation in Dutch high-tech SMEs by industry type and size classes

Type of process innovation	*Total (n=498)*	*Industry type*			*Size class (number of employees)*			
		Manufacturing (n=226)	*Services (n=272)*	F^b	*1-9 (n=218)*	*10-49 (n=205)*	*50-100 (n=75)*	F^a
New development	41%	47%	36%	3.7^	34%	44%	51%	3.4^
modification	32%	39%	26%	5.4^	21%	37%	51%	11.2**
New development or modification[1]	54%	62%	48%	6.3^	43%	60%	71%	8.9**

[1] Respondents reported at least one process new development or modification.

[a] Multivariate F-test controlling for industry type, [b] size class.

** $p < 0.001$, * $p < 0.01$, ^ $p < 0.05$.

As is also shown in table 2, SMEs with more employees were significantly more likely to report process innovations. This is reasonable because more employees is likely to mean more sales – and the greater the amount of processing being done, the greater the return obtainable from any given process innovation (Klepper 1996).

Manufacturing user-innovator firms, controlling for firm size, were significantly more likely to develop process innovations than were service firms. An inspection of innovation descriptions allowed us to discriminate between innovations implemented via software or via hardware in most but not all cases. It appeared to us that manufacturers in our sample developed or modified hardware-related innovations about 90% of the time. In contrast, service firms developed about as many software innovations as hardware innovations.

4.2 User innovation processes

In table 3 we provide descriptive statistics related to the development of the 364 user-developed process innovations in our sample under the two headings of expenditures and networking.

Table 3. Innovation process variables by type of user innovation, industry type and size classes

Variable	***Total*** *(n=364)*	*Type of user innovation*			*Industry type*			*Size class (no. of employees)*			
		New development (n=204)	*modification (n=160)*	F^{bc}	*Manufacturing (n=195)*	*Services (n=169)*	F^{ac}	*1-9 (n=121)*	*10-49 (n=167)*	*50-100 (n=76)*	F^{ab}
Expenditures											
Time investment (person-days)	196	282	86	30.9**	181	215	0.7	205	193	191	0.0
Direct expenses (* € 1 000)	51.1	64.4	34.1	5.1^	60.5	40.2	1.8	42.5	45.1	78.1	1.7
Total expenses (* € 1 000)	184.4	235.0	119.8	6.1^	194.6	172.5	0.4	176.8	177.7	211.3	0.3
Networking											
Received producer assistance	41%	42%	40%	0.2	42%	41%	0.0	36%	40%	51%	2.4
Received user assistance	24%	29%	18%	5.2^	15%	35%	17.7**	32%	22%	16%	1.8
Familiar with other users developing similar innovations	39%	46%	30%	7.0*	28%	52%	17.8**	47%	36%	34%	0.6

[a] Multivariate F-test controlling for type of user innovation, [b] industry type, [c] size class.
** $p < 0.001$, * $p < 0.01$, ^ $p < 0.05$.

Process development expenditures among Dutch high-tech SMEs were far from trivial – especially considering the often modest scale of these enterprises. As can be seen in table 3 under expenditures, high tech SMEs reported spending an average of € 184,400 on their most recent user process innovation. This figure consists of an average time investment of 196 person-days, and an average direct (out-of-pocket) investment of € 51,100.

Significance of difference tests confirm that user development of new process equipment or software are far more expensive than user modifications of existing equipment or software. The average cost incurred for a new development was €235,000, while the average cost for the most recent process modification was €119,800. Direct expenses other than wages (items such as equipment and materials purchased for the innovation project) ranged from 0 to € one million, and estimated total expenses ranged from 1,000 euros to € 2.5 million. With respect to time invested, the number of person-days varied from one (a simple modification in a software program) to 1,826 (five person-years spent on developing a diagnosis instrument for stem cell research).

With respect to networking, 41% of respondents indicated that their innovation efforts had been supported by producers with information, advice or other contributions. Twenty four percent said they had cooperated with other users to develop their innovations. Finally, 39% said they knew of other users developing similar innovations.

As can also be seen in Table 3, when we control for industry and size differences, newly developed user process equipment or software was significantly more likely to be developed with the help of other users than was a process modification (29% versus 18%). Users engaged in new developments were also significantly more likely than process modifiers to be familiar with other users developing similar innovations (46% versus 30%). With regard to type of industry, we found that services firms are more likely to be assisted by other users and to be aware of such users developing similar innovations. Finally, for size classes we found no significant differences on the networking variables reported in table 3.

4.3 Innovation transfer from users to producers

Twenty five percent of the 364 process innovations in our sample were transferred from user-innovators to producer firms for commercial production and sale. An identical fraction of both new user process equipment or software and user modifications were transferred (Table 4). This 25% figure is likely to be conservative with respect to the total number of innovations in our sample transferred by *some* user to a producer. As we saw in table 3, 39% percent of the respondents said they knew of *other* user firms that had developed innovations similar to theirs. It is reasonable that, in some fraction of the

75% of cases where the innovator *in* our sample did not transfer its innovation to a producer, a similar innovation *was* transferred to a producer from an innovating user outside our set of respondents.

Table 4. Innovation transfer-related variables by type of user innovation, industry type and size classes

Variable	***Total*** *(n=364)*	*Type of user innovation*			*Industry type*			*Size class (no. of employees)*			
		New development (n=204)	*modification (n=160)*	F^{bc}	*Manufacturing (n=195)*	*Services (n=169)*	F^{ac}	*1-9 (n=121)*	*10-49 (n=167)*	*50-100 (n=76)*	F^{ab}
Innovation Transfer											
Innovation was transferred to producer	25%	25%	25%	0.0	19%	31%	6.6^	26%	25%	22%	0.2
IP protection obtained	13%	17%	6%	8.5*	9%	16%	3.0	18%	11%	7%	1.3
Willingness to share (scale 1-5)	2.35	2.28	2.43	1.5	2.16	2.59	10.2*	2.37	2.34	2.32	0.0

[a] Multivariate F-test controlling for type of user innovation, [b] industry type, [c] size class.
** $p < 0.001$, * $p < 0.01$, ^ $p < 0.05$.

The transfer of 25% (90) of the innovations in our sample means that we have a 'transfer subsample' too small for the statistical testing we would wish to do. We can, however, report some interesting patterns and tendencies. In 48% of the cases where the innovations were transferred, the innovations were given away without any direct compensation. A further 39% were transferred with only informal promises of some form of direct compensation in the future, such as a promise of price reductions on possible future orders. Only 13% reported compensation via royalty agreements or direct money transfers. In other words, half or more of the innovations transferred to producers were "given away for free."

Only 13% of user-innovators in our sample had acquired any form of intellectual property rights to protect their innovations. Ten percent said their innovations were patented, and a further 2% said they protected their innovations by explicit attempts to maintain it as a trade secret. The remaining 1% reported copyrights or trademarks as the source of protection used. New process equipment or software was protected significantly more often than were process modifications (17% versus 6%). This may be because the former are more likely to contain genuinely new elements which are suitable for patenting. It may also be because user-innovators spend about twice as much on the development of new hardware or software as they do on modifications, and so the incentive to protect may be higher.

There was some relationship between IP protection obtained and the likelihood of receiving financial compensation for a transfer. Due to the small number of respondents, however, these differences were not statistically significant. In our dataset, 14 respondents reported transferring an innovation that they had protected by some form of IPR. Seventy one percent of these reported receiving some kind of compensation – either a royalty agreement (21 percent) or informal promises of compensation (50 percent) from the producer. In contrast, only 47% of 74 respondents that had transferred their innovations without IPR protection had received any compensation. More specifically, 11% received royalties and 36% received informal promises of compensation.

The fact that half of innovations transferred were transferred at no fee to a specific producer does not mean that user-innovators were willing to give their innovations away to anyone or everyone for free. We tested this idea by asking respondents whether they would be willing to give access to *all* interested parties without direct payment or other compensation. Being a latent construct, willingness to share was measured with a multiple-item scale of four items described in Table 1. The items have good reliability ($\alpha = 0.83$). The mean score of the four-item scale was 2.35 – somewhere between "probably not" and neutral on the question of free sharing.

4.4 Generally-useful and valuable innovations are preferentially transferred

The previous section laid out evidence that at least 25% of user-developed innovations are transferred to producers for general sale. In this section we consider whether the innovations transferred to producers tend to be the more generally useful ones, and the ones that provide more value to user-innovators. In overview, we do find a strong association between these factors and likelihood of transfer. When variables associated with the likely general utility and value of an innovation are at a low level, transfer probabilities are lower than 20%. When all these variables are at relatively high levels, transfer probabilities exceed 70%.

We explored this matter via a range of binary logistic regression models. The dummy variable of user innovation transfer to producers was the dependent variable. As independent variables, we entered items from our survey that we thought had a reasonable relationship to the general utility and value of an innovation. With respect to general utility, we reasoned that innovations for which a user-innovator receives help from a producer are likely to be more generally valuable. Producers, we thought, might well prefer to help develop innovations they think likely to have general marketplace appeal. Second, we reasoned that if respondents had received help from other users in developing an innovation, that was a signal that the innovation was of interest to multiple members of the user community. Third, we reasoned that when respondents knew of *other* users that had developed an innovation similar to theirs, that was a sign the innovation had more marketplace potential. With respect to the per-user value of an innovation, we entered time and money spent on the innovations as variables. We reasoned that the more costly a user innovation is to develop, the more profit-enhancing it was likely to be for the innovating user – and possibly for other users as well.

We also tested the dummy variable with respect to the presence or absence of IP protection, and the multiple-item measure for user innovators' general willingness to share. Both variables may be associated with the likelihood of transfer to a producer. In the case of IP protection, innovators may be more likely to invest in protecting attractive innovations. In the case of willingness to share, an expressed general willingness to share may be associated with reduced barriers to transfer. Finally, we entered dummies for the type of innovation (new equipment or software development versus modifications) and industry (manufacturing versus services), as well as an indicator for firm size (number of employees) to control for the potential influence of the background variables on the likeliness of transfer.

Before we estimated our models, the variables for firm size, time investment and direct expenditures were logistically transformed, because descriptive statistics had revealed that these variables violated the assumed normal distribution (absolute values of skewness and/or kurtosis > 2). We also checked if our independent variables suffered from potential multicollinearity. The correlation of total expenditures with the other cost indicators was > 0.80, and so we excluded this variable from our analyses. For the remaining variables, the highest correlation was between log transformed time investment and log transformed direct expenses (r = 0.60), while all other correlations were < 0.40. In such instances, multicollinearity is very unlikely (Hair et al., 1998). All these statistics are not reported here due to space limitations, but available on request.

We first estimated an empty model (intercept only) to obtain baseline values for the transformed loglikelihood value (-2LL) which is used to assess model fit. Other frequently-used indicators to evaluate the results include Wald tests (to test the significance of individual independent variables) and Nagelkerke's R^2 (which is a pseudo R^2-statistic with a theoretical maximum of 1.0, indicating strength of association in the overall model) (Hair et al., 1998). Table 5 shows the results. The first model gives a baseline for the transformed loglikelihood value of 402.6.

Table 5. Binary logistic regression models of transfer to producer firms (n=364)

	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*
Control variables and intercept:										
Intercept	-1.11**	-1.50**	-1.94**	-1.90**	-1.95**	-2.72**	-2.96**	-1.71**	-1.94**	-4.37**
Dummy services industry		.66*	.69**	.47^	.42	.58*	.74*	.67**	.53*	.39
Log firm size		.04	-.01	.14	.06	-.12	-.13	.13	.03	-.56
Dummy user modification		.02	.03	.15	.19	.29	.51	.09	-.08	.49
Independent variables:										
Producer assistance			1.02**							.64^
User assistance				1.08**						.37
Familiar with other users					1.10**					.90*
Log time investment						.76**				.29
Log direct expenses							.77**			.40
Protection								.37		-.06
Willingness to share									.22*	.28^
Fit measures:										
Nagelkerke R-squared		.028	.094	.087	.099	.094	.099	.035	.045	.230
-2LL	402.6	395.7	379.2	381.0	378.2	380.7	383.0	394.7	390.7	369.2
Δ-2LL		6.9	16.5	14.7	17.5	15.0	12.7	1.0	5.0	26.5
Δdf		3	1	1	1	1	1	1	1	7
significance		^	**	**	**	**	**		*	**

** $p < 0.001$, * $p < 0.01$, ^$p < 0.05$.

Model II added our control variables to the equation: a dummy for services industries, log transformed firm size and a dummy for user process modifications. This significantly diminished the transformed loglikelihood value (Δ -2LL = 6.9 with Δdf = 3, $p < 0.05$), implying that when taken together, the independents are linearly related to the log odds of the transfer of user innovations to producer firms. Wald tests on the individual parameters showed that in services industries, users are more likely to see their innovations transferred to producers. For firm size and type of user innovation, no significant effect parameters were found.

Models III-IX test our presuppositions that the likelihood of transfer is associated with indicators for utility and value of the innovations. For example, model III tests if user innovations are more likely to be transferred to producer firms when users were assisted by producers. Adding this indicator to the equation significantly improves model fit ($-2LL = 16.5$ with $\Delta df = 1$, $p < 0.001$) while Nagelkerke's $R^2 = 0.094$. As the effect parameter is very significant too ($b = 1.02$, $p < 0.001$), producer assistance increases the odds of seeing user innovations being transferred to producers. More specifically, in case of producer assistance it is $\exp(1.02) = 2.8$ times more likely that user innovations will be transferred.

For the other indicators shown in table 5, we see that the relationship with transfer is significant as well, so it is confirmed that the likelihood of transfer is associated with the general utility and value of the innovations. One exception was, however, that adding a parameter for IP protection to the equation did not improve model fit. It may be that two opposite tendencies are canceling each other out in this case. Some users may utilize IPR protections because they do not want to see their innovations transferred. Others may protect innovations because they do want to transfer them, and think intellectual property protection will increase the likelihood that they will receive financial compensation.

Model X gives a more robust test of the influence of all independent variables. After entering all independent variables together, we find that producer assistance, being familiar with other users and willingness to share are significant, and apparently the most important correlates of transfer.

We also evaluated the odds of transfer for low and high values of the independent variables in model X. When evaluated at low values (dummy variables at zero, and continuous variables at one standard deviation below their mean scores), the share of transferred user innovations were estimated for various combinations of the control variables. At low values of the independent variables, the estimated share of transferred user innovations was in the range of 6% to 18%. When evaluated at high values, we found that the estimated share of transferred innovations was always in the range of 71% to 89%. These findings clearly illustrate that indicators of general utility and value (and likely commercial attractiveness from a producer's point of view) are strongly correlated with the likelihood of user innovation transfer.

4.5 Innovation transfer case histories

Five brief case histories of user-innovation development followed by transfers to producers will give the reader a richer flavor for the particulars of this kind of activity.

Case 1: Improvement to vegetable processing machine

- User A is a developer and producer of specialty foods for allergic patients. User A reported that it had modified an existing commercial vegetable-processing machine by developing a new input chamber for it. The input chamber for the machine can be visualized is a very large metal box with a hole in bottom. Raw vegetables to be processed are put into the top of the input chamber. They then flow from the bottom of the chamber into the processing machinery as needed. User A regularly processed carrots, and found that his producer-designed input chamber was shaped in such a way that the carrots, rather than aligning in a single orientation, ended up in a jumble - pressing against each other in a way that caused many to break. This created a great deal of waste. User A designed and built a new hexagonal input chamber that caused the carrots to align better and so greatly reduced breakage. Design and construction of the new input chamber took 25 person-days and € 15 000 out-of-pocket costs.

- Supplier A, is a machine manufacturer for the food industry with close ties to User A. Supplier A had produced the machine that User A had modified, and was allowed to copy the user innovation for free. Supplier A then generalized the user-invented idea of different hopper shapes for different vegetables into a new line of add-on feed hoppers to its processing machines, to better adapt to the specific shapes of the wide range of input materials processed by its customers. At the time of our phone call, the manufacturer had invested about € 20 000 in making the user-developed input chamber suitable for production, and about € 100 000 in further development of the full line of input chambers inspired by the user innovation.

Case 2: Novel CAD/CAM software for architectural application

- User B is a engineering firm specializing in complex architectural restoration projects such as major church restorations. To accomplish this work, it uses 3D measurement instruments to precisely measure architectural elements that must be replicated such as deteriorated elements of statues. The output from the measurement instruments must then be converted into the digital files needed to drive the computerized machines that precisely create replacement parts. User B developed a new software tool to automatically perform this task. The software tool was programmed by three employees in an estimated 120 person-days. To integrate the application with current CAD/CAM software, User B also recruited external programmers (at the expense of € 75 000) from Supplier B, a producer of CAD/CAM software.

- Supplier B adopted the user-developed tool and sells it as a software product. Additional development expenses by supplier B prior to putting it on the market were estimated by the supplier to be 20 person-days – 20% of the user's development effort. User A is compensated for its innovation by Supplier B according to the terms of an informal royalty agreement.

Case 3: Improved sugar melting machine

- User C is a manufacturer of bakery products for the health sector (hospitals, outpatient care centers). Its new head of production, a former machine constructor, was dissatisfied with the commercial sugar melting machine used in User C's production line. Melted sugar would often recrystalize in the pipes transferring the melted sugar to the bakery mixing machines, causing pipe blockages and expensive production downtime. The head of production ordered a new melting machine from Supplier C and improved it by installing new blades, increased mechanical power, and smooth coatings in some key pipe parts. He spent an estimated € 200 000 on wage costs and deliveries of new parts.

- The innovation was adopted by supplier C, a wholesale trader in machines and equipment and, as noted above the supplier that had delivered the new sugar melting machine to User C. Supplier C did not conduct any follow-up research or development activities, but rather benefited by replicating User C's modifications in sugar melting machines delivered to other customers.

Case 4: Improved horticultural robot

- User D is a horticulture enterprise specialized in improving orchids. Its director was dissatisfied with his internal transport system in which a robot transports trays of orchids within the firm's greenhouses. By modifying the robot's arms its accuracy was significantly improved, which enabled a higher density of plants per square meter. The modification took an estimated 60 person-days and additional expenses of € 2 000.

- Supplier D is an engineering firm specializing in greenhouse construction, and in equipment used in greenhouses. Supplier D had supplied the robot transport machine that User D modified. Supplier D was allowed to copy the improved robot arm for free, and adopted it for production 'without much additional investment'. The new robot arm is now part of all internal transport systems which Supplier D delivers to greenhouse customers.

Case 5: Modification of a food filling machine

- User E is a food and nutrition firm of Turkish origin, developing and producing new yogurts, cheeses and beverages. After the foods are produced, they must be packaged. The innovation relates to the modification of a package filling machine used to pump yogurts into containers. In User firm E, an engineer modified the filling head of the machine, and improved the cover closing process so that air was more effectively excluded from the product. This reduced product spoilage. The innovation was realized in 20 days and out-of-pocket expenses of € 15 000.

- Supplier E, a producer of food and agricultural machinery, met the owner/manager from User firm E at a trade conference. He was allowed to inspect the modification and to copy it. There was no explicit compensation, except a promise that User E would be generously treated in case of future orders from supplier E. Supplier E adopted the improved cover closing mechanisms for some of its own machines, spending about € 10 000 on additional development activities.

Table 6. Estimated user and producer development expenditures and forms of compensation in five cases

Case	*User development expenses*	*Producer development expenses*	*Compensation*
A	€ 21 250	€ 20 000	None
B	€ 105 000	€ 5 000	Informal royalty agreement (no written contract)
C	€ 200 000	€ 0	None
D	€ 17 000	minimal	None
E	€ 20 000	€ 10 000	Promise of price reductions on future orders

[a] In some cases, costs were reported to us in days of engineering time plus direct expenditures. To arrive at the total expenditures shown in such cases, we converted engineering days into Euros by using the average wage of a Dutch process engineer with 15 years of tenure in 2008 of € 250 / day. (This figure excludes overhead, and so is conservative.) (See www.intermediair.nl/salariskompas)

In table 6 we summarize cost and compensation details of the five cases. Statistical inferences are of course not possible with such a small sample, but three interesting patterns can be seen. First, note that, with the exception of case A, all users invested significantly more to develop their innovations than did the adopting producers. Second, in these cases SME user-innovators did not market their innovations systematically – they simply agreed to a transfer request made by a producer who had learned of their innovation via a preexisting supply relationship with the innovating user.

Finally, notice that, in line with the findings in our total survey sample, the producers adopting user innovations for commercial sale did not financially compensate the user-innovators in 3 of 5 cases, and in the remaining 2 cases compensation was informally agreed upon.

5. Discussion

In our sample of 498 Dutch, high tech, SME firms, we found that 54% of these firms newly develop or modify the process equipment or software they use in-house at significant private expense. Recall from our literature review that this fraction of user innovators is significantly higher than that reported in previous studies. We suggest two factors that may be causative. First, ours is the first study including only high tech SMEs. Recall that 'high tech' SMEs are defined in the Netherlands as firms of between 1 and 100 employees that actively engage in R&D, and develop and/or apply new technologies in their products. Such high-tech SMEs are only 3-4% of the total population of Netherlands SMEs, and they engage in more innovation than the average SME (EIM, 2006). Second, in this survey we ask about *any* type of process innovation, while most earlier studies inquired about whether firms had innovated in much narrower process categories. Presumably, the broader the range of allowable innovations, the higher will be the rate of innovation reported.

We also found that 25% of the user process developments and modifications asked about in our survey were transferred to process equipment and software producers. As was described in our literature review, Gault and von Hippel (2009) found similar patterns with respect to user innovation and transfer. The general agreement found between these two studies offers a very important reliability check. It also shows that the phenomenon we document here is likely to be quite general. Our study examined high-tech SMEs with from 1 to 100 employees across a range of industries. The sample for the Gault and von Hippel (2009) study was drawn from a population of 16,590 Canadian manufacturing establishments that met the criteria of having at least $250,000 in revenues, and at least 20 employees.

In our study, we found indications that the user process innovations most likely to be transferred are those of most value to the innovating user – as indicated by the high expenditures made to develop them - and also of more general interest to the user community. We suggest that these are very important findings. Consider that, when users develop a process innovation, general diffusion is not a given: users, unlike manufacturers, can benefit from a process innovation without diffusing or selling it, via their own in-house use. If user innovations of high value to adopters and of utility to many adopters *are* diffused, user innovation becomes a much more socially-efficient process: each interested user need not invest resources to (re)develop a similar innovation for itself. One would assume that innovations of higher value and more general utility are the ones likely to offer the most potential licensing returns to user-innovators should they elect to follow this route – yet, as we saw, 48% of the transferred innovations were given away to producers by user-innovators without any compensation. This suggests that user-innovators often anticipate that their private returns from non-compensated transfers will outweigh the private returns they could expect from keeping even their most valuable and generally-useful innovations private and/or selectively licensing them.

Most of our user-innovators were not enthusiastic about "freely revealing" their innovations to all – the pattern described in our literature review. On average, we found that the user-innovators were between neutral and slightly negative with respect to the idea of transferring their innovations to *anyone* at no cost. Yet, as we saw, about half of the transfers to producers were in fact made without any direct compensation. How can we reconcile these two findings? We think that it is likely that user-innovators in our sample are more favorable to the idea of transferring their innovations at no cost to *specific* suppliers with whom they have a preexisting relationship than they are to free revealing to anyone and everyone. This more selective revealing pattern is visible in our 5 case studies. Of course, even selective revealing to a producer gives all users and producers in the marketplace access to the innovation-related information via the route of either inspection and/or purchase of the innovation from that producer.

It is also likely that the "incumbent producer" in a particular case can gain more profit from a particular innovation than can other producers. When a machine or software program modified by a user-innovator was originally produced by the firm to which the modification is transferred, the adopting producer has a significant additional advantage over other producers that might contemplate adopting that same innovation. Since the user modification has been prototyped and tested on his particular design of machine or software, the incumbent producer has less cost and risk in adopting the user innovation: the modification has been engineered by the user to function with that producer's specific design.

When many users develop and freely contribute related innovation "options," it has been shown that the private value to each user-innovator participating in the project is enhanced (Baldwin and Clark 2006). It is therefore very interesting to observe that even users acting without collaborators, and innovating independently rather than as part of a collaborative development project such as an open source software development project, sometimes engage in fee-free transfers. If the added benefit from collaborative work is at least sometimes not needed to induce fee-free revealing, this greatly increases the likelihood that this behavior will be broadly present in many sectors of the economy.

Is fee-free transfer of innovations "a good thing" from the social welfare perspective? It certainly offers a benefit with respect to the particular innovation transferred. As was mentioned earlier, charging a price for something that exceeds the marginal cost of production creates a deadweight loss. Charging anything for information – as all innovators do that report charging a fee for their innovation-related information – inevitably creates a deadweight loss. After all, the marginal cost of production of copies of encoded innovation-related information today is essentially zero.

But social welfare is also affected by the number of innovations created. Does fee-free distribution discourage user innovation relative to the alternative of charging a fee? This assumption is at the core of the case for intellectual property systems. Recall that the justification of granting intellectual property rights is largely to, as the U.S. Constitution puts it, "…promote the Progress of Science and useful Arts…" However, our data does not support this link – at least, not as a general matter. Consider that it is likely that *both* fee free and fee-based transfer options were available to many of the user-innovators developing process innovations in our sample. After all, at least trade secrecy protection is always applicable in the case of process innovations that can be used by user-innovators while hidden behind factory walls. Yet, despite the availability of this and probably other intellectual property mechanisms to support exclusivity and the ability to charge fees for access, about half of the survey respondents choose to transfer their innovations at no fee. Given economic rationality on the part of respondents, this suggests that, some significant fraction of the time, innovators think that free transfer gives them greater private returns than does utilizing the monopoly rights enabled by the intellectual property rights system.

In sum, our research findings indicate that many user firms develop and modify process equipment and software at significant private cost, and that many of the most valuable of these user-developed innovations are transferred to producer firms – often at no fee. In our discussion, we have argued that this pattern of user innovation followed by general diffusion by producers is likely to enhance social welfare. It also clearly will affect innovation management prescriptions and government policymaking as well. We suggest that further research is merited.

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