Welfare implications of user innovation

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Abstract

Innovation by users is now understood to be an important part of innovative activity in the economy. In this paper we explore the implications of adding innovation by users to existing models of social welfare that currently assume innovation by manufacturers only. We find this addition removes several inefficiencies, and that social welfare is likely to be increased by the presence of user innovation. Implications for policies that can impact users' freedom to innovate are discussed.

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1. Introduction

Innovation by users is an important part of overall innovative activity in the economy. Users have been found to be the developers of many commercially important innovations and, in fields studied to date, from 10% to nearly 40% of users have been found to have developed or modified products for their own use (see table 1). However, this source of innovation has received little attention in economics research. Indeed, to paraphrase Solow's famous quip, user innovations appear everywhere but in the economic literature. In particular, evidence regarding the existence and importance of innovation by users has not yet been incorporated in the literature on product diversity, innovation, and social welfare. In this paper, we begin to fill this gap.

The central question addressed by the literature on product diversity, innovation, and social welfare is whether, from a societal perspective, a particular market organization yields too much or too little variety or innovation. Effects that would create both over-provisioning and under-provisioning of variety, such as business stealing and the consumer surplus effect, have been identified. Adding another source of innovation – users – to the welfare analysis of new goods might exacerbate a tendency towards overprovision of new goods. Or, it might result in a crowding-out of innovation incentives for manufacturers, potentially increasing a bias towards underprovision of product diversity. In this paper we analyze the impact on social welfare associated with product developments by users. We do this by comparing user innovators to manufacturer innovators with respect to their incentives to innovate and also their innovation-related knowledge. In addition, we explore free revealing of user innovations and its implications. We present and discuss this phenomenon comprehensively via a broad qualitative analysis. Formal models of specific aspects can flow from this analysis, but are not presented here.

Our analyses show user innovation to have several positive effects on social welfare. First, we find that user innovation *complements* manufacturer innovation in two ways. Manufacturers and users tend to create *different* innovations. Manufacturers tend to develop products that many will want, and where they see a chance to capture a large share of the surplus the innovations will create. In contrast, users tend to develop innovations that only they or a few may want, and that create a high consumer surplus for themselves.

Second, the two sources of innovation complement each other with respect to *knowledge* and *capabilities*. Users tend to develop new functionality which they require. Manufacturers can study these early user innovations to gain information about both emerging market needs and possible solutions that would be difficult to obtain otherwise. They can then advance the users' work by turning it into a robust product, producible at low cost. User innovation thus helps to reduce information asymmetries and increase efficiency of the innovation process. It can enable manufacturers to produce a higher fraction of new products that are marketplace successes.

Third, we find that the inefficiency called "*business stealing*" in the social welfare literature is absent for user innovation. This effect is known to bias the number of new goods towards excessive levels in the case of manufacturer innovation.

Fourth and finally, user innovations tend to be *freely revealed* more often than manufacturer innovations. Free revealing of innovation-related information creates positive welfare effects for users of the innovation as well as for second-generation innovators.

We conclude that an innovation system where user innovation is present is welfare superior to one where it is not. This conclusion has important policy implications. Policies related to intellectual property and innovation such as patent and copyright law as well as tax breaks and subsidies strongly influence users' and manufacturers' relative ability to innovate. There is good reason to assume that the current tendency towards stronger intellectual property protections (e.g., Gallini 2002) has a negative impact on user innovation. In particular, policies that restrict product modification by users, or that allow manufacturers to do this, must be considered very carefully. Benkler (2002) makes a related point by showing the impact of IP policies on the innovative potential of small versus large firms.

In section 2 we review the literature. In section 3 we explore welfare aspects of user innovations. In section 4 we conclude with a discussion of some implications of our findings for both innovators and policymakers.

2. Literature review

In this section we first review the literature on innovation by users (section 2.1). Next, we review the literature on the tendency of users to "freely reveal" their innovations (section 2.2). Finally, we review the literature on the gains and losses in social welfare associated with the introduction of new goods to the marketplace (section 2.3).

2.1. Innovation by users

Innovation by end users of products and processes has been shown to be an important phenomenon within economies. Studies in a range of fields have show that many major and minor innovations are first developed and applied by firms or individuals seeking to use them rather than by firms seeking to profit from their manufacture and sale. Industrial fields in which this question has been systematically explored include oil processing (Enos 1962), the early history of computing (Knight 1963), machine tool innovations (Rosenberg 1976), scientific instrument innovations and semiconductor and electronic subassembly processing equipment (von Hippel 1988). In consumer products, the question has so far been explored with respect to sports equipment only (Shah 2000). It has also been found that a considerable fraction of users – from 10% to nearly 40% – engage in developing or modifying products in fields sampled to date (table 1)[1]. Given the ratio of users to manufacturers in the economy, it is possible that *most* innovative effort and investment may well be attributable to users rather than manufacturers – largely unnoticed and untabulated in present economic data series.

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[1] In some studies shown in table 1, the proportion of users innovating in the general user population will be lower than that reported in the study due to intentionally-introduced sample biases. For example, the study of mountain biking by Lüthje et al. (2002) was intentionally directed towards mountain bikers who were members of biking clubs located in a known "hot spot" for user innovation. Other studies without such biases, however, also report high proportions of users innovating. Thus a study of the *entire* population of Australian libraries found that 26% had made in-house modifications to the computer software of the "OPAC" systems they use for record-keeping and patron information searches (Morrison et al. 2000). On the basis of present data, therefore, it seems safe to conclude that "many" users do engage in product development and modification in many fields.

Table 1: Studies of user innovation

Innovation Area	No. Users Sampled	% developing and building innovation for own use
Industrial products		
Printed Circuit CAD Software (a)	136 user firm attendees at PC-CAD conference	24.3%
Pipe Hanger Hardware (b)	74 Pipe hanger installation firms	36%
Library Information Systems (c)	102 Australian Libraries using computerized library information systems	26%
Apache OS server software security features (d)	131 Apache users	19.1%
Medical Surgery Equipment (e)	261 clinic surgeons	22%
Consumer products		
Outdoor Consumer Products (f)	153 outdoor specialty mail order catalog recipients	9.8%
"Extreme" sporting equipment (g)	197 expert users	37.8%
Mountain biking equipment (h)	291 expert users	19.2%

Sources of Data: (a) Urban and von Hippel (1988); (b) Herstatt and von Hippel (1992); (c) Morrison et al. (2000); (d) Franke and von Hippel (2003); (e) Lüthje (2003); (f) Lüthje (2004); (g) Franke and Shah (2003); (h) Lüthje et al. (2002).

The empirical studies listed in table 1, and other studies as well, consistently find that innovation is concentrated among the "lead users" in a user population. Lead users are members of a user population with two distinguishing characteristics. First, they are at the leading edge of important trends, and so are currently experiencing needs that will later be experienced by many users in that marketplace. Second, they anticipate obtaining relatively high benefits from obtaining a solution to their needs, and so may innovate (von Hippel 1986). The effect size found in these studies tends to be very large. For example, in a study of CAD software used for printed circuit design, Urban and von Hippel (1988) found that 82% of the lead user cluster in their sample had developed their own version of or had modified the specific type of industrial product they employed, while only 1% of the non-lead users had done this.

The concentration of innovation activity among lead users within a user population can be understood from an economic perspective. Given that innovation is an economically motivated activity, users expecting relatively high 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 (Franke and von Hippel 2003).

Finally, we note that the nature of innovations developed by users and manufacturers has been found to systematically differ according to the character of "sticky" information users versus manufacturers tend to possess. Much information used by innovators has been found to be "sticky" or costly to transfer from site to site (von Hippel 1994). Thus it is reasonable that users, generators of need-related information, will tend to be the developers of innovations having novel functionality. Such innovations tend to require access to rich need information. Similarly, it is reasonable that manufacturers will tend to be the source of innovations based heavily upon novel solution information that they generate (Riggs and von Hippel 1994).

2.2. Free revealing of innovation by users

Empirical studies show innovating users often choose to freely reveal details of their innovations to other users and to manufacturers as well. Thus, Allen (1983) found furnace design information openly revealed by iron producers in the 19th century iron-making industry; the practice has been found among users of clinical chemistry analyzer equipment (von Hippel 1988); Lim (2000, p. 41) 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 (2003) found user-developed innovations being freely revealed within communities of sports enthusiasts. Contributors to open source software projects also reveal the "source code" of the software they have developed at private expense and convey rights to use and modify that software to others without charge (e.g., Raymond 1999).

When we say that an innovator freely reveals proprietary information, we mean that all intellectual property rights to that information are voluntarily given up by the 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. 2003).[2]

To economists free revealing is, at first glance, surprising, because it violates a central tenant of the economic theory of innovation. In this classical view, returns to innovation can be appropriated to a larger extent the better the knowledge underlying an innovation is kept secret or protected by 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. Recent work seeks to explain free revealing on the basis of two considerations. First, if a user is to benefit from *non-free* diffusion of an innovation to the other users in a marketplace, some form of intellectual property protection followed by licensing is required. Both have been found to be costly to attempt for user innovators, with very uncertain outcomes (Harhoff et al. 2003). Second, it has been found that some forms of private rewards to innovators survive the act of free revealing – or are even enhanced by it. When benefits from free revealing exceed the benefits that are *practically* obtainable from other courses of action such as licensing, then free revealing should be the preferred course of action for a profit-seeking firm.

Examples of forms of private rewards to innovators that survive or are enhanced by the act of free revealing include the fact that user innovations are developed to precisely suit the private needs of the innovator – and may serve the needs of free riders less well. Also, some forms of rewards may be linked to the development process itself rather than to its result. E.g., the learning and enjoyment that programmers of open source software gain from actually writing the code cannot be shared by free riders who only adopt the completed product (Lakhani and Wolf 2005). Open Source programmers, and other innovators as well, can benefit from free revealing due to a gain in private reputation among peers (Raymond 1999) or on the job market (Lerner and Tirole 2002). Finally, a strong potential benefit of free

[2] "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. 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 lobbying to get others to adopt an technical standard it has developed.

revealing is that adopters of the innovation can improve it, develop it further, and reveal their improvements in turn. Such open and "collective" innovation processes are common in the case of open source software (Raymond 1999), even when most contributors are commercial firms (Henkel 2003). However, they have also been found in iron making and steam engines, i.e., industries that strongly differ from software (Allen 1983, Nuvolari 2004).

2.3. Product diversity, innovation and welfare

The issue of socially optimal product diversity has concerned economists for a long time (Chamberlin 1950). A larger diversity is, other things being equal, assumed to be desirable. This may be so either because each consumer benefits from larger variety in his or her shopping basket, and/or because a larger selection on offer allows, on average, a better match between each user's needs and the respective consumed good. These beneficial effects of diversity are counteracted by the higher cost that a large variety presumably brings with it. Producing many goods in small quantities means scale economies are less fully exploited than when production is focused on larger outputs of fewer goods.[3] Scale economies may be caused by specificities of the production technology and/or by innovative activity required to develop new products. More recently, the conflict between diversity and returns to scale has been somewhat alleviated by the introduction of flexible manufacturing (see, e.g., Röller and Tombak 1990, Eaton and Schmitt 1994). However, while modern manufacturing technologies do shift the optimal degree of diversity upwards, the conflict persists.

The trade-off between diversity and returns to scale forms the basis for several modeling approaches tackling the issue of optimum product variety. Eaton and Lipsey (1989) subsume them under the headings of "address branch" and "non-address branch". Address models follow Hotelling's (1929) approach of describing goods, as well as tastes, as points on a line. Related to this is Lancaster's product characteristics approach (1975). Contributions in this branch of the literature commonly assume that each consumer buys only one good; put differently, goods are not combinable. This means that diversity in these models is valuable because it allows each consumer to, on

[3] When goods exhibit network externalities, and when product diversity implies a certain degree of incompatibility, then the benefits of product variety will also be reduced. Our analysis abstracts from this aspect. The goods we consider either do not exhibit network externalities, or we look at diversity *within* a group of compatible types of network goods.

average, better satisfy his or her taste. In contrast, papers in the non-address branch employ utility functions in which quantities of several goods enter (Dixit and Stiglitz 1977, Spence 1976a, 1976b). The most obvious interpretation is that of a representative consumer who values diversity in her shopping basket. Alternatively, the utility function may be the result of an aggregation of diverse consumer tastes (Anderson et al. 1988, Hart 1985, Perloff and Salop 1985, Sattinger 1984).

The literature cited above explains the higher cost of larger variety by production non-convexities such as indivisibilities of fixed capital or development cost. However, the approach is static in the sense that implications of new product development for subsequent innovations are not considered. These are the subject of a broad literature on growth, innovation, and intellectual property (see, in particular, Aghion and Howitt 1992, Arrow 1962, Bessen and Maskin 2000, Grossman and Helpman 1991, Nordhaus 1969, Oi 1997, Romer 1990, Schmookler 1966). While there are (few) models in this strand of the literature that assume horizontal differentiation between goods (e.g., Grossman and Helpman 1991, pp. 43), vertical differentiation seems more appropriate to the idea of technical progress. If new goods are superior to existing goods to such a degree that the latter become obsolete, then the issue is no longer product variety but rather innovation and technical progress. The principal trade-offs, however, persist (while additional ones appear), as we will discuss below.

The central question of all the research outlined above is whether, from a social welfare perspective, a particular market organization yields too much or too little variety or innovation. Researchers have identified effects that would create both over-provisioning and under-provisioning of variety, the most important of which are business stealing and the consumer surplus effect. When new goods are considered as innovations that following innovators can build upon, intertemporal spillovers and a number of further effects appear. The net result is that the answer to this question is generally unclear.

3. Welfare aspects of user and manufacturer innovation

In this section we assess the impact on social welfare resulting from adding an additional source of product innovations – innovations developed by users – to the manufacturer source of innovations that has been traditionally considered in the literature. In our analysis we will separately consider the impact of this added source of innovations upon each of the several major effects that have been discussed in the literature on product diversity, innovation, and social welfare as inducing either over-provisioning or under-provisioning of product variety or innovation. We will find that the introduction of user innovation eliminates some deleterious effects and ameliorates others.

We will begin by discussing two types of effect, consumer surplus and information asymmetries, where social welfare is affected by attributes that inherently differ between users and manufacturers. Next we will briefly review the impact of three factors with well-known impacts on social welfare: business stealing, monopoly distortions and impacts on second-generation innovators. These are relevant to our present discussion because all are affected by free revealing and, as we have argued, users are more likely to freely reveal the innovations they develop than are manufacturers.

In the analysis that follows, by "innovation" we mean information sufficient to build a novel product. We will use the term to denote both minor variations of existing products as well as radically new ones. We assume that both user and manufacturer innovators are solely motivated by their own utility gains and profits, and neither by gains or losses that their innovation might cause for others. We also abstract from uncertainty by assuming that innovators correctly anticipate the cost and outcome of their activity (or that they know the expected values and are risk-neutral).

3.1 Inefficiencies related to appropriation of innovation rents

Consumer surplus effect

Manufacturing firms generally cannot capture the entire consumer surplus created by new products they introduce to the marketplace. As a consequence, the number of products it pays them to develop is biased downwards to sub-optimal levels. In particular, manufacturers will have a bias against development of products which only allow them to capture a small share of the surplus these goods create. Under some additional assumptions (e.g., with constant elasticity of demand), these are products with relatively inelastic demand (Spence 1976a).

User innovators make a completely different calculation with respect to the desirability of developing innovations – and this has the interesting consequence that user and manufacturer innovations will in general be of a different nature. Consider that an end-user captures none of the consumer surplus that its innovation generates for others, but does capture the full surplus that it generates for itself via in-house use. Thus, a user with a high and very inelastic in-house demand for an innovation will have an incentive to "price discriminate" against itself by investing a high proportion of its anticipated consumer surplus into the development of the innovation it requires. That is, users will tend to develop products having (so far) relatively small marketplace demand – because manufacturer products are not likely to be present there – and for which the user itself has high and inelastic demand (very precise requirements). Manufacturers, in contrast, will tend to prefer to develop products intended for relatively large markets having relatively elastic demand. The consequence is that product innovations developed by users will tend to fill small niches of high need left open by commercial sellers – the two sources of innovation are complementary to each other.

Note that the argument so far does not prove existence of innovations that are profitable for user innovators but not for manufacturer innovators. With full information and equal cost on both sides, and ignoring transaction cost, the locus of innovation should be irrelevant (we will show in section 3.2, though, that these issues do make a difference). However, the argument does prove that typical user innovations are *relatively* less attractive for a manufacturer innovator than other types of innovations. Taking, in addition, information and cost aspects into account it will become clear that users, and not manufacturers, are the likely originators of the type of innovation we focus on.

Hence, the introduction of a user innovation can have an offsetting effect to the tendency of manufacturers, due to the *consumer surplus effect*, to underprovide product diversity to a marketplace. This positive welfare effect is strengthened by the fact that, as was discussed in section 2.1, user needs evolve over time and innovations created by "lead users" for market niches tend to become of interest to the bulk of the market later. Of course, an innovation system with *only* user innovators would just as well lead to an underprovision of variety, however, for different reasons. The point is that incentives for user and manufacturer innovators differ in such a way as to make their innovative activities complementary to each other.

Business stealing

By introducing an additional product to a market, an innovator diverts sales from substitute products already on the market to its own product, thus exerting a negative externality on incumbents. A commercial innovator, selling its product above marginal cost, benefits from this negative externality of "business stealing". Since the diverted gross profit will, at least partly, be used to pay for the development and other fixed cost of the new product, this causes a bias towards excessive product diversity and a related loss in net social welfare (Spence 1976a).

This bias towards socially excessive diversity is absent for user innovations. Consider that a user innovator adding a new product to a marketplace may exert the same negative externality on incumbent manufacturers in a marketplace that was described above – or an even greater one if the user innovation is made available without charge. However, the lost profits of incumbent manufacturers do not benefit a user-innovator (assuming potential sales to the user-innovator itself are negligible). They therefore are not spent by that user on product development costs. Instead, such costs are fully covered by the benefit the user innovator derives from in-house use of the innovation: if not, the user would not find it profitable to innovate in the first place. As a result, the profit loss to incumbents due to the introduction of the user innovation does not imply a loss of social welfare, but rather a redistribution of surplus to users. This conclusion holds independent of whether the user-developed innovations are used only by the user-innovator or are diffused in the marketplace.

Now consider the reverse case: a marketplace with only user-developed products present to which a manufacturer-developed product is added. Depending on the relative quality of the goods and users' tastes, the commercial product may be preferred by some or even all users. However, while there is business stealing in the sense of "units adopted", there is no business stealing in terms of margins and profits, since the user innovations are given away at marginal cost. As a result, there is no negative externality exerted by the manufacturer on the user innovators.[4] The manufacturer will only introduce the additional product if the surplus that it creates is

[4] There may be a negative externality when the user innovator benefits from diffusion of its innovation. However, unlike for a commercial innovator, such diffusion-related benefits will be minor for a user innovator compared to the direct benefits derived from own use. In addition, as we will discuss in section 3.2, there will often be a *positive* externality exerted by a commercial second-generation innovator on the user innovator.

at least as great as the cost of doing this. Hence, if the innovation is profitable, then it is also welfare enhancing. In particular, the increase in variety is not excessive.

3.2 Information asymmetry-related inefficiencies

As was laid out in section 2, user innovators often have "sticky", need-related information that manufacturers lack. On the other hand, manufacturers typically know more about how to turn a prototype into a robust product, and how to manufacture it at low cost. Two implications of these patterns are discussed in this section. First, innovative activity by users can embody sticky user need information in a form that can be easily transferred to manufacturers, enabling manufacturers to become more successful in new product development. Second, user and manufacturer knowledge concerning innovations are to some degree complementary. This implies that users and manufacturers can benefit from each others' innovations rather than compete with each other. This in turn implies a welfare-enhancing (partial) internalization of spill-overs.

Reduction of information asymmetries

It is commonplace knowledge in industry that many – perhaps most – new products developed and introduced to the marketplace by manufacturers fail commercially. Since much development investment is product-specific, this represents a huge inefficiency in the conversion of R&D investment to useful output. It is difficult to put a firm number on the proportion of R&D investment lost in this manner, because there clearly is some recycling of knowledge from failed to successful projects, some projects are deemed failures and stopped before commercial marketplace introduction, etc. However, studies of the matter clearly show the scope of the problem. Thus, Mansfield and Wagner (1975) studied the project portfolios of three industrial development labs and found an overall probability of success for new industrial products to be 27%; Elrod and Kelman (1987) find an overall probability of success of 26% for consumer products. More recent reviews by Balachandra and Friar (1997), Poolton and Barclay (1998), and Redmond (1995) confirm high failure rates in new product commercialization. Clearly, an improvement in these statistics would be socially desirable.

The primary reason for the commercial failure of manufacturer-developed products has been found to be inaccurate understanding of user needs by manufacturer-innovators. Mansfield and Wagner (1975) found that 62% of the technical projects they studied were terminated because of poor commercial prospects rather than technical problems. A major study of product pairs with very similar function – one pair member a marketplace success and one a market failure (Achiledelis et al. 1971, Rothwell et al. 1974) came to the same conclusion: the primary cause of commercial failure was a lack of market and need understanding, not a lack of technical understanding. As Poolton and Barclay (1998) phrase it in their review, "new products failure has been demonstrated to be highly associated with a 'we know best' attitude, especially where technical inventors fail to consult with potential users regarding new innovations."

We propose that the presence of user innovations in a marketplace will reduce this important cause of commercial failure of new products that are developed by manufacturers. Our reasoning is that users (individuals or firms) have better information about their needs than do manufacturers. After all, as was discussed in section 2, users are the *generators* of information regarding their needs, and the quality of this information can only degrade during the process of collecting it and transmitting it to manufacturer-innovators. The degree of degradation is likely to be substantial, because much of this information has been found to be "sticky," costly to transfer from one locus to another (von Hippel 1994, Ogawa 1997).

How will this improvement in user need information for manufacturer product development be effected? As we saw earlier, much innovation by users is carried out by lead users. These lead users encounter needs that later are felt by many in a market – and a significant number of them innovate in order to develop a solution to their needs in advance of the availability of commercial solutions from manufacturers. Innovating users test their solutions in their own use environments, and thereby learn more about the real nature of their needs and appropriate solutions. They also often freely reveal information about their innovations. Other users then either do or do not begin to adopt that innovation and perhaps modify it in turn.

All this user activity gives manufacturers a great deal of useful information. They no longer need to understand user needs very accurately and richly in order to innovate successfully. Instead they have the easier task of replicating the functionality of user prototypes that users have demonstrated to be responsive to their needs. User innovation and adoption activity also gives manufacturers a better understanding of marketplace potential. Projections of product sales have been shown to be much more accurate when they are based on actual behavior – information regarding early adoption and actual value in use – rather than on pre-use expectations by potential buyers. Monitoring of field use of user-built prototypes and their adoption by other users gives manufacturers rich data on precisely these matters and so should improve manufacturer commercial success records. (Certainly it is difficult to imagine a scenario in which this improved information would *reduce* manufacturer success rates.) Hence, innovation-related inefficiencies due to information asymmetries will in general be reduced by user innovations.

Complementarity between user and manufacturer innovations

While users often have an advantage over manufacturers with respect to need information, they will in general lack knowledge of the most efficient technical solutions both with respect to the product itself and with respect to processes to manufacture it. The resulting potential inefficiency is resolved by manufacturers' building upon and improving the user innovation, provided user innovations are revealed to them. When user innovations are revealed, the manufacturer might either develop a complement or modify the user innovation and introduce an improved substitute to the market. Only in the latter case can there be a negative effect on the user innovator. This will be so when the negative effect from competitors' using the manufacturer-improved product – assuming that the manufacturer offers it to the entire market – outweighs the positive effect that the improved product has on the user innovator. It is hard to quantify how often one effect or the other dominates. However, one can make a relative statement: The positive effects of free revealing on the innovator will dominate for user innovations more often than for manufacturer innovations. This has to do with differing roles of second generation innovators in the two cases, the existence of non-financial user innovators, and aspects of competition (see section 3.3 for a detailed discussion).

Hence, we argue that the user innovator often benefits from having a commercial vendor (or follow-on user innovators) modify and improve its innovation. In other words, spill-overs to subsequent innovators will often actually *increase* a user's incentive to innovate, since the positive externality exerted on subsequent innovators is partly internalized. This helps explain why user innovations are often *actively* diffused by their originators (Harhoff et al. 2003). In addition, there will likely be a welfare increase resulting from a cost-reduction in this "staged" innovation process as compared to one where all steps are performed by a manufacturer innovator.

Now consider the reverse case. Suppose that a manufacturer anticipates that users might develop a substitute for *or* a complementary innovation or improvement to a commercial innovation it is considering developing – and that the user's efforts will be aided by information spill-overs from manufacturer to user. If the user exploits spillover information from manufacturer innovators to develop a *substitute* product, the net effect on manufacturer incentives to innovate is likely to be negative. Further, if user innovators freely reveal their developments while competing manufacturers do not, the negative impact on the manufacturer's profits is likely to be larger than if the substitute had been introduced by a competing manufacturer.

On the other hand, if the user exploits the information contained in a manufacturer innovation to develop innovations *that improve or complement* the manufacturer-developed innovation, the effect on a manufacturer's incentive to innovate – and on social welfare – will in general be positive (assuming the improvement comes as an add-on, not as a substitute). Such improvements and complements will increase sales of the manufacturer's innovation and make it more valuable to users. Indeed, there are many examples in which manufacturers consciously employ a strategy to encourage the development of complements by users. Thus, Stata, a software vendor specializing in statistical software, has created a proprietary "platform" product to which users can add new and better statistical tests. Users encode these in a software language proprietary to Stata. This increases the value of and sales of Stata's platform product. Add-ons developed by users that are freely revealed will increase Stata profits more than will equivalent add-ons developed and sold by manufacturers. As a consequence, Stata is more likely to innovate if it anticipates the likelihood of follow-on complementary and improvement innovations by users (Jokisch 2001). Similar strategies are pursued by manufacturers of simulator software who provide tools to their users to develop add-ons (Henkel and Thies 2003, Jeppesen 2002).

In sum, we see that there are both positive and negative effects from intertemporal spillovers of innovation-related information in a world containing both user and manufacturer innovators. Manufacturer incentives to innovate – and social welfare – are likely to be *increased* if manufacturers anticipate that users will develop innovations that they can learn from – and/or develop complements and improvements to innovations that manufacturers develop. In contrast, manufacturer incentives to innovate – and social welfare – are likely to be *decreased* if manufacturers anticipate that users benefit from information-spillovers from a manufacturer innovation in order to develop substitutes that are possibly even freely revealed. In net across the economy, we think that the effects associated with social welfare enhancement will dominate. As was discussed earlier, users-innovators tend to be lead users. Lead users tend to develop innovations that manufacturers have not yet had the "sticky" need information to develop and/or the market size incentive to want to develop. In such cases manufacturers will tend to benefit rather than suffer from spillovers.

3.3 Free revealing-related effects

User innovations are often freely revealed, as was noted and explored in section 2. When user *or* manufacturer-developed innovations are freely revealed, a number of positive welfare effects appear. These are relevant to our discussions here because we think that user innovators are more likely to freely reveal their innovations than manufacturer innovators. We see two reasons for this. First, as was pointed out earlier, "second generation innovation" can be of value to both users and manufacturers. However, user-innovators must reveal *more* information than manufacturers to induce such innovations and channel them in directions they will find profitable. User innovators tend to benefit from having their innovations converted from "home-made" devices into more robust commercial products. If manufacturers are to rebuild user innovations into a more robust form, their inner workings must generally be revealed in detail. In contrast, a manufacturer-innovator typically seeks to benefit from subsequent user innovations in the form of valuable "add-ons" to a platform product (Jokisch 2001). For this purpose a user need only be provided with appropriate interface specifications: complete details of the platform's inner workings need not be revealed. Second, some user innovations but no manufacturer innovations are developed for a non-financial end use. For example, individual end users may develop novel sports equipment simply to enjoy it rather than use it as a competitive tool. When this is so, there is no competition among users that would induce them to protect rather than freely reveal their innovations.

Monopoly distortion

If user innovations are made publicly available for free (become "public" innovations), a potential user only has to bear the cost of adoption. This is statically efficient if, as we assume, the marginal cost of revealing an innovation (i.e., the respective information) is zero. As a consequence, for public user innovations there is no dead-weight loss from above-marginal-cost pricing. A second positive welfare effect of public user innovations is that they might induce sellers of competing commercial offerings to reduce their prices, thus indirectly leading to another reduction in dead-weight loss.[5] Finally, prices above marginal cost can induce excessive variety by shifting up the demand curve for substitutes, which might make the introduction of the latter profitable (Tirole 1988). Again, this inefficiency is absent for public user innovations.

Restrictions imposed on second generation innovators

Manufacturer innovators would usually price information sought by potential second generation innovators above marginal cost, by either charging licensing fees and/or by keeping the innovation secret or protected by legal means. This causes a static inefficiency.[6] In contrast, a public user innovation can be freely used by agents other than the original innovator as a basis for new products and further developments, since it is neither protected by legal means nor by secrecy. Hence, the introduction of goods building upon the original innovation is simplified compared to a situation where the latter is brought forth by a manufacturer. This efficient use of the information describing public user innovations implies an increase in social welfare relative to a situation in which only manufacturer-developed innovations are present in a marketplace. Goods will be developed which otherwise would not have been, and/or the same goods will be developed while avoiding either licensing fees and transaction cost or a wasteful multiplicity of innovation expenditures.

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[5] While a price reduction of competing commercial goods is plausible, it can not generally be proved. Under some circumstances, commercial sellers might react to the introduction of a substitutive user innovation by increasing their prices.

[6] See Gallini and Scotchmer (2002) for an extensive discussion of the effects of different aspects of IP protection.

4. Discussion

In this paper we have explored the impact of user-developed innovations on effects that tend to drive the economy to overprovide or underprovide product variety. We conclude that the addition of user innovation to models that have previously incorporated only innovations developed by manufacturers is likely to result in an increase in welfare. A central observation is that user and manufacturer innovations tend to be of a different nature, with product innovations developed by users tending to fill small niches of high need left open by commercial sellers. Furthermore, innovation-related knowledge of users and manufacturers complement each other. Hence, the introduction of a user innovation can have an offsetting effect to the tendency of manufacturers to underprovide product diversity to a marketplace. This positive welfare effect is strengthened by the fact that, due to user needs evolving over time, innovations created by "lead users" for market niches often become relevant to the bulk of the market later.

Given that user innovation is welfare enhancing, policymakers may find it useful to encourage product (and process and service) development and modification by users followed by free revealing. In this section we consider positive steps that can be taken to this end, and social policies likely to have negative impacts that should be avoided. We also note that manufacturers can enhance their benefits from user innovation by developing strategies that integrate user innovation more closely (and consciously) with their own product development efforts.

4.1. Implications for social policy

Currently, manufacturer firms are rewarded for their innovative activity by R&D subsidies and tax credits. Such measures can make economic sense if median social returns to innovation are significantly higher than median private returns, as has been found by Mansfield et al. (1977) and others. Ignoring the issue of the optimal level of this support, we want to point out the strong discrepancy that exists between the high importance of user innovations for the economy – as evidenced by the number of important commercialized innovations whose roots can be traced to user-developed prototyping and learning by doing – and the low level of public support they receive. This at least raises the question as to whether tax dollars paid to manufacturers – sometimes to subsidize development of proprietary "me too" products – might be better spent on incenting additional user innovation.[7] Bresnahan and Greenstein (1996a) make a similar point. They investigate the role of "co-invention" in users' move from mainframe to client-server architecture.[8] By co-invention they mean organizational changes and innovations developed and implemented by users that are required to take full advantage of that new invention. The authors point out the high importance that co-invention has for realizing social returns from innovation. They consider the federal government's support for creating "national information infrastructures" as insufficient or misallocated, since "[co-invention] is the bottleneck for social returns and likely the highest value locus for noncommercially motivated invention." (p. 69).

If a user innovation is kept private it can lead to even more duplicative work and less subsequent innovations than a comparable manufacturer innovation, since the latter will more likely be sold or licensed. To avoid the welfare loss this entails, public policy should think about how to strengthen users' incentives both to innovate and to freely reveal their innovations when this behavior is not already present due to insufficient reward.

Policymaking for other purposes should also be examined for any deleterious side effects on user innovation, such as are present in current technical and legal efforts to prevent users from reverse-engineering manufacturer-supplied products or modifying them. Users often modify existing products to serve as low-cost components for their own novel prototypes. Technical barriers inserted by manufacturers such as controls to prevent the refilling of manufacturer-supplied ink-jet printer cartridges with low-cost ink can also prevent other forms of user activity such as innovation by users who wish to fill them with novel materials for novel applications. Similarly, efforts to prevent copying of digital information such as the Digital Millennium Copyright Act (DMCA) can prevent users from modifying and adapting existing material to new purposes (Varian 2002).

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[7] As in other cases of public subsidies there are potential downsides of government support for user innovation, as laid out by Schmidt and Schnitzer (2003) for the case of open-source software. Without entering the debate on whether and to what extent government subsidies are desirable, we simply note that *given* the considerable level of government support for innovation in general, a re-allocation of some of this support to user innovators might well make sense.

[8] See also Bresnahan and Greenstein (1996b), Bresnahan and Saloner (1997), and Saloner and Steinmueller (1996).

In a more general context, Benkler (2002) argues that institutional changes strengthening intellectual property protection tend to foster concentration and homogenization of information production. This happens to the detriment of alternative (and complementing) information production strategies. User innovations are a case in point, or even *the* case in point. Lessig (2001) and Boldrin and Levine (2002) arrive at a similarly negative valuation of overly strong IP protection.

4.2. Implications for innovators

User innovations can have both positive and negative aspects for a manufacturer that offers a commercial partial or full substitute to the user-developed product. On the positive side, there can be cost savings when a manufacturer develops a product after a user innovation has been made available. Since the later will often be freely revealed, the manufacturer can build upon information about needs and solutions developed by the innovating user. Importantly, manufacturers – that commonly devote a high share of their innovation-related efforts to products that fail commercially when introduced to the marketplace – gain "free market research" from observing user product prototyping, product use and product adoption activities.

However, we also saw that the presence of user innovations can also affect manufacturers negatively, in cases where they represent increased market competition.[9] When a user-developed product and a commercial substitute exist alongside, some buyers might prefer the user development, causing a loss of market share and profit to the manufacturer. The profit maximizing price will, in general, be reduced due to competition from the user development (but could be increased in particular cases). And even if, at the profit maximizing price, no one prefers the user development, it might still be so attractive for some users that it restricts the manufacturer's pricing power. Finally, the mere threat of users developing a free substitute limits the manufacturer's pricing power, similar to the way a threat of entry works in the theory of contestable markets (Baumol et al. 1982). In particular, this means that price discrimination (which is likely to be difficult anyway) becomes

[9] Saint-Paul (2003) focuses on this issue in a model of growth and innovation, finding that "philanthropical" innovation – developed and diffused for free, without any profit motive – may even reduce growth and welfare. However, his assumptions differ from ours, and they do not fit the real-world cases we are studying. First, user innovators are not philanthropists, but profit-oriented economic agents; second, their innovations and those of manufacturers tend to be of a complementary nature, as we have seen.

harder, because those users with a high willingness to pay might find innovating for themselves an attractive alternative.

The impact of a reduction in a manufacturer's pricing power might be particularly significant for manufacturers that create "platform" products linked to separately-sold enhancements or complementary products. Often, a manufacturer of such a product will want to sell the platform – the razor, the ink-jet printer, or the video-game player – at a low margin or a loss, and then price the add-ons at a much higher margin. Obviously, this strategy will work less well if users can develop free add-ons for the same platform. However, the overall effect depends on details: the availability of user-developed add-ons may indirectly increase demand for commercial add-ons for which no free substitute exists, thus again benefiting the manufacturer.

If the possibility of free add-ons developed and made generally-available by users makes development of a platform unprofitable for a manufacturer, social welfare can thereby be reduced. However, it is only the razor vs. blade pricing scheme that may become unprofitable. If the manufacturer makes positive margins on the platform, then the availability of user-developed add-ons has an additional positive effect: it increases the value of the platform to users, and so allows manufacturers to charge higher margins on it and/or sell more units. Indeed, manufacturers can profit by taking proactive steps to make their platform more hospitable to user-developed add-ons ("this platform is 'open'") and thus more valuable to users. Such a strategy is systematically pursued, e.g., in the cases of Stata statistical software and consumer simulator software mentioned above.

Finally, we note that free revealing of innovations bears a potential that is often not exploited by user-innovators. There obviously are cases where it makes sense for a user to keep an innovation secret. However, it is likely that user innovations are sometimes kept private not so much out of rational motives, but either because of a general, not thought-through attitude "we do not give away our intellectual property", or because the (administrative) cost of revealing are deemed higher than its perceived benefits. We propose that firms that develop user innovations should develop a conscious strategy as to what should be kept private and what should be freely revealed. For example, firms often have employee non-disclosure agreements that prevent their programmers from publicly revealing changes they have made to *any* software – yet it can be beneficial to reveal improvements employees make to open source software.

We conclude by noting again that user innovation is an important – and welfare enhancing – phenomenon in economic life. We propose that it will be valuable to study this phenomenon more deeply, and to integrate it more fully into economic theory, policy making, and innovator practices.

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